J Electr Eng Technol Vol. 9, No. 5: 1551-1561, 2014
http://dx.doi.org/10.5370/JEET.2014.9.5.1551

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

Time Domain Based Digital Controller for Buck-Boost Converter

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Abstract – Design, Simulation and experimental analysis of closed loop time domain based Discrete PWM buck-boost converter are described. To improve the transient response and dynamic stability of the proposed converter, Discrete PID controller is the most preferable one. Discrete controller does not require any precise analytical model of the system to be controlled. The control system of the converter is designed using digital PWM technique. The proposed controller improves the dynamic performance of the buck-boost converter by achieving a robust output voltage against load disturbances, input voltage variations and changes in circuit components. The converter is designed through simulation using MATLAB / Simulink and performance parameters are also measured. The discrete controller is implemented, and design goal is achieved and the same is verified against theoretical calculation using LabVIEW.

Keywords: Buck-Boost converter, Discrete controller, Analog to Digital Converter (ADC), Digital Pulse Width Modulator (DPWM).

1. Introduction

Electronic control Switched mode DC-DC converters convert an unregulated dc input voltage into regulated dc output by varying the duty cycle of the converter. These converters are smaller in size, more power efficient provides an efficiency of 75% to 98% therefore, they are used extensively in computer peripherals, personal computers, communication, medical electronics, Hybrid electric vehicle [13-14] and adapters of consumer electronic devices to provide different levels of DC voltages.

The buck-boost converter also known as step-down and step-up converter [1]. It is highly efficient and also very simple to design as it excludes the usage of transformer. Also there is minimal stress on the switch, and requires a relatively small output filter for low output ripple. This converter is widely used for energy management applications. The switching devices and passive components such as inductors and capacitors introduce nonlinearities in the converters. As a result, the linear control techniques cannot be directly applied for analysis.

The analog PID control scheme has been used successfully in many industrial control systems. Digital controllers are superior in performance and lower in cost compared to analog counterparts. Digital controllers are extremely flexible; easy to handle nonlinear control equations involving complicated computations or logical operations. A very much wider class of control laws can be used in digital controllers than in analog controllers. Digital controllers are capable of performing complex computations with constant accuracy at high speed and can have almost any desired degree of computational accuracy alternatively with little increase in cost.

Digital controller is introduced in the design of Buck-boost converter to obtain a tight voltage regulation, robustness, fast switching transient and improved dynamic performance for buck-boost converter. Digital controller offers many extra features compared to analog controller. Digital controller has low component aging, low cost, zero drift characteristic, high reliability and controllability. Numerous research work involves development of a digital controller for DC-DC converter as mentioned in [2-12].

Discrete PID controller is designed for the proposed buck-boost converter. The controller design involves two steps 1) Design an analog controller in a continuous time domain for the buck-boost converter. 2) Approximate the behavior of an analog controller with a digital controller which converts continuous domain into discrete domain. In the discrete domain, the controller compensates the error signal and tracks the accurate output. The digital controller is simple to design for all types of converters.

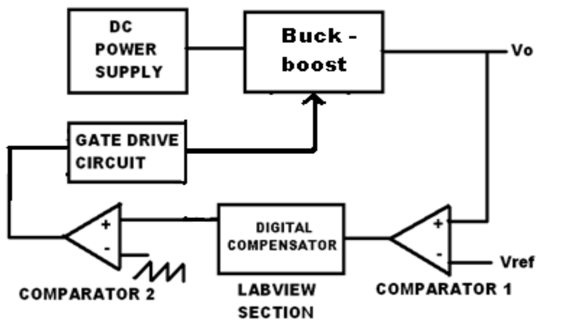

Fig. 1. Digitally controlled buck-boost converter

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Received: November 6, 2013; Accepted: February 14, 2014

It does not produce any limit cycle oscillation for any resolution of DPWM; also the performance of proposed controller is very good. The controller parameters such as rise time, settling time and peak overshoot are very low. It does not have steady state error and ripple voltage. For any uncertainty in input voltage and load, the controller continuously tracks the reference and produces a constant output voltage and proves its enhanced robustness. The errors caused by component variations up to certain limits are proportionately rectified by digital compensator by varying the duty cycle of the converter to produce the constant output voltage. The variations in the input voltage will not take more time to attain constant output.

The overall block diagram of the buck-boost converter with the entire set up is shown in Fig. 1. The output voltage of the buck-boost converter is compared against the desired value of the reference voltage using the comparator1 (Operational Amplifier IC 741). The Digital compensator is designed for the buck-boost converter using discrete PID controller. The error output thus obtained is fed into the inbuilt block diagram section of the LabVIEW through the Data Acquisition Card DAQ NI 9221. LabVIEW section consists of Analog to Digital conversion, discrete transfer function and Digital to Analog conversion blocks. Inside the DAQ card Analog to digital conversion takes place and thus processed signal is fed into the discrete transfer function block in which the designed controller value is entered. The output of the controller is acquired back by DAQ card converts digital to analog signal and fed into the comparator 2 designed using operational amplifiers (IC 741). This signal is compared against high frequency carrier signal (ramp signal) with desired switching frequencies obtained from signal generator. The resulting PWM switching pulses are fed to the switch of the converter through the gate drive circuits.

2. Design of Buck-Boost Converter

The schematic diagram of buck-boost converter is shown in Fig. 2. The converter provides an output voltage that may be less than or greater than the input voltage. As the polarity of the output voltage is always opposite to that of the input voltage, it is also called as inverting converter [15]. V_o is the output voltage and V_s is the input voltage [8].

