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Time Domain Based Discrete PID Controller for Cascaded Boost Converter

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Abstract:This paper exhibits demonstrating of discrete PID controller for cascaded boost converter (CBC). For high voltage increase, simple enactment and better performance the cascaded boost converters are best. The discrete PID controller is compared with linear PID controller for cascaded boost converter to validate its performance. The control depends on voltage which is feedback into control hoop of converter arrangement. The intended controller improves enduring state reaction and dynamic reaction of converter against input voltage vacillations and gigantic load unsettling influences. The gain and inactive component estimations of cascaded boost converter are theoretically assessed utilizing outline conditions. The closed loop arrangement of cascaded boost converter is planned and checked through simulation employing MATLAB/Simulink environment and execution details are measured for cascaded boost converter.

Keywords: Cascaded boost converter, discrete PID controller, modeling, performance specification.

I. INTRODUCTION

In a preceding two decade, the utilization of DC-DC converters are enhanced. An exploration of converters requisition is appeared in [1]. These converters are used to either expand or lessen the input DC voltage. Distinctive topologies of DC-DC converters are accessible in the face of Buck, Boost, Cuk, Cascaded Boost, Flyback, Forward, Half Bridge, Full Bridge, Luo, Sepic and Zeta converter [2]. Each converter has its own upsides and downsides. Facilitate converters are delegated disconnected converters and non-isolated converters.

DC-DC converters with high voltage gain is crucially necessitated in regions of industries, telecommunication and sustainable power source change framework. A super-lift technique aid to expand the voltage transfer gain of converter. This super-lift calculation has been viably possessed with DC-DC converters. This calculation permits cascaded boost converter to grasp stage by stage voltage transfer gain [3].

Boost converters are uncomplicated to contraption in light of insignificant exertion and better execution. Yet, cascaded boost converters can give high voltage gain contrasted with boost converters for a given duty cycle proportion. As switching frequency is settled, for a similar load if the duty cycle proportion is less, the voltage and current swell is additionally be less [4].

Linear PID and PI controllers are typically intended for DC-DC converters utilizing standard frequency retaliation systems in view of the little flag model of converter. A bode plot is employed as a part of configuration to get coveted hoop gain, phase margin and crossover frequency.

The stability of the framework is ensured by a satisfactory phase margin [5]. Anyhow, linear PID and PI controllers must be intended for one titular working point.

Discrete PID controllers are the most ultimate one. Computerized controllers are predominant in execution and lower in cost. Computerized controllers are greatly adaptable and simple to deal with nonlinear control conditions including confused calculations or coherent conditions [6].

Discrete controller is presented in the plan of cascaded boost converter to acquire heartiness, better voltage direction, and enhanced dynamic reaction. Basic block diagram for CBC with discrete PID controller has been shown in Fig. 1.

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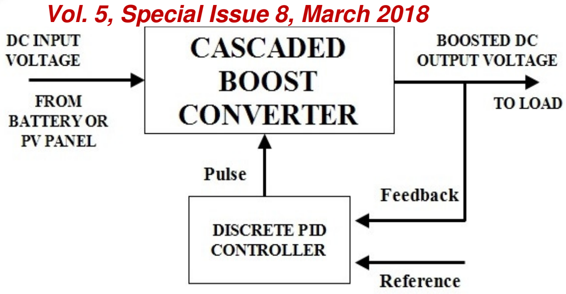

Fig. 1 Block diagram of CBC using discrete PID controller.

In Fig. 1, cascaded boost converter changes over lower dc input voltage into boosted dc output voltage. Input dc voltage is given to converter either from battery or PV board. Boosted dc output voltage is given to reasonable loads, for example, lighting and battery worked devices. Control is relies upon voltage which is input to the control hoop of converter plan. Controller controls the power semiconductor switch of the converter. Here output voltage and reference voltage are given to the controller which analyses the real and reference esteems and delivers mistake flag. The pulse which is made by controller is given to converter to set or change the duty cycle to shape a superior yield voltage and current waveform. The coveted output voltage is gained through this setup.

