Time domain based Digital Controller for Boost Converter

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Abstract –This work analyses the performance of Discrete PID controller for Boost converter. The purpose of designing discrete time controller is to attain higher voltage regulation in output, excellent energetic performances and good efficiency in a converter. In this method, the conversion from continuous to discrete is based on time domain bilinear transformation technique, so that the errors in the converter can be avoided. The feedback from the digital controller can continuously tunes the compensator parameters to attain the converter specifications. This control provides a whole compensation, which additionally develops the sturdiness and stability of the closed loop system. The discrete PID controlled boost converter has been simulated using MatLAB / Simulink and the experimental results have been presented to reveal the success of the controller using LabVIEW.

Keywords: Boost converter, Analog to Digital Converter (ADC), Pulse Width Modulation (PWM), Data Acquisition cable (DAC).

1. Introduction

DC-DC converters are widely used in battery charger, Photo Voltaic applications, switching mode power supplies. This conversion method is the most efficient one as it gives an efficiency of 80% to 97%. The efficiency of the converter is being increased by the use of MOSFET which is capable to switch at higher frequency more capably than bipolar transistor. These DC-DC converters are small in size and are utilized widely in computer peripherals, communication, personal computers, adaptors of consumer electronic devices, and medical electronics to give various levels of DC voltages [1 – 5].

Particularly in solar cell and charge pump applications Boost converter plays a very important role. The main advantage of this Boost converter is its higher efficiency, as the switching devices dissipate less power. Other advantages comprise light weight, smaller in size, and lesser heat generation due to higher efficiency. The major challenge in the field of DC-DC converter is the control aspect. The control method necessitates efficient modeling and enabling systematic study of the converters. In general the converters are time invariant and non-linear, and it reliance with the large passive components. In common, analog controller design technique experiences higher complexity in control, lesser flexibility to superior functions and system changes, and have lack of consistency. The proposed discrete controller provides lot of advantages than their analog controller.

Few of them could be i) not highly influenced by the environmental variations and aging ii) Less interference from noise, iii) No need to change the underlying hardware to modify the controller design iv) enhanced sensitivity to deviation in parameter v) flexibility of its changing controller characteristics vi) simplicity in operation. It also offers in its dynamic response as firmness, fast response and less peak overshoot.

The significant stages in the design of digital controller are 1) In order to sample the error signal Analog to Digital Conversion (ADC) takes place 2) To reimburse the error signal digital compensator is to be used 3) To produce high resolution PWM pulse Digital Pulse Width Modulation (DPWM) is to be designed. In this proposed work, high degree DPWM signals are produced by maintaining high system switching frequency. The purpose of control in the design of discrete controller has to run the boost converter along with a duty cycle so that the reference voltage and the output voltage of the dc component are equal. The parameter support stability in spite of changes in the load or variations in the input voltage. In addition to the limitation in the proposed discrete controller consequences owing to the duty cycle is bounded between one and zero. This problem can be solved by modeling the boost converter using state space averaging technique. After applying this method, the converter is represented by a single equation roughly over a number of switching cycles. The state space model builds the controller and makes simulation much faster than the other method [6].

The above stated problem in DC-DC converter can be solved by designing a robust compensator based on discrete PID controller, this controller design is based on continuous domain in which the dc-dc converter requirements such as peak overshoot, steady state error, rise time and settling time are met. The boost converter is modeled using state space averaging technique and the simulation is carried out by MATLAB/Simulink software. The hardware model has been executed out using LabVIEW along with DAQ card NI – 9221 and the results are depicted in later section.

2. Overall Block Diagram

The complete block diagram of the digitally controlled boost converter is shown in Fig.1. The desired reference voltage is compared against the output voltage of the boost converter by means of the comparator circuit (IC 741 -

Operational Amplifier).

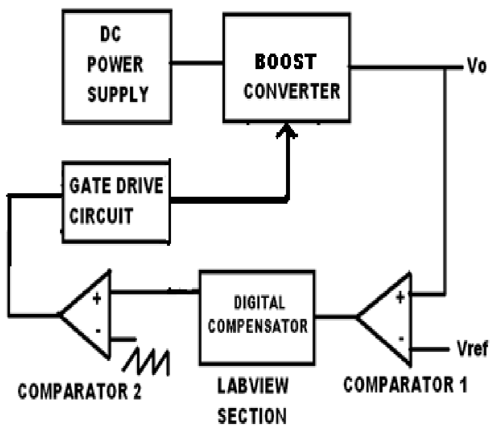

Fig.1. Block diagram for digitally controlled Boost converter

The proposed Digital compensator is intended for the boost converter using bilinear transformation technique. The Error voltage obtained in the output is fed to the LabVIEW block diagram through the DAQ cable NI 9221. The LabVIEW software includes Analog to Digital conversion, Digital to Analog conversion and discrete transfer function blocks. Analog to digital conversion takes place in the LabVIEW section and thus processed signal is applied into the digital compensator (discrete transfer function) block in which the designed controller value is entered. The output voltage of the controller is received by DAQ cable and applied into the newly designed comparator 2 using IC 741 (operational amplifiers). The compensated signal from the compensator is compared with the high frequency ramp carrier signal (required switching frequencies taken from signal generator). Through MOSFET gate drive circuit, the resulting PWM switching pulses are fed to the MOSFET.