The relationship between the input voltage and the output voltage is

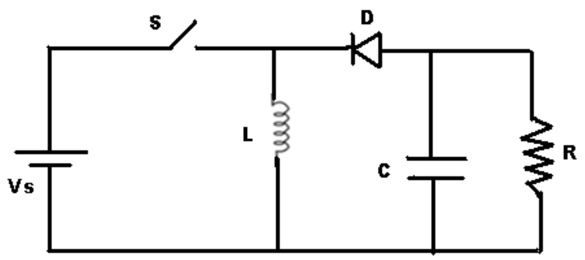

Fig. 2. Schematic diagram of buck-boost converter

$$V_o = \frac{V_s d}{1-d} \tag{1}$$

Where d is the duty-cycle. The value of inductor L and capacitor C can be found by [10]:

$$\Delta I = \frac{V_s d}{fL} \tag{2}$$

$$\Delta V_c = \frac{I_o d}{fC} \tag{3}$$

ΔI is the ripple current, $\Delta V_c$is the ripple voltage, f is the switching frequency, L is the filter inductor and C is the filter capacitor of the circuit. The designed buck-boost converter circuit parameters are input voltage V_s=14V, Switching frequency f=400 KHz, L=11 µH, C=14 µF, Load resistance R=14 Ω, d=60%, Output power P_o= 31.5 Wand Output voltage V_o =21V.

3. Modeling of Buck-Boost Converter

After designing buck-boost converter, simulation is done using state space averaging technique. The unique feature of this method is that the design can be carried out for a class of inputs such as step, ramp or impulse function in which all the initial conditions are also included. This technique is convenient to use for low frequency approximation of the true dynamics where the discontinuous effect introduced by the switching is ignored [7]. The Simulink requires the system equations of the power converter circuit. The state space analysis is given below.

The switches S is driven by a pulse sequence with a constant switching frequency f. The state vector for the buck-boost converter is defined as $x(t) = \begin{bmatrix} I_L \\ V_C \end{bmatrix}$, where$I_L$ is the current through an inductor; V_c is the voltage across the capacitor. For the given duty cycle d(k) for k^{th} period, the systems are illustrated by the following set of state space equations in continuous time domain :

The system is described by the following set of continuous time state space equations [10]:

$$\left.\begin{aligned} \dot{x}(t) &= Ax(t) + BV_s(t) \\ y(t) &= Cx(t) + DV_s(t) \end{aligned}\right\} \tag{4}$$

Where x is a state vector, V_s is a source vector, A, B, C, D is the state coefficient matrices. State model of the buck-boost converter is derived as

High power densities are possible only for continuous conduction mode (CCM) of operation. Diode D and MOSFET S are always in a complementary state, when S-ON, D-OFF and vice versa. Two modes of operations are possible, corresponding state equations are

Mode 1: S is ON and D OFF

$$\dot{x}(t) = A_1x(t) + B_1V_s(t) \quad (5)$$

Mode 2: S is OFF and D ON

$$\dot{x}(t) = A_2x(t) + B_2V_s(t) \quad (6)$$

where

$$A_1 = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{bmatrix}; \quad A_2 = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \quad (7)$$

$$B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}; \; B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (8)$$

The state space model is of the following form:

$$\dot{x}(t) = [A][x] + [B][u] \quad (9)$$

where

$$A = dA_1 + (1-d)A_2 \quad (10)$$

$$B = dB_1 + (1-d)B_2 \quad (11)$$

where

$$A = \begin{bmatrix} 0 & \frac{d-1}{L} \\ \frac{1-d}{C} & \frac{-1}{RC} \end{bmatrix} \quad (12)$$

$$B = \begin{bmatrix} \frac{d}{L} \\ 0 \end{bmatrix} \quad (13)$$

$$Y = [0\ 1]\begin{bmatrix} I_L \\ V_C \end{bmatrix} + [0]\, V_s(t) \quad (14)$$

The state space equations (4) can be converted into transfer function of the buck-boost converter. The continuous state equations are discretized for the design of discrete PID controller. It is considered that the discrete system is same as that of the continuous system except that the system is sampled with a sampling time, which is assumed as 1μS. The state space solution is evaluated and finds an analog PID controller equation using Ziegler-Nichols method [2].

4. Closed Loop Control System of Buck-Boost Converter

Fig. 3 shows the closed loop control system of the buck-boost converter with Discrete PID-based feedback. The goal is to minimize the error between V_{ref} (Reference voltage) and V_o which make the system to track the reference signal that is considered as a step input. The output is regulated by using the feedback. The feedback ensures that the output must be insensitive to load disturbances, stable and provides good transient response thereby improving the dynamic performances. The error voltage V_e (difference between V_{ref} and V_o) is fed to Analog to Digital converter which samples at a sampling rate equal to 1μS. The function of the digital compensator is to generate the control signal by compensating the error (V_e).

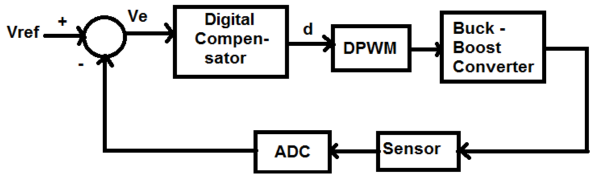

Fig. 3. Closed loop control system of buck-boost converter with Discrete PID controller

The error is processed by digital compensator block with PID algorithm to generate control signal. For the digital control of buck-boost converter switching, discrete PID control can be realized by its compensation block. The control signal from the compensator will affect the converter characteristics significantly, so it is vital to identify a suitable compensation technique to provide improved converter performance by making the best use of discrete controller. The output samples control the switch by generating gating pulses when it is processed through Digital Pulse Width Modulation (DPWM) block. The DPWM is nothing but a demodulator that consists of sample and hold block. It includes the delay time (t_d), A/D conversion time, switch transition time, computational delay and modulator delay.

Fig. 4 shows the block diagram of Analog to digital converter block. It is a device that converts a continuous time signal to a discrete time signal by using sampling. The converter block consists of delay, zero order hold, quantizer and saturation. The delay block carried out the total time between sampling the error signal and updating the duty cycle at the beginning of the next switching period. The zero order hold is mainly for modeling the sampling effect. Quantizer is mainly used for rounding off or truncating the signal that will map a larger set of input values to a smaller set such as rounding values to desired unit of precision.