This paper is orchestrated as takes after: portion II oversees modeling of cascaded boost converter with proper circuit outline. Portion III approaches plan of discrete PID controller for cascaded boost converter. Portion IV presents simulation and results of planned converter. Portion V deals with conclusion.

II. Modeling of Cascaded Boost Converter

A two stage boost converter is for the most part known as cascaded boost converter. Including L_2, C_2, D_2, D_3 into boost converter with a specific end goal to shape a cascaded boost converter to get twofold the yield of boost converter [2]. Fig. 2 shows cascaded boost converter circuit plot.

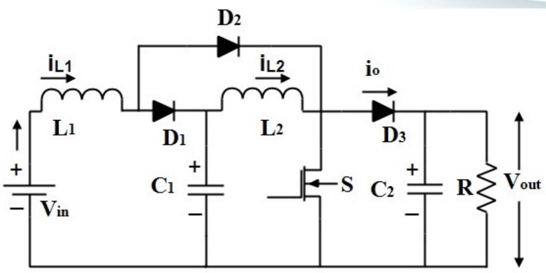

Fig. 2 Basic circuit diagram of CBC

This circuit made out of switch (S), two capacitor (C_1, C_2), two inductor (L_1, L_2), three diode (D_1, D_2, and D_3), and resistor (R) [11]. This converter works under two methods of operation. Guaranteeing that cascaded boost converter working under continuous conduction mode (CCM) with a specific end goal to decrease the current variations ξ through the inductor. It should be lower than unity [7]-[8]. The proportionate circuit of cascaded boost converter when switch S is on in the time of DT (mode 1) is shown in Fig. 3.

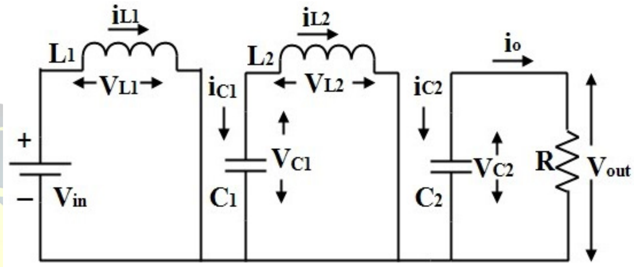

Fig. 3.Mode 1 operation of CBC

During switch on condition, input voltage V_{in} present across inductor L_1 and capacitor C_1 voltage is available across inductor L_2. Consequently, current through inductor L_2 increments with voltage across capacitor C_1.

Voltage crosswise over capacitor C_1 is,

$$V_{C_1} = \frac{V_{in}}{(1-D)} \quad (1)$$

Dynamic conditions for mode 1 is procured by applying Kirchhoff's law as given underneath,

$$\frac{di_{L_1}}{dt} = \frac{V_{in}}{L_1} \quad (2)$$

$$\frac{di_{L_2}}{dt} = \frac{V_{C_1}}{L_2} \quad (3)$$

$$\frac{dV_{C_1}}{dt} = \frac{-i_{L_2}}{C_1} \quad (4)$$

$$\frac{dV_{out}}{dt} = \frac{-V_{out}}{RC_2} \quad (5)$$

Where i_{L1}, i_{L2} are inductor current and V_{C1} and V_{out} are capacitor voltages. Fig. 4 indicates equivalent circuit of cascaded boost converter when switch S is off in the time of (1-D) T (mode2).

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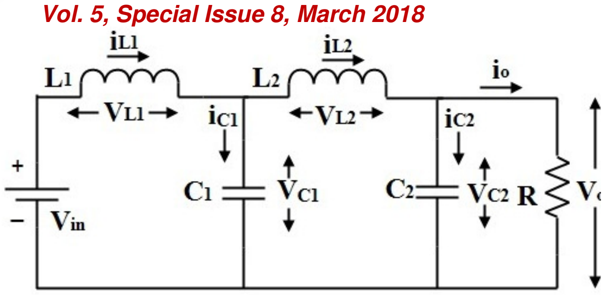