3. Boost Converter Design

The Boost converter with the DC voltage is also called as step up transformer, and the conventional Boost converter diagram is depicted in Fig. 2. The boost converter converts low level fixed input dc supply into an enhanced dc voltage to an unpredictable load. This boost converter consists of diode D, MOSFET switch S, inductor L, load resistor R, and capacitor C. The non-linearity and the noise experienced by an inductor coil are neglected, and they are influenced mainly outstanding to the oscillations of stray inductance and parasitic capacitance at each switching instants. The MOSFET S is considered with an ideal characteristic [6]. The following section explains the design of the boost converter.

The relation between the output and input of the boost converter is given by,

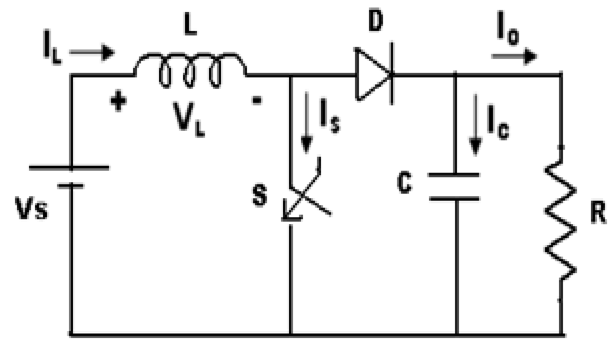

Fig.2. Boost converter

$$V_o = \frac{V_s}{1-d} \quad (1)$$

Where, d denotes the duty cycle of the boost converter, f is the switching frequency, and the critical value of inductor $L_c$is given by,

$$L_c = \frac{d(1-d)R}{2f} \quad (2)$$

Depending upon the amount of ripple current that flows through the capacitor which fixes the inductor value. The load current variation is obtained by the suitable inductor value. For this reason, the value of inductor is derived as,

$$\Delta I = \frac{V_s(V_o-V_s)}{fLV_o} \quad (3)$$

Where, ΔI refers to the ripple current, and ΔV_c is the ripple voltage of the capacitor. The value of capacitor is found by considering the ripple voltage as 2 % to 3 % of the output voltage. The value of the capacitor value is derived as,

$$\Delta V_c = \frac{I_o(V_o-V_s)}{V_o f C} \quad (4)$$

The following parameters are calculated for the design of boost converter: input voltage V_S = 8V, output voltage (V_O) = 16V, frequency f = 400 kHz, inductor L = 11µH, capacitor C = 11 µF and resistor R = 26Ω.

4. Modeling of Boost Converter

The second step of this planned work is modeling. After the design, the boost converter should be modeled by state space averaging technique and the exclusive characteristic of this method is to the design can be over for a different input like impulse, step, or ramp functions and its initial conditions are also considered. In this approach is expedient to employ for the approximation of minimum frequency of the true dynamics so that in the switching, discontinuous outcome is ignored [7]. This modeling process requires the dc-dc converter system equations. The analysis of boost converter using state space approximation is presented below:

The MOSFET switch S is driven by a PWM pulse in which the switching frequency of this pulse is considered as f. The Boost converter state space vector is described as $x(t) = \begin{bmatrix} I_L \\ V_C \end{bmatrix}$, where I_L refers to the current through an inductor; V_c represents the voltage across the capacitor. For the given duty cycle d(k), the time domain state space averaging equations of the boost converter is expressed by :

$$\left.\begin{aligned} \dot{\boldsymbol{x}}(\boldsymbol{t}) &= \boldsymbol{A}\boldsymbol{x}(\boldsymbol{t}) + \boldsymbol{B}\boldsymbol{V_s}(\boldsymbol{t}) \\ \boldsymbol{y}(\boldsymbol{t}) &= \boldsymbol{C}\boldsymbol{x}(\boldsymbol{t}) + \boldsymbol{D}\boldsymbol{V_s}(\boldsymbol{t}) \end{aligned}\right\} \quad (5)$$

Where, x is the state vector, V_s is the input source vector, and the state coefficient matrices are A, B, C, D. The boost converter state space representation is derived as follows.

In Continuous Conduction Mode (CCM) of operation, high densities are possible. The connection of Diode D and MOSFET S in a boost converter is such that these two devices are working in a complementary state that is when MOSFET (S) is ON, Diode (D) is OFF and vice versa. The modes of operations and its relevant state equations are given below:

Mode 1: MOSFET S is ON and Diode D is OFF

$$\dot{\boldsymbol{x}}(\boldsymbol{t}) = \boldsymbol{A1x}(\boldsymbol{t}) + \boldsymbol{B1V_s}(\boldsymbol{t}) \quad (6)$$

Mode 2: MOSFET S is OFF and Diode D is ON

$$\dot{\boldsymbol{x}}(\boldsymbol{t}) = \boldsymbol{A2x}(\boldsymbol{t}) + \boldsymbol{B2V_s}(\mathbf{t}) \quad (7)$$

Where

$$A1 = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{bmatrix} \quad (8)$$

$$\boldsymbol{A2} = \begin{bmatrix} \mathbf{0} & \frac{-1}{L} \\ \frac{1}{c} & \frac{-1}{RC} \end{bmatrix} \quad (9)$$

$$\boldsymbol{B1} = \boldsymbol{B2} = \begin{bmatrix} \frac{1}{L} \\ \mathbf{0} \end{bmatrix} \quad (10)$$