The discrete time Compensation block is shown in Fig. 5. The output of the A/D converter is fed to the discrete zero-pole block which in turn is converted into PWM Pulses using DPWM blocks [8] as shown in Fig. 6. The discrete time integral compensator thus designed minimizes the error and sends the command signal to the switch in the form of

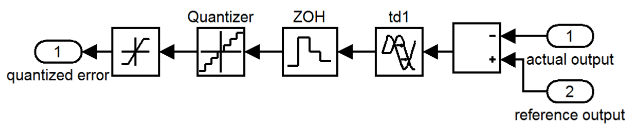

Fig. 4. Analog to digital converter

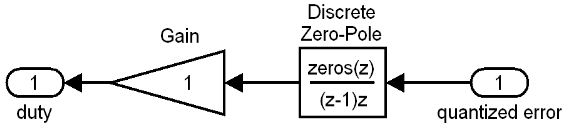

Fig. 5. Discrete time compensation

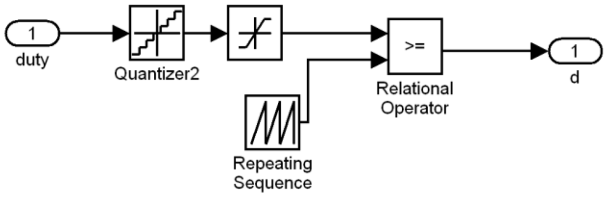

Fig. 6. Digital pulse width modulation

pulses in order that the output tracks the reference signal [6, 7]. The output of the compensator is compared against high frequency ramp signal in order to obtain the duty cycle pulse for the switch as discussed in [11].

5. Design of Robust Digital Controller

In a closed loop system, PID controller block provides the compensation in the feedback control of the buck-boost converter. PID controller has the advantages of both PD & PI controller. PD controller is a special case of phase-lead controller that improves system stability and increases system bandwidth. PI controller reduces steady-state error which is a special case of the phase-lag controller. Hence PID controller is also called as phase lag-lead controller [9-10].

The continuous time PID controller can be expressed as:

$$u(t) = K_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}] \tag{18}$$

Where u(t) is the control output, K_p is the proportional gain constant, T_d is the derivative time or rate time constant, T_i is the integral time or reset time constant and e is the error (difference between reference voltage V_{ref} and output voltage V_o). The value of K_p, T_d and T_i are tuned depending on the present error, accumulation of past errors and prediction of future error respectively [12].

The Laplace transfer function of the corresponding PID controller is given as:

$$U(s) = K_p\left(1 + \frac{1+T_iT_dS^2}{T_is}\right)E(s)$$
$$= K_p\left(1 + \frac{1}{T_is} + T_ds\right)E(s) \tag{19}$$

By proper choice of these tuning parameters a controller can be adapted for a specific converter to obtain a good behavior of the controller system. By using routh - array technique one can find the range of K_P. The values of T_d and T_i are obtained using Ziegler - Nichols tuning rule method. Table 1 shows Ziegler - Nichols tuning formulae. Where K_{cr} is the critical gain and P_{cr} is the critical period. By solving characteristic equation, find natural frequency of the system ω_o and using the relation $P_{cr} = \frac{2\pi}{\omega_o}$, T_i and T_d. The transfer function of the PID controller is

Table 1. Ziegler-Nichols tuning formulae

Type of controller	K_p	T_I	T_D
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2P_{cr}}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

$$G(s) = \frac{U(s)}{E(s)} \tag{20}$$

$$G(s) = K_P + \frac{K_I}{s} + K_Ds = \frac{K_Ds^2+K_Ps+K_I}{s} \tag{21}$$

Where K_p is the proportional gain, $K_I = K_p/T_I$ is the integral gain, and $K_D = K_pT_D$ is the derivative gain of the controller. Pole-zero cancellation technique is the most suitable one to remove unstable poles in the transfer function. In order to use pole-zero cancelation technique, the discrete PID controller equation can be re-written in the form as:

$$G(s) = \frac{K_D\left(s^2+\frac{K_P}{K_D}s+\frac{K_I}{K_D}\right)}{s} \tag{22}$$

This form is easy to determine the closed loop transfer function.

$$H(s) = \frac{1}{s^2+2\xi\omega_os+\omega_o{}^2} \tag{23}$$

$$\frac{K_i}{K_d} = \omega_o{}^2 \tag{24}$$

$$\frac{K_p}{K_d} = 2\xi\omega_o \tag{25}$$

Then

$$G(s)H(s) = \frac{K_d}{s} \tag{26}$$

Where, ξ the damping ratio and ω_o is the natural frequency oscillation of the system. The buck-boost converter under consideration is of second order and the desired poles can be easily placed by assuming the following converter specifications,

$$\left.\begin{array}{l}\text{Settling time} \approx \frac{4}{\xi\omega_o} \leq 1ms \\ \text{Max. Peak Overshoot} \approx 100e^{-}\xi\pi\sqrt{1-\xi^2} \leq 1\%\end{array}\right\} \tag{27}$$

For the system to be stable, the closed - loop poles or roots of the characteristic equation must lie within the unit circle. The Kp, K_I and K_D values are satisfying the above condition then the poles and zeros of the function should be placed within the unit circle and the system is said to be in stable condition.

The transfer function of the controller for buck-boost converter is

$$G(S) = \frac{-4.547*10^{-12}s+1.558*10^{9}}{s^2+5102s+1.039*10^{9}} \quad (28)$$

By following the above equation and conditions, the value of $K_p = 0.009$, $K_I = 143.54$ and $K_D = 1.40625*10^{-7}$ and $\omega_o = 37416$ rad /sec. Then the analog PID controller equation is

$$U(s) = \frac{1.406x10^{-7}(s^2+64000s+1021)}{s} \quad (29)$$

The continuous-time domain controller as mentioned in the above equation (29) is transformed into the discrete-time domain using Trapezoidal method which is referred as Tustin method or Bilinear-Transformation method. This Tustin method tracks the analog controller output more accurately by sampling at frequent intervals and approximate to the analog integration are better than other methods. The trapezoidal approximation is given below:

Let n(t) be the integral of e(t), then the value of the integral of t = (K+1) T is equal to the value at KT plus the area added from KT to (K+1)T.