Fig. 4 Mode 2 operation of CBC

During Switch off condition inductor L_2 current reductions with voltage (V_{C_1}-V_{out}). At that point voltage crosswise over capacitor C_2 exhibits crosswise over V_{out}. In this way voltage across resistor Vout is,

$$V_{out} = \frac{V_{in}}{(1-D)^2} \qquad (6)$$

Dynamic conditions for mode 2 is gotten by applying Kirchhoff's law as given underneath,

$$\frac{di_{L_1}}{dt} = \frac{V_{in}}{L_1} - \frac{V_{C_1}}{L_1} \quad (7)$$

$$\frac{di_{L_2}}{dt} = \frac{V_{C_1}}{L_2} - \frac{V_{out}}{L_2} \quad (8)$$

$$\frac{dV_{C_1}}{dt} = \frac{i_{L_1}}{C_1} - \frac{i_{L_2}}{C_1} \quad (9)$$

$$\frac{dV_{out}}{dt} = \frac{i_{L_2}}{C_2} - \frac{V_{out}}{RC_2} \quad (10)$$

Normal state space conditions are merged articulation of each state (turn ON and OFF state) of exchanging of converter. These conditions are using Duty cycle extent. State space averaging conditions for cascaded boost converter is,

$$\frac{di_{L_1}}{dt} = \frac{V_{in}}{L_1} - \frac{(1-D)V_{C_1}}{L_1} \quad (11)$$

$$\frac{di_{L_2}}{dt} = \frac{V_{C_1}}{L_2} - \frac{(1-D)\,V_{out}}{L_2} \quad (12)$$

$$\frac{dV_{C_1}}{dt} = \frac{(1-D)\,i_{L_1}}{C_1} - \frac{i_{L_2}}{C_1} \quad (13)$$

$$\frac{dV_{out}}{dt} = \frac{(1-D)\,i_{L_2}}{C_2} - \frac{V_{out}}{RC_2} \quad (14)$$

Where D is duty cycle. State variable conditions are composed as take after,

$$\dot{X} = Ax + BU \quad (15)$$

$$\begin{bmatrix} \tilde{i}_{L_1} \\ \tilde{i}_{L_2} \\ \tilde{V}_{C_1} \\ \tilde{V}_{out} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -\frac{(1-D)}{L_1} & 0 \\ 0 & 0 & \frac{1}{L_2} & -\frac{(1-D)}{L_2} \\ \frac{(1-D)}{C_1} & -\frac{1}{C_1} & 0 & 0 \\ 0 & \frac{(1-D)}{C_2} & 0 & -\frac{1}{C_2 R} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ i_{L_2} \\ V_{C_1} \\ V_{out} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} [V_{in}] \quad (16)$$

$$\dot{Y} = Cx + DU \quad (17)$$

Where $C = [\,0\;0\;0\;1\,]\,;\;\; D = [0]\,;$

MATLAB/Command window environment discovers transfer function of this state space model of cascaded boost converter through dissecting A, B, C, and D esteems. Here transforming equations into S domain which is easy to solve for transfer function. What's more, S space conditions are converter into Z area for discrete PID controller operations.

Continuous transfer function is,

$$G(S) = \frac{2.01\,e^{14}}{S^4+26.67\,S^3+1.563\,e^8 S^2+4.148\,e^9 S+4.392\,e^{13}} \quad (18)$$

Discontinuous transfer function is,

$$G(Z) = \frac{0.625Z^3-0.627Z^2-0.6095Z+0.619}{Z^2-3.697Z^3+5.369Z^2-3.644Z+0.9737} \quad (19)$$

While plotting of CBC it is fundamental to consider per unit inductor ripple current ($\Delta i_L/i_L$)and per unit capacitor ripple voltage ($\Delta V_C/V_C$). Plan equations for discovering inactive components esteems are appeared in underneath,

$$L_1 = \frac{D(1-D)^4 R\, i_{L_1}}{\Delta i_{L_1} f} \quad (20)$$

$$L_2 = \frac{D(1-D)^2 R\, i_{L_2}}{\Delta i_{L_2} f} \quad (21)$$

$$C_1 = \frac{D\, V_{C_1}}{(1-D)^2\, R\, \Delta V_{C_1}\, f} \quad (22)$$

$$C_2 = \frac{D\, V_{C_2}}{R\, \Delta V_{C_2}\, f} \quad (23)$$

TABLE I

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PARAMETERS	VALUES
Input voltage (V_{in})	$24v$
Inductor (L_1)	$1.0358mH$
Inductor (L_2)	$4.7476mH$
Capacitor (C_1)	3.9877µF
Capacitor (C_2)	87.004µF
Resistor (R)	408.33Ω
Duty Cycle (D)	53.29%
Output voltage (V_{out})	$110v$

CALCULATED DESIGN VALUES FOR CBC

The above table I of substance helps to draw CBC in MATLAB/Simulink. Open loop and closed loop Simulink model of this converter has been executed utilizing figured parameters regards.

