International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8, Issue-1, May 2019

Frequency Domain Approach for Designing a Lag Compensator for Buck-Boost Converter

Bandan kumar Panigrahi, Manoj Kumar Sahu

***Abstract:** DC-DC converter makes vital contribution in the field of effective power supplies for regulation of ripple free voltage with high quality. This paper presents an effective Lag controller design in frequency domain for dc-dc Buck Boost converter. Steady state analysis of high power buck-boost converter is done in order to draw the control mechanism needed for its faithful operation by time- average model. The proposed control scheme is implemented with buck boost converter in MATLAB SIMULINK platform to verify the theoretical concept. Lastly a comparison is made between the closed loop and open loop response of buck-boost converter.*

***Index Terms:** DC-DC converter, lead controller, MATLAB*

I. INTRODUCTION

Dc-dc converters plays an important role in power factor correction for any line supply.During this process, converter faces high stress on switching components and losses associated with it[1]. This paper presents a novel multi switch(two switch) buck –boost inverter which offers better response than conventional single switch. The proposed converter has a enhanced performance in power factor correction [PFC] application. Now a days , enabling of multi input function to a power electronic DC-DC converter helps to extract the energy from different sources of energy[2]. The output voltage can be maintained constant while making arbitrary power command taken into account in idealized converter. This technique finds its major application when there is a need of multiple sources of energy load like automobile household, aerospace. The performance of conventional capacitor switched converters can be increased by replacing it by flying capacitor prototypes[3]. The new proposed prototype has the boosting capability which is the twice of the ratio of the ON time (switching) to total time (ON+OFF). Around the constraint of heavy load and light load, this paper adopts pseudo current dynamic acceleration technique to enhance the transient stability. The proposed converter frequency ranges from 1MHz to 1.0-4.5 v output. The detail and through study of state of art of dual interleaved buck-boost converter is presented in this paper[4].

The converter consists of two inductors coupled magnetically but not electrically.

In this article , the simillarness between the current waveforms of both buck and boost converter is the basis depending on which the seven different pattern of discontinuous mode of operation for each circuit is identified. The paper developed prototypes of proposed converter and experimented it. The experimental result validates the proposed scheme of discontinuous current operation. The traditional double duty cycle output converter is combined with synchronizing rectified(SR) in order to reduce the voltage bucking capability of KY converter for making its boarder application[5] . The default continuous conduction mode of operation of this converter makes enable it to eliminate the deviation from average value to the output as well as the voltage stress on the output filter. The concept of soft switching is applied to buck- boost converter by making parallel operation of two single stage converter[6]. A inductor bridge is used to complete the circuit which also helps to achieve soft switching by making voltage across the switch to zero at switching intervals. The mode of working and control mechanism of buck-boost converter can be achieved by taking the piezoelectric transformers (powered by vibration mechanism) in to consideration [7]. The proposed control scheme is based upon the fact that electrical requirement of input in discontinuous mode of operation is perfectly analogous to the criteria taken for control optimization. In this research article, the proposed optimal control technique is verified by experimenting the plant (with control to a load of rechargeable battery(8v) at output side. A high power Dc-Dc power electronics buck-boost converter can be controlled by non-linear adaptive control technique [8,9]. This method of control design is based upon pulse width modulation[PWM] technique of switching for DC-Dc converter. In this paper, the parameters of the plant are assumed to be unknown and stability of the system can be assumed by formulating CLF[Control Laupnv Function]. Type-III controller plays an important role for improving the control parameters in case of dc-dc high power converters[10]. This paper presents the detail way of designing the novel type-III controller which makes the transient response faster by reducing the value of steady state error if applied to converter. A two-input fourth-order integrated (TIFOI) dc-dc converter regulates dc-bus voltage and low voltage source current with two switching devices and four energy storage elements[11].To overcome the selection of suitable architecture of controller, centralized interaction independent controller was designed for a TIFOI dc-dc converter using H-infinity Loop-shaping design procedure.

Revised Manuscript Received on 30 May 2019.

* Correspondence Author

Er. Bandan Kumar Panigrahi*, Dept. of Electrical Engineering in CAPGS, BPUT, Govt. of Odisha, India .