$$N[(K+1)T]=u(KT)+\int_{KT}^{(K+1)T} e(\tau)d\tau \quad (30)$$

Using Trapezoidal rule, e(t) is the area curve from t = KT to t = (K+1)T is approximated as

$$\frac{e[(K+1)T]+e(KT)}{2}xT \quad (31)$$

Therefore

$$N\{(K+1)T=n(KT)+\frac{T}{2}\{e[(K+1)T]+e(KT)\} \quad (32)$$

Taking the z-transform of (32) then

$$zN(z) = N(z) + \frac{1}{2}[zE(z) + E(z)] \quad (33)$$

Thus
$$\frac{N(z)}{E(z)} = \frac{T}{2}\left[\frac{z+1}{z-1}\right] \quad (34)$$

Hence equation (34) is the transfer function of a discrete Integrator. Trapezoidal approximation to differentiation, Derivative of e(t) at t = KT is n(KT), then

$$n(KT) \cong \frac{e(KT)-e[(K-1)T]}{T} \quad (35)$$

Taking z-transform of (35)

$$\frac{N(z)}{E(z)} = \frac{(z-1)}{Tz} \quad (36)$$

Now discrete PID controller transfer function becomes [2]

$$G(z) = \frac{U(z)}{E(z)} = \left[K_P + K_I\frac{Ts}{2}\frac{z+1}{z-1} + K_D\frac{z-1}{Tz}\right] \quad (37)$$

$$U(z) = \left[\frac{\left(K_P+K_I\frac{Ts}{2}+\frac{2Kd}{Ts}\right)z^2+\left(K_IT_S+\frac{4K_D}{T_S}\right)}{z(z-1)}\right]E(z) \quad (38)$$

Now applying equation (38) in the designed buck-boost converter then the discrete controller for the buck-boost converter is

$$U(z) = \frac{0.4771z^2-0.9238z+0.4471}{z(z-1)} \quad (39)$$

$$U(z) = \frac{(z-0.9909)(z-0.9643)}{z(z-1)} \quad (40)$$

6. Simulation Results

The proposed closed loop response of the buck-boost converter is simulated using MATLAB / SIMULINK is shown in Fig. 7. Simulation has been carried out using the values same as that of the experimental values. The aim of this work is to achieve robust controller in spite of variations in load and uncertainty.

Table 2 shows the performance of the various controllers using the same buck-boost converter. Table 2 shows that the output voltage obtained using digital controller settle down at 3mS with a rise time of 2mS. The controller parameters under considerations are settling time, Peak overshoot, rise time, steady state error and output ripple voltage which is compared against its Discrete PI, and analog PI and PID controllers are designed for the same buck-boost converter.

Steady state error observed for load variations is much lesser than 1% and no overshoot or undershoots are evident.

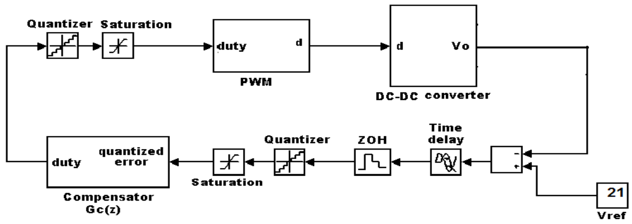

Fig. 7. Closed loop response of buck-boost converter using MATLAB/SIMULINK

Table 2. Performance parameters of the closed loop Buck-boost converter

Controller	Settling Time (ms)	Peak Over shoot (%)	Rise Time (ms)	Steady State Error (V)	Output Ripple Voltage (V)
Discrete PID	3	0	2	0	0
Discrete PI	10	10	2	0. 02	Less
Analog PID	18	2	18	0. 01	More
Analog PI	20	10	20	0. 03	More

The performance specifications for the buck-boost converter with discrete PID controller are better than PI and analog controllers. The results are thus obtained with digital controller for buck-boost is in concurrence with the mathematical calculations. It is proved that the digital system shows improved results than the analog controllers.

The simulation is carried out by varying the input voltage, load resistance and the corresponding output voltage, output current, reference voltage are shown in Figs. 8 and 9. In Fig. 8 the reference voltage is 7V, the input voltage is first set as 8V until 0. 05S and then varied from 8V to 12V and again at 0. 1S, 12V is varied to 16V. Similarly the load resistance is first set as 12Ω until 0. 05S and then varied from 12Ω to 16Ω and finally 20Ω is set at 0. 1S. Fig. 8 shows the performance of buck operation in buck-boost converter with the variations in input voltage and load resistance. Similarly the performance of boost operation in buck-boost converter with the variations in input voltage and load resistance is shown in Fig. 9.

Fig. 9 shows the boost operation the input voltage is varied from 8V to 16V, load resistance is varied from 12 Ω to 20Ω, the reference voltage is 18V and the corresponding output response of the buck-boost converter shows fixed output voltage regulation. In both operation undershoots or overshoots are not seen and the steady state error is also not apparent. In order to check the dynamic performance of

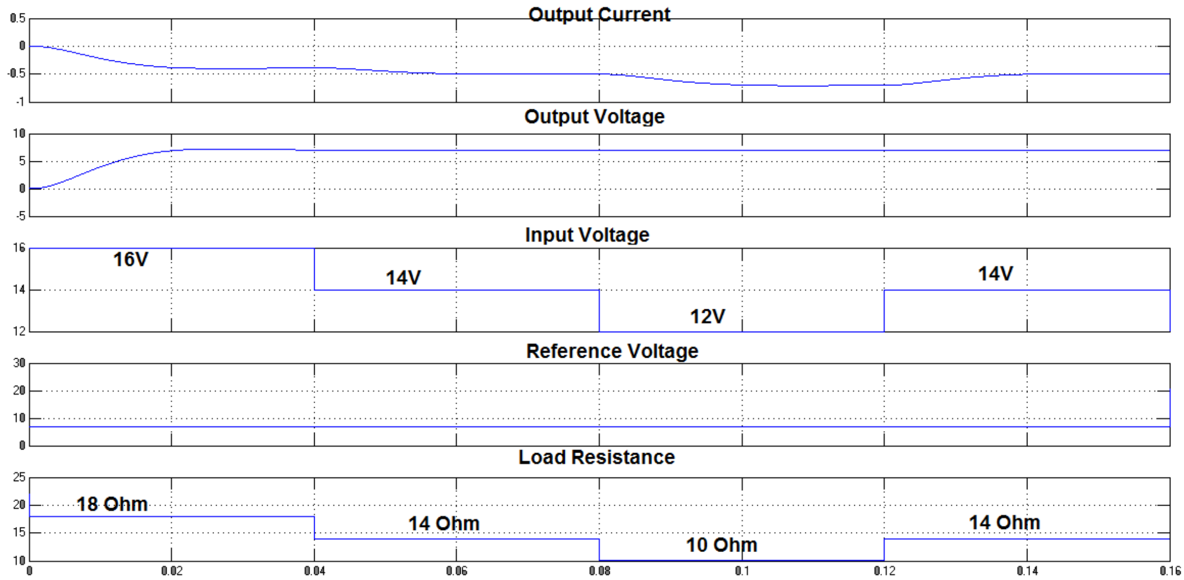

Fig. 8. Output response of the discrete PID controlled buck-boost (buck performance) converter