III. Discrete PID Controller of Cascaded Boost Converter

PID's out-turn is a mix of proportional, integral and derivative controller. It is a feedback mechanism that used in control system. PID is considered as the best controller in the control system family. The point of PID loop for cascaded boost converter is to lessen the peak overshoot, enduring state mistake and to give fast response and relaxed stability. The downsides that PID is a linear system and subsidiary part is noise sensitive [9-10]. Fig. 5 shows the diagram of simple PID control of CBC.

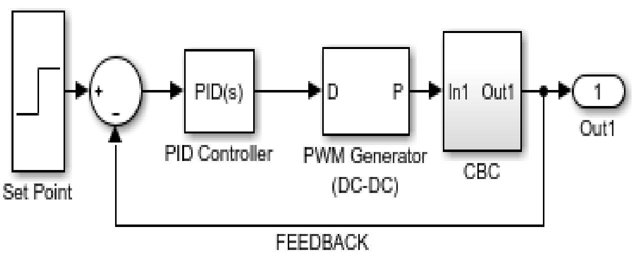

Fig. 5 Simple PID control of CBC

Discrete PID controller parameters are the function of sampling time. Here derivative term gives just less noise contrasted with linear PID controller. Along these lines discrete PID controller offers more functionalities contrasted with linear PID controller.

Steps including in PID tuning for converter is given beneath,

- Modeling,
- Parameter Designing,
- Finding Transfer Function (Continuous or Discontinuous)
- Finding Step response of the system,
- Calculating PID consistent Values (K_p, K_i, K_d, T_s),
- Finding Plant Equation.

Ziegler-Nichols Rules used to set estimations of relative proportional gain K_p, integral time T_i and derivative time T_d as appeared in table II. This will give stable operation of a plant and influence the dynamic execution. These consistent values are calculated according to the formula of Ziegler and Nichols rules.

At first set Ti value become infinity and T_d value become zero and increment the K_p value from zero to critical gain K_{cr} at which output exhibits oscillations. Thus, the critical gain K_{cr} and the corresponding critical period P_{cr} are calculated. Kc_r value can be figured by utilizing root locus strategy. Where= $(2 * \pi)/\omega$, ω is frequency of sustained oscillation.

Continuous time PID controller transfer function is,

$$G_c(S) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \quad (24)$$

Discontinuous time PID controller transfer function is,

$$G_c(Z) = \left(K_p + K_i \frac{Ts}{2}\frac{z+1}{z-1} + K_d \frac{z-1}{Tz}\right) \quad (25)$$

These time domain specification values are affected by gain values of PID controller. By diminishing settling time, peak overshoot and rise time, controller provides good behavior and stable operation for cascaded boost converter. The assessed gain values for linear PID controller are K_p=0.001, K_i=0.8004, K_d=6.242e-7 and for discrete PID controller K_p=0.001e-3; K_i=6.66e-7, K_d=3753e-7, T_s=0.001s.

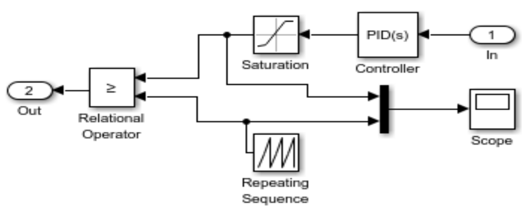

Fig. 6 PWM generation representation

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PWM is a modulation method which is defined as the normal estimation of voltage and current sustained to the load is controlled by turning the switch between supply and load on and off at a quick rate. Simply PWM technique gives pulse to set the duty cycle ratio which is characterized as the proportion of switching on time to total switching period.The PWM generation for converter is displayed in Fig. 6.