The state space averaged model is given as follows:

$$\dot{\boldsymbol{x}}(\boldsymbol{t}) = [\boldsymbol{A}][\boldsymbol{x}] + [\boldsymbol{B}][\boldsymbol{u}] \quad (11)$$

Where

$$\boldsymbol{A} = \boldsymbol{dA1} + (\mathbf{1} - \boldsymbol{d})\boldsymbol{A2} \quad (12)$$

$$\boldsymbol{B} = \boldsymbol{dB1} + (\mathbf{1} - \boldsymbol{d})\boldsymbol{B2} \quad (13)$$

Where d is the duty cycle of the boost converter. Therefore

$$\boldsymbol{A} = \begin{bmatrix} \mathbf{0} & \frac{d-1}{L} \\ \frac{-(d-1)}{c} & \frac{-1}{RC} \end{bmatrix} \quad (14)$$

$$\boldsymbol{B} = \begin{bmatrix} \frac{1}{L} \\ \mathbf{0} \end{bmatrix} \quad (15)$$

$$\boldsymbol{Y} = [\mathbf{0} \;\; \mathbf{1}] \begin{bmatrix} \boldsymbol{I_L} \\ \boldsymbol{V_C} \end{bmatrix} + [0]\, V_s(t) \quad (16)$$

The transfer function of the boost converter can be obtained from the state space equations (5). The derived transfer function of the boost converter is

$$\boldsymbol{G}(\boldsymbol{s}) = \frac{-4.093*10^{-12}\; s + 4.132*10^{9}}{s^2 + 3497s + 2.066*10^{9}} \quad (17)$$

5. Closed Loop Discrete Controller for Boost Converter

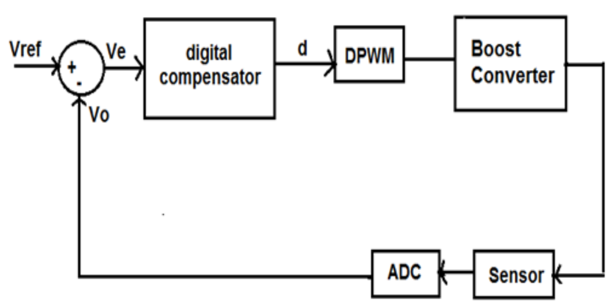

Fig. 3. Closed loop discrete controller for boost converter

The closed loop discrete controller for boost converter is depicted in Fig. 3 and the objective of this controller is to reduce the error between the reference voltage V_{ref} and the output voltage V_o. In this system, a step input voltage as a reference voltage which is to be tracked by the controller. The success of the feedback control is that thereby enhancing the dynamic performances, offers good dynamic performances and the output should not be sensitive to load variations. The error signal V_e (difference between V_{ref} and V_o) from the sensor is applied to the Analog to Digital converter samples the error signal at a rate of 1μS, and the corrected error signal is obtained from digital compensator which compensating the error generated by the sensor.

The converter characteristics are influenced by the compensator significantly, hence to find suitable compensation approach by the design of discrete PID controller which provides improved converter performance. The DPWM block which generates the gating Pulse Width Modulated pulse to organize the switch. The DPWM block is the demodulator, contains sample and hold block and it considers the A/D conversion time, switching transition time, delay time (t_d), and the delay of computational & modulator.

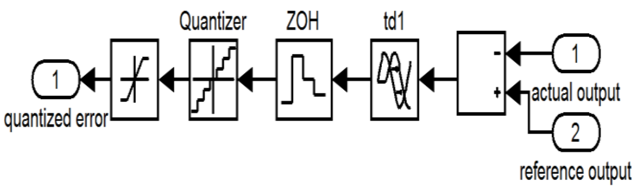

Fig.4. Analog to Digital converter

The Analog to digital converter is depicted in Fig. 4, and it samples the continuous time signal which is to be converted into a discrete time signal. The delay unit, Zero order Hold unit, quantizer and saturation unit are comprised by the converter. To sample the error voltage and improving the duty cycle command at the beginning of the next switching period takes some time delay which is provided by the delay block appear in the ADC. The modeling and sampling effect of the error signal is carried over by Zero Order Hold block. The Quantizer is used to truncate or round off the signal from the ZOH.

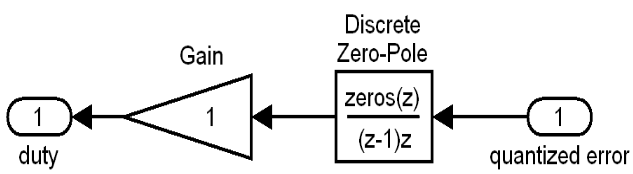

Fig.5. Discrete Time compensator

The discrete time Compensator is illustrated in Fig. 5 consists of Discrete Zero-Pole block which is the heart of the discrete PID controller. This blocks whose zeros and poles values are determined using bilinear transformation technique which compensate the error from the ADC. The compensator output is changed into PWM pulse by means of DPWM [8] which is depicted in Fig. 6. The discrete time integral compensator (Discrete time compensator) always track the output with respect to the reference voltage accordingly provides the command signal in the form of pulses. The PWM pulse is obtained from the DPWM block by compared against the compensator output and the carrier signal (high frequency ramp).