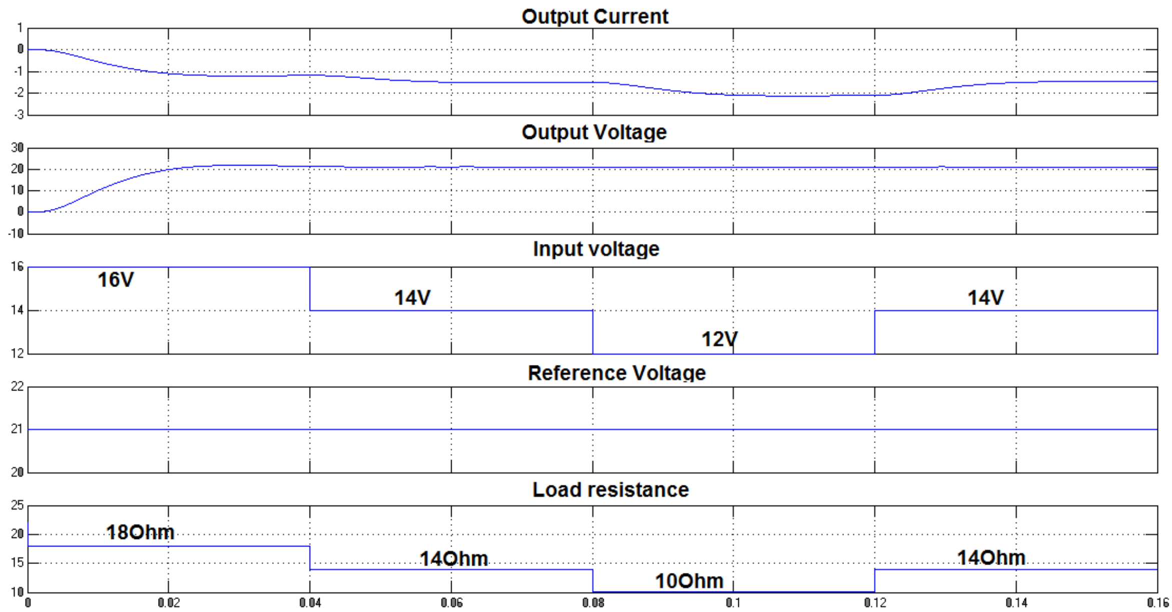

Fig. 9. Output response of discrete PID controlled buck-boost (boost performance) converter.

the controller, the L, C and R values are varied and the output response of the system is shown in Table 3.

Table 3 proves that the system is very much dynamic in tracking the reference voltages in spite of the variations in the inductance L, capacitance C and Load resistance R values. The system does not show any steady state error overshoots or undershoots and it settles down at a faster rate with a settling time of about 0. 03S for all the values. In order to confirm the better performance of Discrete PID controller over its Analog PID controller, the output response of the reference voltage of 21V, discrete controlled buck-boost converter is compared against the response produced by an analog PID controller and its graph is shown in Fig. 10.

Table 3. Variations in different parameters and performance of the discrete PID controller.

R(Ω)	L(μH)	C(μF)	Reference Voltage (V)	Output Voltage (V)
13	10	15	8	8
18	12	25	8	8. 002
23	16	35	16	16. 001
25	19	40	7	7. 001
30	22	45	16	16. 001
30	25	50	16	16. 002

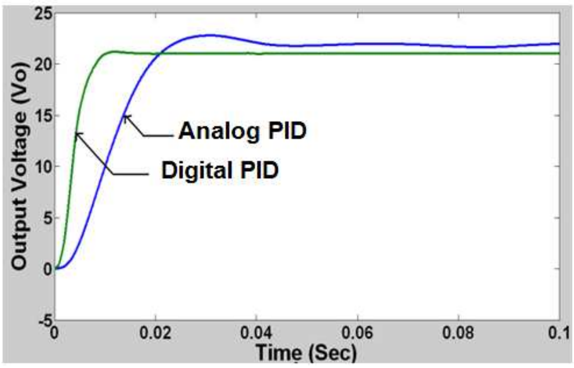

Fig. 10. Comparison between Digital PID and analog PID controller responses

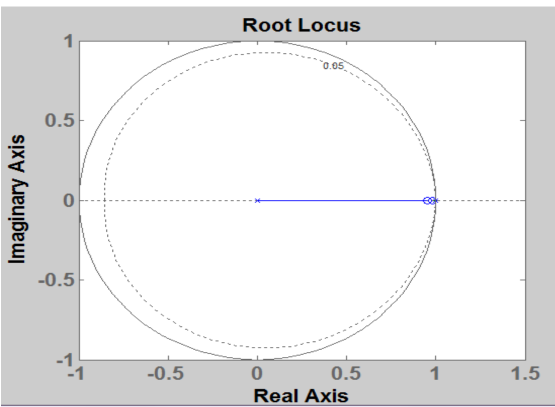

Fig. 11. Bode plot response of proposed discrete PID controller for Buck-Boost converter

In order to analyse the stability of the discrete controlled buck-boost converter, Bode plot response is drawn as shown in Fig. 11. The stability properties are

1. Any closed loop pole outside the unit circle makes the system unstable.
2. If a simple pole lies at z = -1, then the system becomes critically stable.
3. Any multiple closed-loop pole on the unit circle makes the system unstable.
4. Closed loop zeros do not affect the stability and therefore may be located anywhere in the z plane.