Dr Manoj Kumar Sahu, Associate Professor and Head of Dept. in the Dept. of Electrical Engineering in CAPGS, BPUT, Govt. of Odisha, India

The output voltage regulator of dc-dc boost converter can be designed by structured singular value in continuous current mode of conduction[12]. In this way of designing the controller, the effect of tolerances of reactive components and variation of operating point on converter performance can be minimized. A highly efficient and novel control strategy for improving the transients in the output voltage of a dc–dc positive buck–boost converter, required for low-power portable electronic application[13,14].The proposed control technique can regulate the output voltage for variable input voltage, which is higher, lower, or equal to the output voltage. A systematic method for developing isolated buck boost (IBB) converters is proposed in this paper, and single-stage power conversion, soft-switching operation, and high-efficiency performance can be achieved with the proposed family of converters[15].

II. BUCK BOOST CONVERTER

Buck-boost converter plays an important role in the state of art of the renewable energy extraction process. Low installation cost, high voltage developing capability, revesre voltage polarity with respect b to input given makes its wide area of application in the field of Clean energy. The absence of ground terminal in the switch makes no difference as source is isolated from the load electrically.

A. Circuit and working principle

The working of buck boost converter can be divided into three modes. Switch on operation consist of combining the mode-1 and mode-3 operation . Similarly switch off operation of the above stated converter is equivalent to mode 2 operation. The power circuit of buck boost converter is shown in fig 1 below. The equivalent circuit for operation of buck boost converter during switch ON and switch OFF condition can be shown in fig 2 and fig 3 respectively.

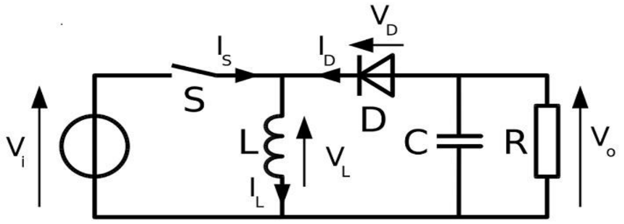


Fig 1- power circuit of buck boost converter

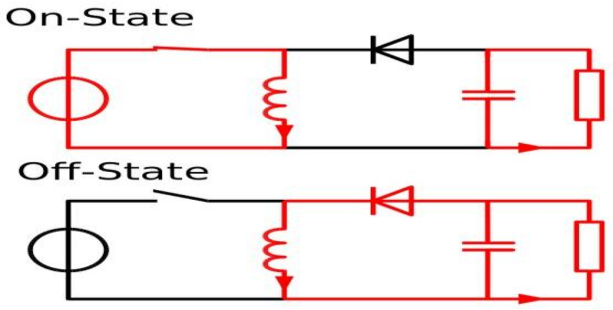


Fig 2 – equivalent circuit during switch ON and OFF condition

Mode 1 operation starts when the switch is turned on. In this condition the current through input inductor rises ie inductor is getting magnetized through the path provided by switch. Mode 2 operation starts when the switch is getting off after some time. By this moment the inductor is magnetized up to the rating of source voltage ie in previous state now starts demagnetizing with opposite polarity to charge capacitor and supply the load with opposite polarity. Mode 3 begins when the switch is again turned ON .Same operation prevails as in mode 1 but in addition to that the output capacitor which is charged earlier is now being discharged with same polarity across its terminals as before. The theoretical waveform of buck boost converter is shown in figure 3.

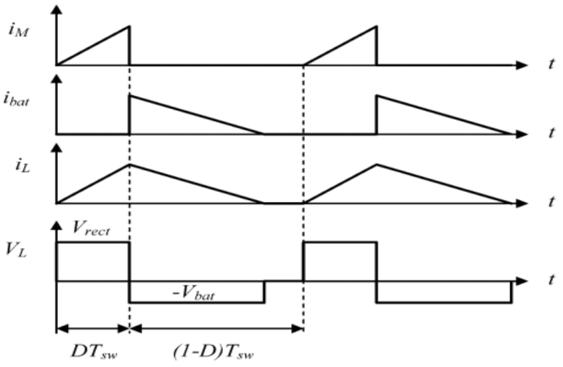


Fig 3-Theoratical waveform of buck boost converter

III. SIMULATION AND RESULT

The open loop simulation of buck boost converter is shown in figure below which indicates the need of a controller for efficient and faithful operation of buck-boost conver.