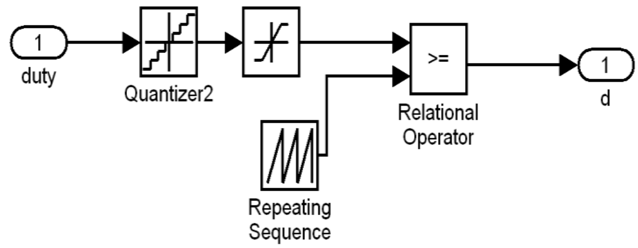

Fig.6. Digital Pulse Width Modulator

6. Design of Robust Digital Controller

A PID controller is widely used in feedback control of industrial process. This controller takes the present, the past, and the future errors into consideration. A closed loop system with discrete PID controlled boost converter is portrayed in Fig.3. The discrete PID controller offers the solution in the feedback control of the converter and this PID controller possesses the advantages of two controllers as PD & PI controller. The PD controller is the phase-lead controller that enhances the stability and bandwidth of the controller. The steady state of the controller can be decreased by PI controller which is also known as special phase-lag controller; hence PID controller is called as phase lag – lead controller [8].

The equation (18) shows an analog PID control system. The error voltage e(t) is used to generate the proportional, derivative and integral actions so that the resulting signals weighted and summed to form the control signal u(t) is applied to the boost converter model. The proportional term, gives an overall control action proportional to the error e(t) of the signal through the all pass gain factor. The integral term of the integrator, decreases the steady state errors by through low frequency compensation. The derivative term of the differentiator enhances the transient response by high frequency compensation.

The time domain PID controller can be delineated as [11]:

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

Where, u(t) refers to the control output, K_p, T_d, T_i are the proportional gain constant, derivative or rate time constant and the integral or reset time constant respectively. Error e is the difference of reference voltage V_{ref} and an output voltage V_o. In the PID controller, P proportional to the present error, I and D depends upon the summation of past and prediction of future error [11] respectively.

The Analog PID controller whose Laplace transfer function is outlined as:

$$U(s) = K_p\left(1 + \frac{1+T_I T_D s^2}{T_I s}\right)E(s) = K_p\left(1 + \frac{1}{T_I s} + T_D s\right)E(s) \quad (19)$$

The most favorable option of the varying parameters for a PID controller could be adjusted as per the type of the converter to obtain extraordinary performance of the controller system. The range of K_P is obtained using routh array technique, and T_d and T_i values are get from Ziegler–Nichols Table 1. In Table 1 $K_{cr}$is the critical gain and P_{cr} is the critical period of the controller.

By resolving 1+ G(s)H(s) = 0 is the characteristic equation, natural frequency of the system ω_o can be found. The transfer function of the boost converter is G(s) and H(s) is the unity gain feedback of the closed loop system. Using the relation, $P_{cr} = \frac{2\pi}{\omega_o}$, T_i and T_d can be found from Table 1.

Table 1. Ziegler – Nichols Tuning parameters

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	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

The equation (19) becomes

$$U(s) = K_P + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_P s + K_I}{s} E(s) \quad (20)$$

Where $K_p$specifies the proportional gain, $K_I = K_p/ T_i$ specifies the integral gain, and $K_D = K_p T_d$specifies the derivative gain of the controller. The stability of the analog PID controller can be inspected through root-locus technique, the effects on the locations of the closed loop poles and/or zeros are not placing on the right hand side.

Using the above states, the values of K_p, K_I and K_D can be calculated. Finding values are $K_I = 2000$, $K_D = 7.98*10^{-10}$, and $K_p= 0.08$, and $\omega_o = 45453$ rad /sec. Then the analog PID controller equation can be derived as :

$$U(s) = \frac{6.6528x10^{-6}(s^2 + 13528s + 28409)}{s} \quad (21)$$

In order to get better controller parameters, analog PID controller has been converted into discrete PID controller. In general Ziegler-Nichols tuned PID controller functions are not suitable for applications involving accurate control. This work proposes an enhanced discrete PID scheme for boost converter, where huge load changes are often expected and hence the need for fast response time [5] is more emphasized.

Three methods are used for transforming continuous to discrete time transfer function, i.e. Bilinear transformation or Tustin method, impulse invariant method, and forward difference method. Among these, Tustin method is preferred as it conquers the problem of distortion, which is very much desirable in the design of filter and compensator. Stability is guaranteed as it maps the left half S – plane onto the interior of the unit circle in the Z – plane. It ensures the stability of the compensator. Other two methods are not appropriate for the design of all kinds of filters and compensator and moreover they are also less stable. This Tustin method, which tracks the analog controller output more precisely at the predefined sample times. Tustin method is summarized below.

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

$$M[(L+1)T] = u(LT) + \int_{LT}^{(L+1)T} e(\tau)d\tau \quad (22)$$

By using Tustin rule, e(t) the area curve from t = LT to t = (L+1)T is approximated as

$$\frac{e[(L+1)T] + e(LT)}{2} xT \quad (23)$$

Therefore

$$M\{(L+1)T = n(LT) + \frac{T}{2}\{e[(L+1)T] + e(LT)\} \quad (24)$$

The Z-transform of equation (24) is

$$zN(z) = M(z) + \frac{1}{2}[zE(z) + E(z)] \quad (25)$$

$$\text{Thus} \frac{M(z)}{E(z)} = \frac{T}{2}\left[\frac{z+1}{z-1}\right] \quad (26)$$