The discrete PID controller transfer function of the designed buck-boost converter is

$$\mathbf{U(z)} = \frac{\mathbf{0.4771z^2 - 0.9238z + 0.4471}}{\boldsymbol{z\,(z-1)}}$$

The root locus plot has drawn for the above transfer function equation. From the root locus plot, it is clearly obvious that the poles are placed neither outside the unit circle nor at -1. Multiple poles have not occurred. All poles are placed in the right half of the z-plane, thereby satisfying the stability condition of the transfer function frame for our proposed controller.

7. Hardware Implementation

The Buck-boost converter with Discrete Controller has been implemented using LabVIEW (Laboratory Virtual Instrumentation Engineering Work Bench) as a controller platform. LabVIEW is primarily used as a platform for implementing any closed loop system and it can also be used for the improvement of a control system. It is

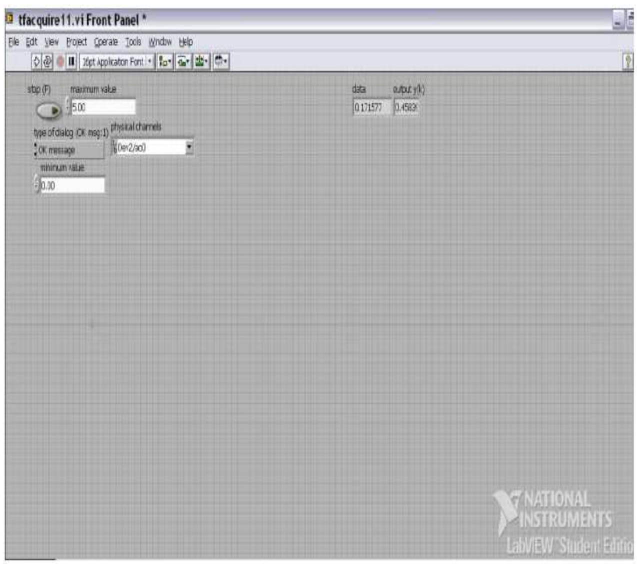

Fig. 12. Front panel

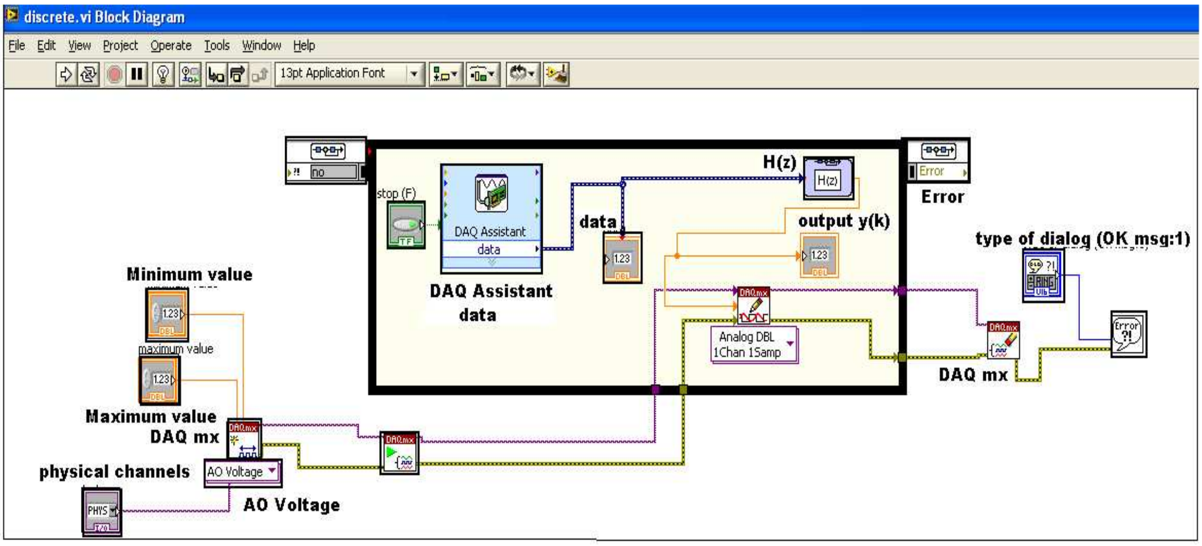

Fig. 13. Functional block diagram

extensively used software for analyzing the projects experimentally with a shorter duration due to its programming flexibility along with integrated tools designed especially for testing, measurements and control. The key feature of LabVIEW is that it extensively supports accessing the instrumentation hardware. The drivers and abstraction layers are provided for almost all types of instruments. The buses are also accessible for addition. The abstraction layers and drivers act as graphical nodes and enable to communicate effectively with the hardware devices thereby offering standard software interfaces [12].

This software is used to build up virtual instrumentation (vi) which comprises of the front panel and a functional block diagram. The front panel shown in Fig. 12 is mainly used for user interactions. It is through the front panel the desired transfer function of the discrete controller is entered and the corresponding parameters of the closed loop control and hence the restructured condition of the system is obtained. The block diagram, data acquisition, transfer function and signal generation are built using the functional block diagram as shown in Fig. 13. It provides wide varieties of small icons to perform the desired task. The LabVIEW package provides many libraries with large number of tasks for data acquirement, signal production, arithmetical and statistical analysis, signal conditioning and investigation along with many graphical interface elements. These features make it a superior one when compared with other development environment.

Interfacing Circuit: The NI 9221 multifunction data acquisition (DAQ) device is used. It can be easily connected via PCI 6221 for data acquisition, generation and data sorting in a wide range of convenient and portable applications. It comprises of 8 analog inputs with referenced single ended signal coupling or 4 inputs with differential coupling, 2 analog outputs, 12 bits A/D and D/A converters and 32 bits counters. There are 12 channels of digital Input/output lines which can be used either as input or output. It eventually offers a tremendous platform for the proposed discrete controller.