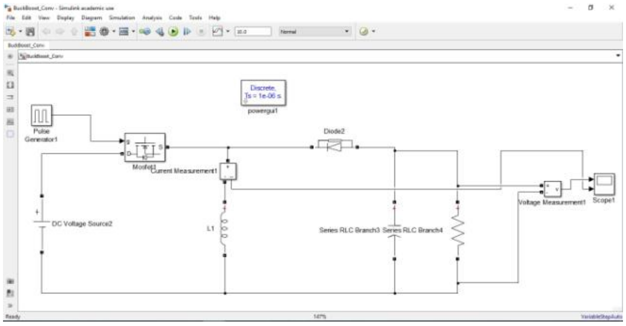


Fig 4 open loop simulation of buck boost converter

The figure shown below indicates the simulated output voltage and current waveform of above stated dc-dc converter.

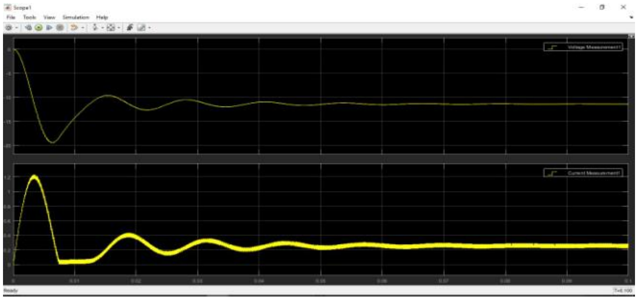
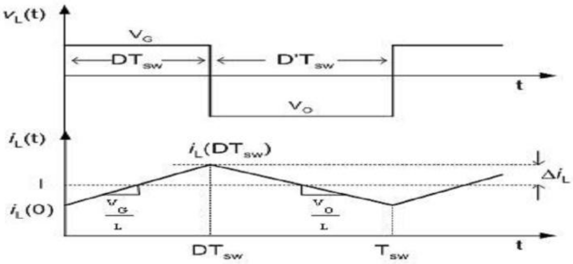


Fig 5 simulated o/p voltage and current waveform of buck boost converter

IV. CONTROLLER DESIGN

A. State space analysis of buck boost converter:



The steady state inductor current and voltage waveforms are shown above.Applying volt-sec balance theory across the inductor and Applying amp-sec balance theory across the capacitor in fig2(during switch ON), we can have

$$-v_1 + L\frac{di}{dt} = 0 \text{ ....(1)}$$

$$C\frac{dv}{dt} + \frac{v_0}{R} = 0 \text{ ....(2)}$$

Taking inductor current and capacitor voltage as state variable we have

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} * \begin{bmatrix} i_L \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} * v_1 \text{ ....(3)}$$

Applying volt-sec balance theory across the inductor and amp-sec balance theory across the capacito in fig2(during switch OFF), we can have

$$-L\frac{di_L}{dt} + v_{C=0} \text{ ....(4)}$$

$$i_L + C\frac{dv_C}{dt} + \frac{v_2}{RC} = 0 \text{ ....(5)}$$

Taking inductor current and capacitor voltage as state variable we have

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{L} \\ \frac{-1}{C} & \frac{-1}{RC} \end{bmatrix} * \begin{bmatrix} i_L \\ V_C \end{bmatrix} \text{ ....(6)}$$

From equation (3) and (6) w have the two vcalues foer the system matrix A and also for B,C,D.So in order to find the equivalent values for A,B,C,D we have

$$A_{eq} = A_{ON} * d + A_{off} * (1 - d) \text{ ....(7)}$$

So the final values of A,B,C,D are given below

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

D=[0]................(8)

The transfer function from state space analysis is given by

TF=C* inverse of (sI-A)*B +D..(9)

In order to find ou5t the transfer function of buck boost converter we have to find the value of inverse of (sI-A) which is given by

$$\text{Inverse of (sI-A)} = \frac{cofactor\ of\ (sI-A)}{det.of\ (sI-A)} \text{ ....(10)}$$

By putting equation (8) and (10) in equation (9) is given by

$$TF = \begin{bmatrix} 0 & 1 \end{bmatrix} * \begin{bmatrix} \frac{s+\frac{1}{RC}}{p} & \frac{1-d}{Lp} \\ \frac{-(1-d)}{Cp} & \frac{s}{p} \end{bmatrix} * \begin{bmatrix} \frac{d}{L} \\ 0 \end{bmatrix} + 0$$

$$= \frac{-d*(1-d)}{LC} * \frac{1}{s^2 + \frac{s}{RC} + \frac{(1-d)^2}{LC}} \text{ ....(11)}$$