Therefore equation (26) represents the transfer function of a discrete Integrator. Tustin approximation to differentiation, derivative of e(t) at t = LT is m(LT), then

$$m(LT) \cong \frac{e(LT) - e[(L-1)T]}{T} \quad (27)$$

Taking z – transform of equation (27), thus

$$\frac{M(z)}{E(z)} = \frac{(z-1)}{Tz} \quad (28)$$

The discrete PID controller transfer function is

$$G_c(z) = \frac{U(z)}{E(z)} = \left[K_P + K_I \frac{Ts}{2}\frac{z+1}{z-1} + K_D \frac{z-1}{Tz}\right] \quad (29)$$

$$G_c(z) = \left[\frac{\left(K_P + K_I\frac{Ts}{2} + \frac{2Kd}{Ts}\right)z^2 + \left(K_I T_s + \frac{4K_D}{T_s}\right)}{z(z-1)}\right]E(z) \quad (30)$$

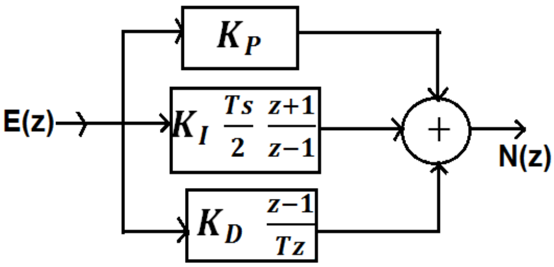

Fig.7. Discrete PID Controller

$G_c(z)$ represents the discrete PID controller transfer function. The discrete PID controller block is shown in Fig.7. The designed discrete PID controlled boost converter equation is determined as given below:

$$U(z) = \frac{0.1677z^2 - 0.319z + 0.1517}{z\,(z-1)} \quad (31)$$

$$U(z) = \frac{(z-0.9535)(z-0.9487)}{z(z-1)} \quad (32)$$

The discrete PID controller response for boost converter is explained below.

7. Simulation Results

To achieve a effective robust controller despite of variation and huge load disturbances, closed loop response of the discrete PID controlled boost converter is simulated. The experimental values are considered for simulation and the circuit is simulated using MATLAB / SIMULINK is depicted in Fig. 8. From Table 2, the settling time of the obtained output signal at 6 mS with a rise time of 3 mS is as shown in

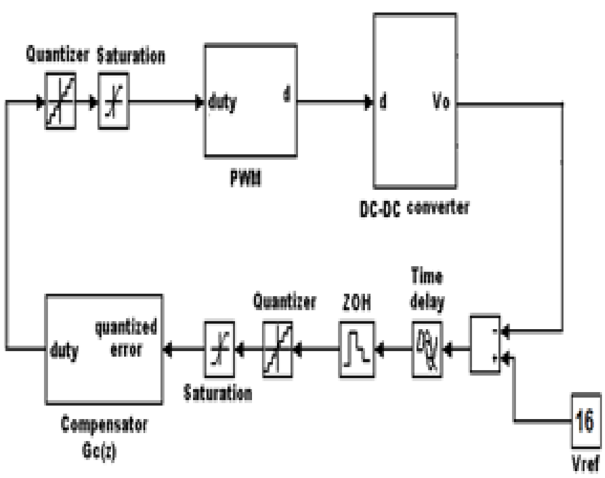

Fig.8. Simulation circuit for Boost converter with Discrete PID controller

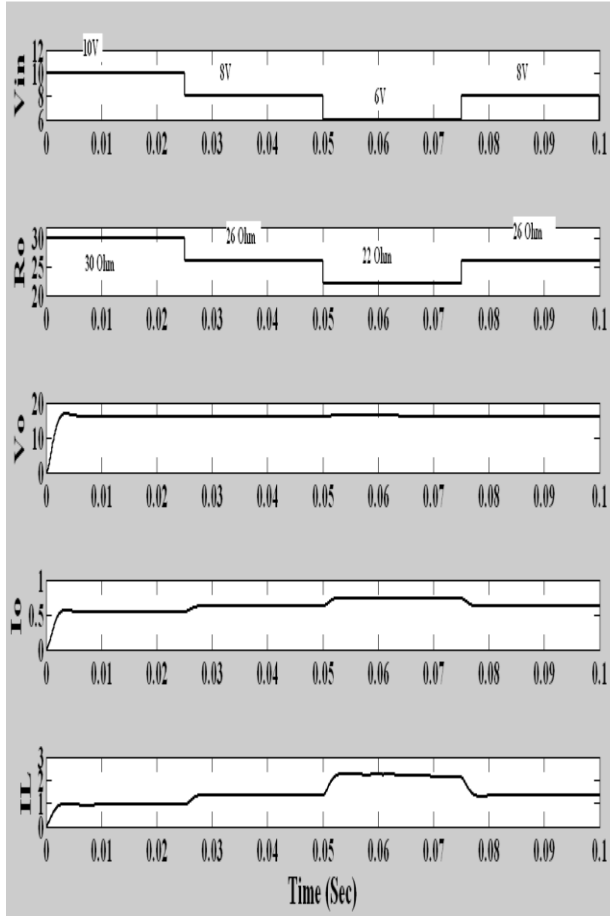

Fig.9. Output response of the boost converter along with discrete PID controller (V_s is the input voltage, R_o is the load resistance, $V_o$is the output voltage, I_o is the output current, and I_L is the inductor current)

Fig. 9. The converter requirements under consideration are maximum peak overshoot, rise time, setting time, and steady state errors are compared against an analog counterpart in Table 2. By using Tustin method, the output voltage and current shapes of the converter are almost ideal one as illustrated in Fig. 9. The output voltage has less ripple, low rise time and settling time are evident from the figure. In the waveform shown in Fig. 9 has small overshoots and zero undershoots are apparent and the steady state error observed for load changes is much lesser than 1%. The performance parameters of the boost converter along with the discrete PID controller are superior than the analog PID controller. Thus the results attained from the discrete PID controller are on part with that of the mathematical calculations, and it proves that the discrete system establishes enhanced results than the analog controller system.