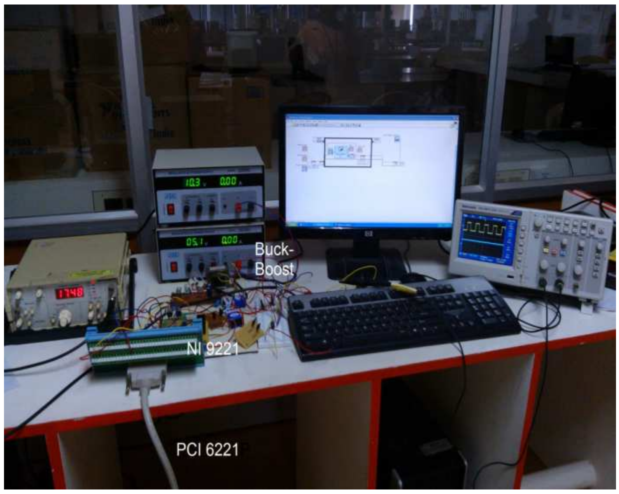

Fig. 14. Experimental set up

The prototype model of the buck-boost converter with discrete PID controller is shown in Fig. 14. The functioning of DC is substantiated well in the experimental study and the LabVIEW also provides the most feasible solution for the controller platform. To evaluate the performance, the reference value of 16V is set for which the output is obtained as 16. 04V. The steady state error thus observed is very small of the order of 0. 04V and the system settles down fast. The acquisition of the error signal from the hardware takes place instantaneous, when the program is run and at the same time the controlled signal from the LabVIEW package is also generated within a shorter duration of time without any delay or time lag. The experimental results thus obtained are in concurrence with the simulation results and mathematical calculations.

Prototype model is developed using the values shown in Table 4.

The input voltage and load resistance have been varied in the range of 12V, 14Ω and 18V, 10Ω , the corresponding output voltage is measured as 21. 042V, and 21. 068V respectively for the reference of 21V and is illustrated in Figs. 15 and 16 respectively. In these Figures channel 1 indicates the input voltage and Channel 2 indicates the corresponding output voltage. It can be observed from the result that there are no undershoots or overshoots but steady state error is of very minimum order. Fig. 17 shows the input and output voltage of the buck response of the buck-boost converter. The input voltage is 14V, 18Ω reference voltage is 8V and the obtained output voltage is 8. 002V.

The output voltages for the references of 21V & 8V along with their switching pulses are shown in Fig. 18 and 19 respectively. From the output waveforms, it is clearly understood, that the output observed shows better performance, thereby ensuring that the controller is more appropriate and can be tuned to track the references in spite of the variation in input voltage. The discrete controller changes the duty cycle according to change in reference voltage and is not subjected to any change in the input voltage.

Table 4. Experimental values

Description	Experimental values
f_r	400 KHz
V_s	14 V
L	11µH
C	14 µF
R	14 Ω
S	IRF840
D	1N4001
DAQ	NI 9221

Table 5. Efficiency comparison between conventional and discrete controlled Buck-boost converter

Converter	R_o (Ω)	V_{in} (V)	I_{in} (A)	V_o (V)	I_o (A)	%η
Conventional Buck-boost	14	14	2. 2534	19. 616	1. 4018	87. 16
Discrete controlled Buck-boost	14	14	2. 501	21. 005	1. 495	89. 7

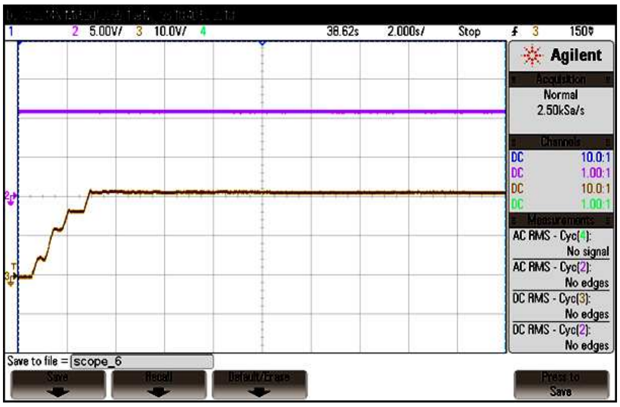

Fig. 15. Output (boost) voltage obtained for 12V input and load resistance of 14Ω (ch-2 5V/1mS & ch-3 10V/ 1mS)

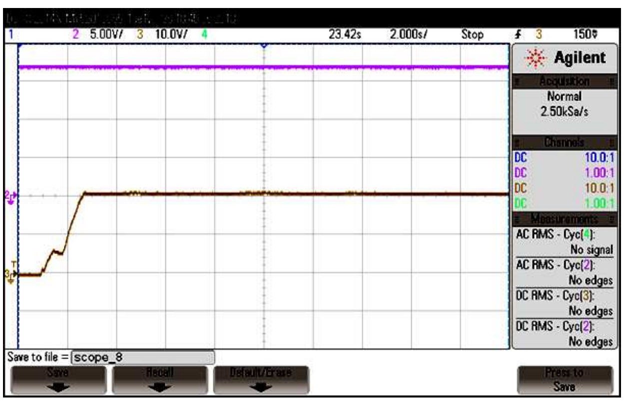

Fig. 16. Output voltage (boost) obtained for 18V input and load resistance of 10Ω (ch-2 5V/1mS & ch-3 10V/ 1mS)

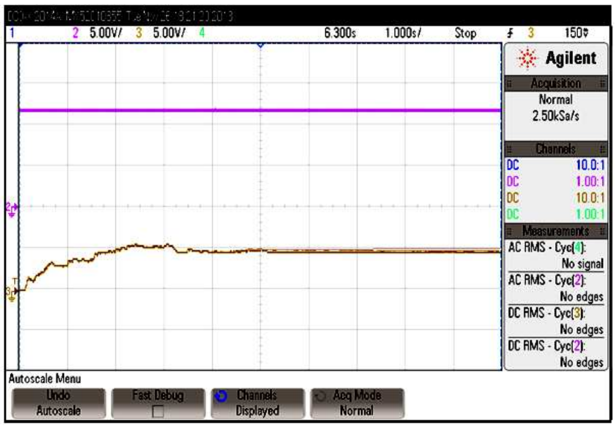

Fig. 17. Output (buck) voltage obtained for 14V input and load resistance of 18Ω (ch-2 5V/1mS & ch-3 5V/ 1mS)