IV. Simulation and Results

MATLAB/Simulink is utilized to outline and check the cascaded boost converter to know its performance. The designed parameters are shown in Table I. To observe the fundamental attributes of cascaded boost converter, it is vital to put open loop control. Fig. 7 demonstrates open loop control for cascaded boost converter.

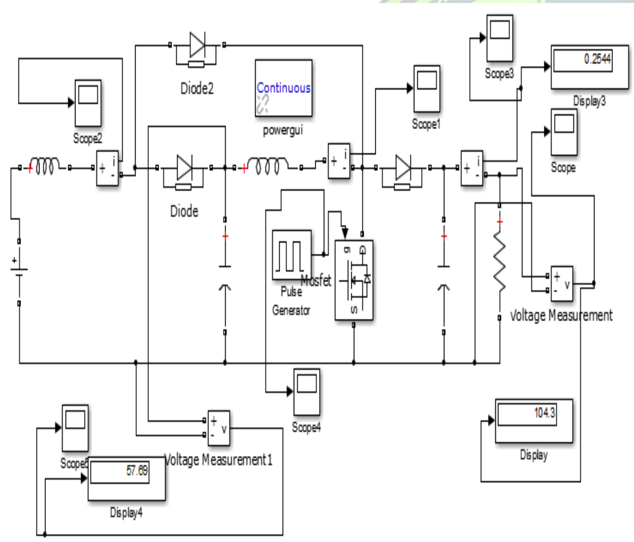

Fig. 7 Open loop model for CBC

Output voltage waveform for open loop CBC is shown in Fig. 8. CBC without control producing high peak overshoot and oscillations and slow response. Thus it is important to put controller for cascaded boost converter.

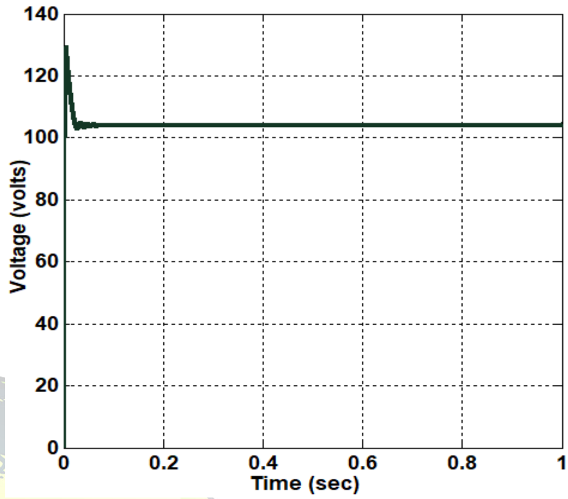

Fig. 8 Output voltage waveform for CBC

Fig. 9 demonstrates the Simulink model of cascaded boost converter with PID controller. The configuration for PID controller and Discrete PID controller are same. The main distinction is discrete PID incorporating with sampling time.

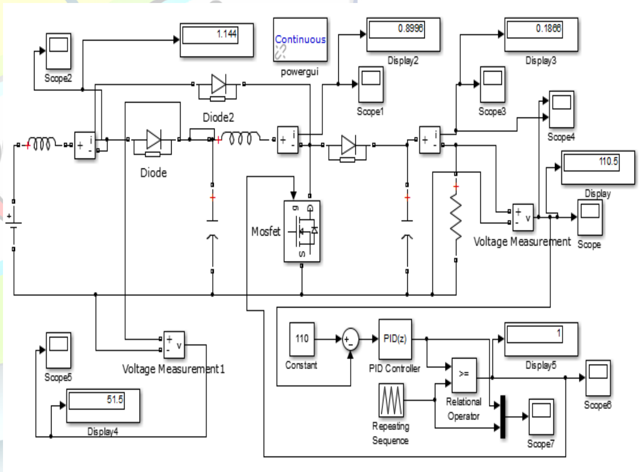

Fig. 9 Simulink model of closed loop control of CBC

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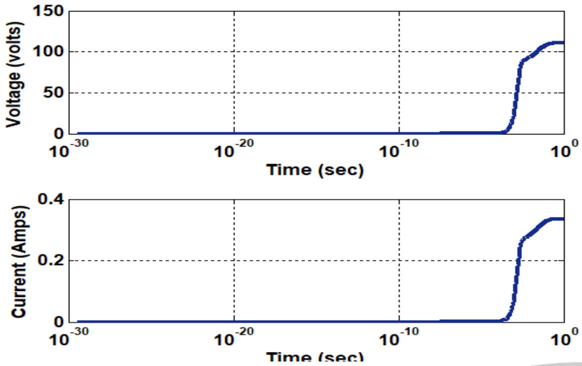