Table 2. Performance parameters of the various controllers for the boost converter

Controller	Settling Time (ms)	Peak Overshoot (%)	Rise Time (ms)	Steady State Error (V)	Output Ripple Voltage (V)
Discrete PID	6	1	3	0.001	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

Table 3. Output voltage response of the various converter parameters

L (µH)	C (µF)	R (Ω)	REFERENCE VOLTAGE (V_{REF})	OUTPUT VOLTAGE (V_O)
15	15	26	16	16.001
18	15	22	16	16.001
8	12	20	16	16.002
20	8	18	16	16.0
11	20	15	16	16.001

Fig. 9 Shows the output voltage, output current, and current through an inductor response for the variation in source voltage and load resistance. Initially fix the source voltage as 10 V till 0.025 S, then it varies from 10 V to 8 V upto 0.05 S, 8 V to 6 V until 0.075 S, finally 8 V is set at 0.075 S likewise the load is fix as 30 Ω till 0.025 S, then varies from 30 Ω to 26 Ω and then changes from 26 Ω to 22 Ω at 0.05 S. Finally 26 Ω is set at 0.075 S. The corresponding output voltage response of the discrete PID controlled boost converter shows fixed output voltage regulation. The negative characteristic likes Undershoots or Overshoots are not seen and the steady state error is also obscure. To verify the dynamic performance of the controller, vary the values of L, C & R and the output voltage response of the system is tabulated in Table 3.

From Table 3, one can understand that the controller has more active in tracking the reference voltages irrespective of the changes in the inductor L, capacitor C and Load resistor R values. This controller portrays less steady state error, and it has no overshoots or undershoots are obtainable. It settles down fast with a less settling time of around 6 mS for all the values. In order to find the most excellent act of Discrete PID controller over Discrete PI counterpart, the output voltage response of the discrete PID controlled boost converter is compared against the response produced by a PI controller, whereas the result obtained is plotted in the graph Fig. 10.