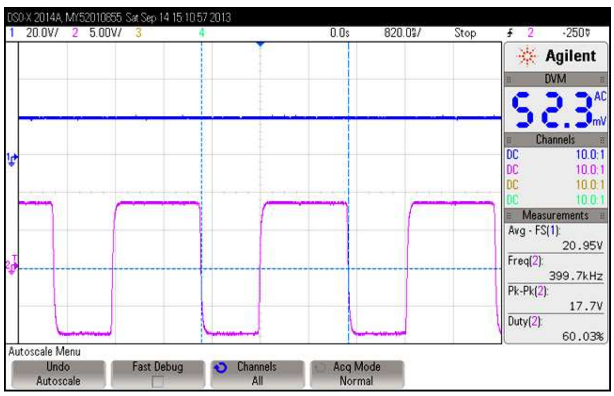

Fig. 18. Duty cycle obtained for 21V reference

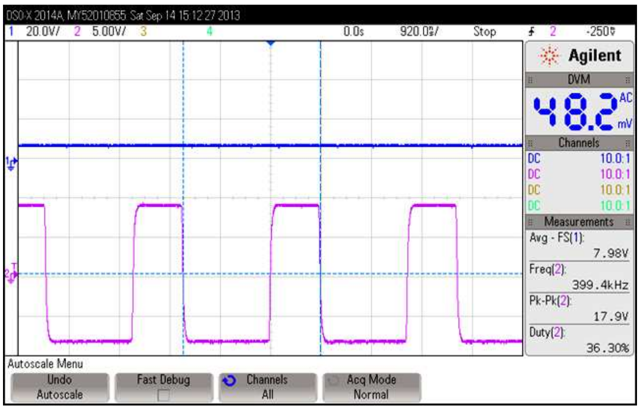

Fig. 19. Duty cycle obtained 8V reference

Table 5 given below provides the efficiency of conventional buck-boost converter and the proposed Discrete controlled buck-boost converter. It clearly justifies that proposed Discrete controlled buck-boost converter is 2.5% more efficient than the conventional buck-boost converter.

8. Conclusion

A discrete controller for buck-boost converter has been designed. Simulation results demonstrate that the converter not only exhibits the steady state and transient performance but also improves the efficiency of conventional buck-boost converter. The design of time domain based discrete PID controller for buck-boost converter has been implemented to adapt to the variation in error signal by changes the duty cycle. The design incorporates an Analog to Digital Converter and discrete pulse width modulator. The discrete controller is thus designed for the buck-boost converter and also implemented using LabVIEW as a control platform and the corresponding results are illustrated. The mathematical analysis, simulation study and the corresponding experimental results show that the controller thus designed achieves tight output voltage regulation and good dynamic performances. This topology is independent and is compatible to make itself suitable to extend for any sort of applications like as speed control, photo voltaic cell and medical electronics.

References

[1] K. K. Sajeesh and Agarwal, "Digital controller implementation for non-inverting buck-boost converter using run-time partial reconfiguration of FPGA," in Proc. *IEEE-IICPE*, 2012, pp. 1-6.

[2] P. Mattuveli, " Digital controls of DC-DC boost converters with inductor current estimation," in Proc. *IEEE-APEC*, 2004, pp. 74-80.

[3] Subhash Chander, "Auto-tuned, Discrete PID Controllers for DC-DC Converter for fast transient response," in Proc. *IEEE-ICEMSC*, 2011, pp. 1-4.

[4] Angel, V Peterchev and R Sanders, "Quantization resolution and limit cycling in digitally controlled PWM converters," *IEEE Trans. Power Electronics*, vol. 18, pp. 301-308, Jun 2003.

[5] Hao Peng, A Prodic, E Alarcon and D Maksimov, "Modeling of Quantization Effects in Digitally Controlled DC-DC converters," *IEEE Trans. Power Electronics*, vol. 22, pp. 208-215, Jan 2007.

[6] M M Peretz and S Ben-Yaakov,"Time domain design of digital compensators for PWM DC-DC converters," *IEEE Trans. Power Electronics*, vol. 27, pp. 887-893, Jan 2012.

[7] Shuibao GUO, Yanxia GAO, Yanping Xu, Xuefang LIN-SHI and Bruno ALLARD, "Digital PWM Controller for High-Frequency Low-Power DC-DC switching Mode Power Supply," in Proc. *IEEE-IPEMC*, 2009, pp. 1340-1346.

[8] Sebastein Mariethoz et. al, "Comparison of Hybrid Control Techniques for Buck and Boost DC-DC Converters," *IEEE Trans. Control systems Technology*, vol. 18, pp. 1126-114, Sep 2010.

[9] Benjamin, J Patella and Aleksandar Prodic, "High-Frequency Digital PWM Controller IC for DC-DC Converters," *IEEE Trans. Power Electronics*, vol. 18, pp. 438-446, Jan 2003.

[10] H Matsuo, F Kurokawa, H Etou, Y Ishizuka and C Chen, "Design oriented analysis of the digitally controlled DC-DC converter," in Proc. *IEEE-PSEC*, 2000, pp. 401-407.

[11] L. Peng, X. Kang and J. Chen, "A novel PWM technique in digital control and its application to an improved DC/DC converter," in Proc. *IEEE-PSEC*, 2001, pp. 254-259.

[12] Chien-Ming Lee et. al, "LabVIEW Implementaton of an Auto-Tuning PID Regulator via Grey-predictor," in Proc. IEEE-CISC, 2006, pp. 1-5.

[13] Bong-Gi Youet. al, "Optimization of Powder Core Inductors of Buck-Boost Converters for Hybrid Electric Vehicles," Journal of Electrical Engineering and Technology, vol. 6, No. 4, pp. 527-534, July 2011.

[14] Anbukumar Kavitha et. al, "Resonant Parametric Perturbation Method to Control Chaos in Current Mode Controlled DC-DC Buck-Boost Converter," Journal of Electrical Engineering and Technology, vol. 5, No. 1, pp. 171-178, Mar 2010.

[15] Jingquan Chen, "Analysis and Design of a Low-Stress Buck-Boost Converter in Universal-Input PFC Applications," IEEE Trans. Power Electronics, vol. 21, No. 6, pp. 320-329, Mar 2006.

[16] "A General Approach to Control a Positive Buck Boost Converter to Achieve Robustness against Input Voltage Fluctuations and Load Changes," IEEE Trans. Power Electronics, vol. 18, pp. 438-446, Jan 2003.

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