Fig. 10 Output voltage and current waveform for CBC with Discrete PID controller

Output voltage and current waveform of CBC with discrete PID controller has been shown in Fig. 10. The acquired values from Fig. 10: Output voltage = 110V, Output current= 0.27A. Table III shows comparison of PID and discrete PID controller execution determination which is obtained from Fig. 11.

TABLE III

PERFORMANCE SPECIFICATION FOR CLOSED LOOP CASCADED BOOST CONVERTER

Controllers	Peak Overshoot (%)	Settling Time (sec)	Rise Time (sec)	Peak time (Sec)
Discrete PID	0	0.05	0.002	0.03
PID	13.63	0.2	0.004	0.04

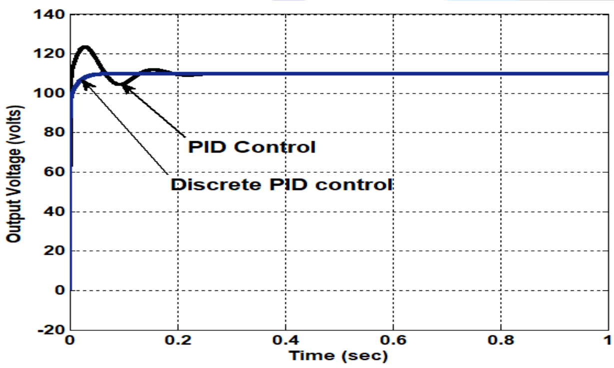

Fig. 11 Comparative Output voltage for Linear PID and Discrete PID controller of CBC

Accordingly, in PID control, crest over shoot is high and settling time is more contrasted with Discrete PID control.Discrete PID controller gives limited the peak over shoot and provides quicker reaction. Both of the systems reached the expected output voltage yet however closed loop control of discrete PID system just the most secure one in which providing high voltage gain and enhanced dynamic reaction.

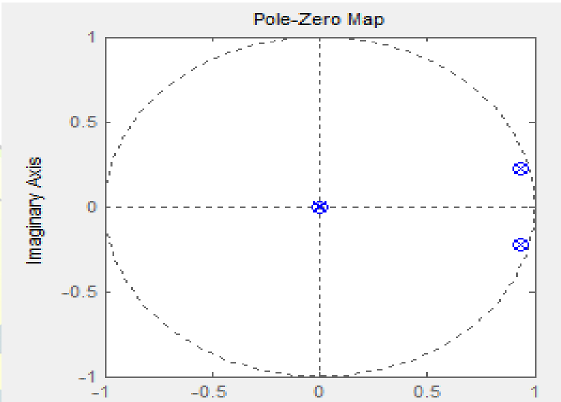

Fig. 12 Pole-Zero map for cascaded boost converter

In order to examine the stabilization of system for cascaded boost converter pole zero map is used as shown in Fig. 12. This map has been drawn utilizing transfer function equation of discrete PID controller for cascaded boost converter.

On the off chance that the poles is inside the unit circle it influence the framework to stable. On the off chance that poles lies external unit circle makes framework unstable. Closed loop zero doesn't affect system stability. The Discrete PID controller poles for cascaded boost converter are lying into the circle. Accordingly Discrete PID controller gives stable operation to this converter.

V. Conclusion

In this paper modeling and design of time domain based discrete PID controller for cascaded boost converter has been implemented. Discrete PID controller furnished better performance contrasted with Linear PID controller for cascaded boost converter which is affirmed through simulation employing Matlab/Simulink software. Thus discrete PID controller superior to Linear PID controller bygained upgraded dynamic response and stable operation.

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