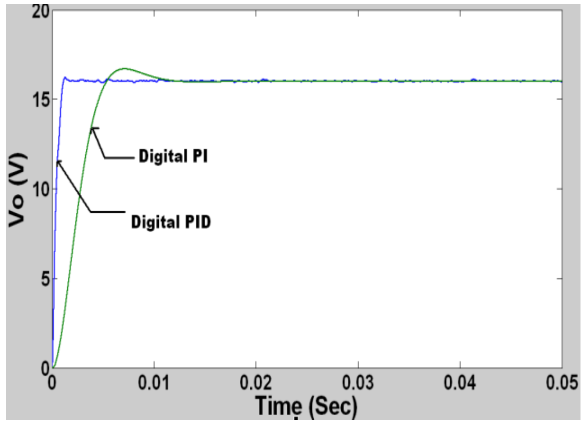

Fig.10. The output response of Digital PID and Digital PI controller

8. Hardware Implementation

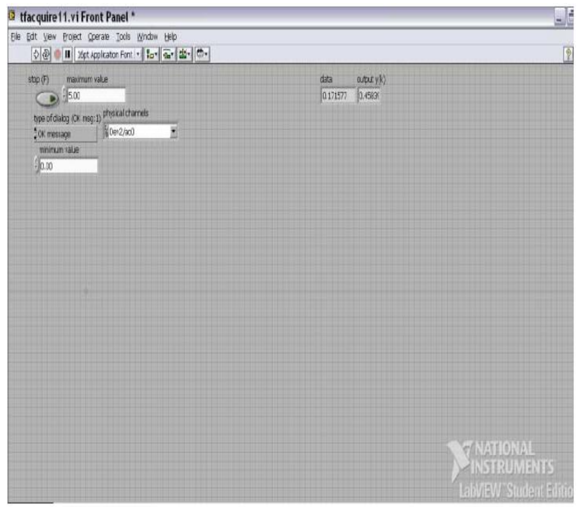

Fig. 11 Front panel

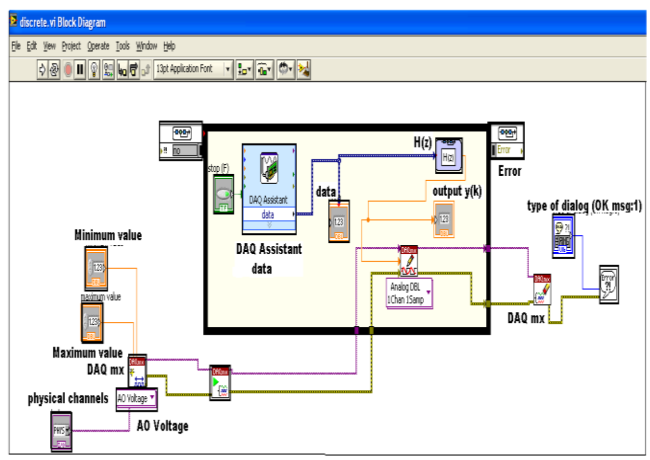

Fig. 12 Functional block diagram

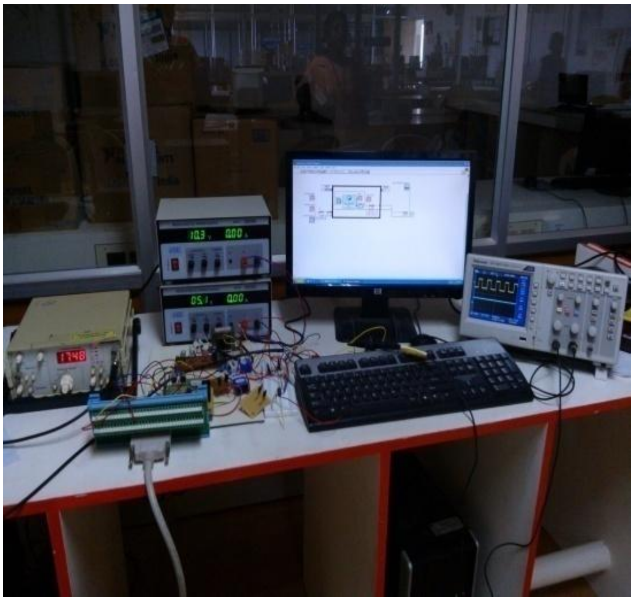

Fig. 13 Experimental set up

The boost converter with discrete PID controller has been realized using LabVIEW as a controller platform. LabVIEW (Laboratory Virtual Instrumentation Engineering Work Bench) is a controller design platform for a visual programming language developed by National Instruments. The LabVIEW software consists of three main parts as the block diagram, the front panel, and the icon/connector.

The LabVIEW front panel with the control circuit is illustrated in Fig. 11. The diagram shown in Fig. 12 contains executable icons, wires, DAQ Assistant, data transfer function H(Z) and signal generation. In the front panel the desired transfer function of the discrete PID controller can be entered and along with the require specifications of the controlled process, and thereafter the updated status of the system can be attained. The analog signal from the external circuit is obtained and converted into digital signal by the data acquisition cable (DAC). The digital error signal from the DAC is corrected by discrete PID controller H(z) block. The corrected digital signal is again converted into analog signal and give to the external circuit by the DAC.

8.1 Interfacing Circuit

The NI 9221 has 25-pin DSUB connector along with it has 10 screw terminal. The channel has an Analog Input (AI) terminal can attach a voltage signal with it. This multifunction data acquisition device provides plug and play connectivity via USB for obtaining, making and data logging for various transferable applications. It consists of 8 analog inputs, out of which 4 inputs are differential coupling, A/D and D/A converters and 64 bits counters. It ultimately provides an outstanding platform for the proposed controller.

Table 4 Component values

Description	Experimental values
Frequency f	400 KHz
Input voltage V_s	8 V
Inductor L	11 µH
Capacitor C	12 µF
Load Resistor R	26 Ω
MOSFET S	IRF840
Diode D	1N4001
DAQ cable	NI 9221

Fig.13. depicts experimental setup of discrete PWM controlled boost converter, in this setup the gaining of the error signal from the boost converter is taken place on the spot instantly. When the LabVIEW program runs then the corrected controlled signal is generated within a very shorter duration of time. To evaluate its performance, the reference voltage is fixed at 16 V and the given input voltage is 8 V whose corresponding output voltage measured is 16.04 V. Thus the acquired steady state error is very minimum in the range of 0.04V and the controller settles down at a faster rate. The experimental results are obtained in concurrence with the mathematical calculations, and simulation results. As per the values given in Table 4, the miniature model is developed

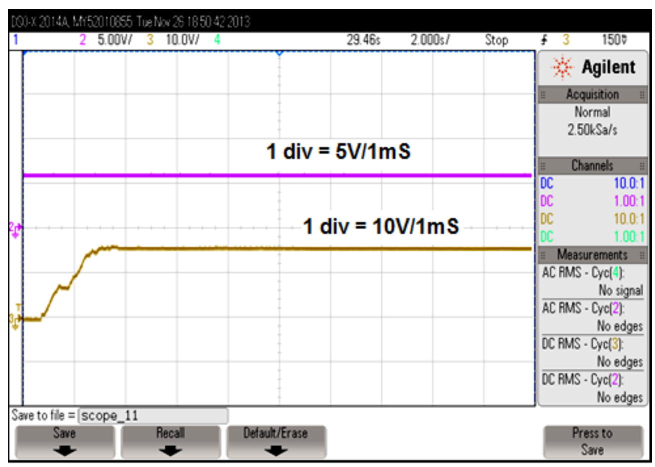

Fig. 14 Output signal obtained for 6V input, V_{ref} = 16 V

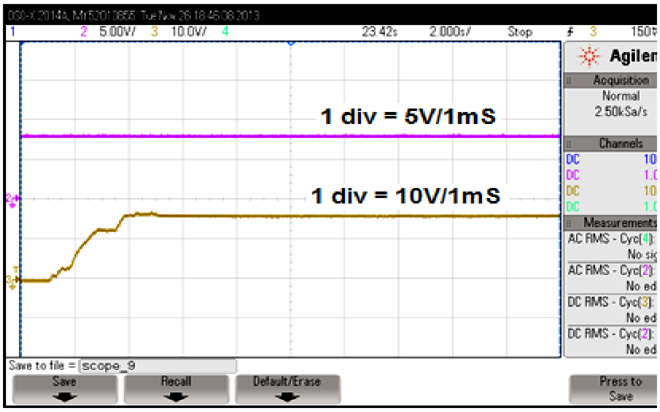

Fig.15 Output signal obtained for 8V input, V_{ref} = 16 V

In the hardware output, the input signal has been varied as 6 V, 8 V, 12 V and the relevant output signal is changed as 16.01 V, 16.0 V and 16.02 V respectively with the reference of 16 V and the same is depicted in Figures 14, 15 and 16 respectively. In the output graph, Channel 2 characterizes the input voltage and Channel 3 indicates the corresponding steady state output voltage. From the output signal one can understand that there is no overshoot or undershoot, and has less steady state error only. The settling time, and rise time is very meager in the order of not more than 5 mS and hence can be ignored.

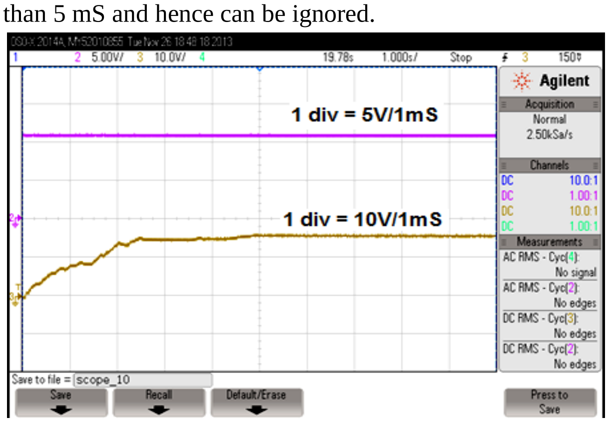

Fig.16 Output signal obtained for 12V input, V_{ref} = 16 V

Likewise the output signals for the reference voltages of 16 V & 20 V along with their gate pulses are shown in Fig. 17 & 18 respectively. Channel 1 designates reference voltage as 16.02 V and 20.04 V respectively and channel 2 renders their equivalent PWM pulses with the duty cycle of 50.06 % and 60.22 % respectively. As shown in Figures 17 & 18, the reference voltage has been changed from 16 V to 20 V which is proportionally instantiated in duty cycle to get the output signal at the same reference voltage.

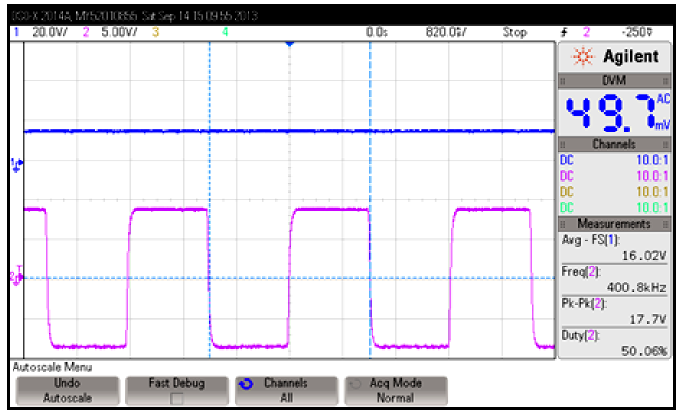

Fig. 17 Duty Cycle gets for 16V reference

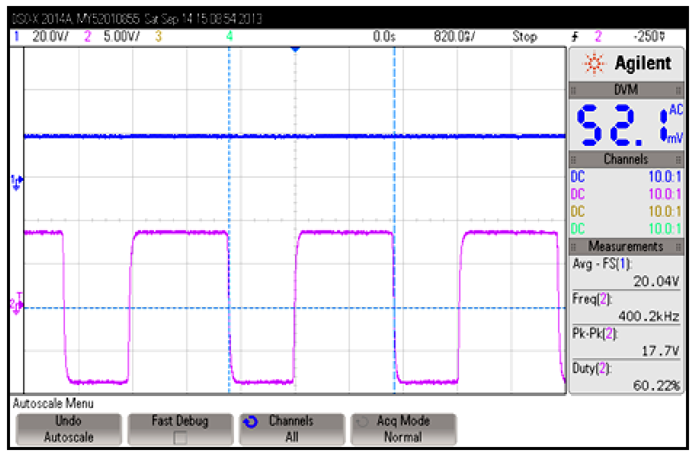

Fig. 18 Duty Cycle gets for 20V reference

9. Conclusion

In this work, the proposed boost converter with the PWM discrete PID controller has been analysed, designed and simulated. The simulation results which prove that boost converter along with discrete PID controller has been improved the performance of steady state and transient state. This controller increases the efficiency of the boost converter and it has been derived using bilinear transformation approach. It reveals that the changes in duty cycle as per the changes encountered in the error signal can influence the performance. The discrete PID controller for the Boost converter is extracted from LabVIEW and the results exhibit a positive impact on the performance. The controller attains the regulated output voltage, enhanced efficiency, and excellent dynamic performance is proved through the mathematical analysis, simulation study and the experimental results. This topology is very much compatible and competent with all other DC-DC converters and hence can be a practical choice for many applications such as PV based applications, speed control, and also in the field of medical electronics.

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