V. LEAD CONTROLLER DESIGN

Controller is required in case of powervelectronic converters in order to control the vduty cycle to get the desired response at output.In other words controller is requird for either stabilizing the plant or helping to get desired response at a given set of specification. Lead controller has a zero at s=$\frac{1}{\tau}$ and a pole at s= $\frac{1}{\alpha\tau}$ with zero closer to origin thanthe pole.The general form of the lead compensator is given by

$$G_c(s) = k * \frac{s+z_c}{s+p_c} = \frac{s+\frac{1}{\tau}}{s+\frac{1}{\alpha\tau}} \text{ ....(12)}$$

Table-1:values of parameter for controller design

Sl no	parameter	values
1	Input voltage	10 volt
2	Duty cycle	.6
3	Output voltage	15 volt
4	Input inductor	15e-3 H
5	Output capacitor	470e-6 F
6	Losd resistor	100 ohm

Putting the values from table 1 in equation (11) we have

$$G_p(s) = TF = \frac{-3.404e-4}{s\text{^}2 + 1.418e05\ s + 2.27e04} \text{ ....(13)}$$

Plotting bode plot on MATLAB of buck boost converter transferfunction we have the values of overshoot =.07 and settling time as 36 sec.So system specification is taken as less than equal to the above specified value.By calculating the vvalue of $\mu = .643$ (damping factor) and $w_n = 13.996\ radian\ per\ sec.$ So the characteristic equation of a second order system is given by

$$s^2 + 17.998s + 195.88 = 0 \text{ ....(14)}$$

Roots of equation (14) are

$$s_1 = -8.999 + 10.719i$$
$$s_2 = -8.999 - 10.719i$$

Next step is the calculation of angle of uncompensatated buck boost converter at s=s_1 which turns to be -50.48 degree.So extra amount of phase margine required to meet -180 degree is

$$\emptyset = -129.52\ degree \qquad (15)$$

Calculating the angle contribution of poles of the uncompensated plant we have

$$\theta = 49.94\ degree \qquad (16)$$

So the value of γ is given by following formula

$$\gamma = .5 * (\pi - \theta - \emptyset) \qquad (17)$$

Putting equation (15) and (16) in equation (17), we have value of γ as 151.78 degree.So next step is to calcualte the zero and pole opf lead controller wom expressions are given by

$$z_c = w_n * [\frac{\sin\gamma}{\sin(\pi-\theta-\emptyset)}] \qquad (18)$$

$$p_c = w_n * [\frac{\sin(\gamma+\theta)}{\sin(\pi-\theta-\gamma-\emptyset)}] \qquad (19)$$

By putting the equations 15-17 in equation (18) and (19) we have the values of z_c=21.77 and p_c= 8.99. So the controller transfer function is given by

$$G_c(s) = k * \frac{s+z_c}{s+p_c} = \frac{s+\frac{1}{\tau}}{s+\frac{1}{\alpha\tau}} = k * \frac{s+21.77}{s+8.99} \qquad (20)$$

The value odf consat k in equation (20) can be found out by apllying the following condition

$$1+G_p(s) * G_c(s) = 0 \qquad (21)$$

The values of K can be calcuilated as -34.48.So the final expression for lead controller is given by

$$G_c(s) = -34.48 * \frac{s+21.77}{s+8.99} \qquad (22)$$

The close loop simulation of buck boost converter with proposed controller is given below

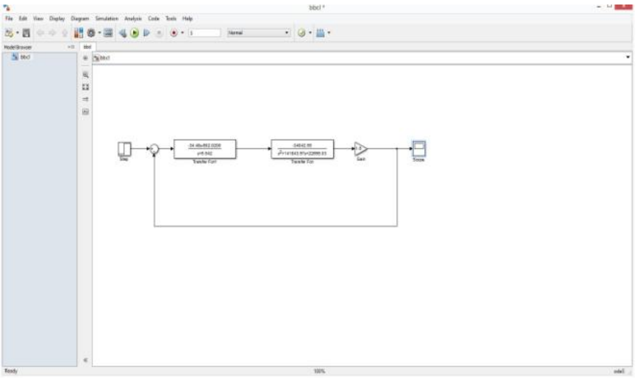


Fig 6-Simulation diagram of Plant with proposed controller

The simulated wavefrom of buck boost converter is given by

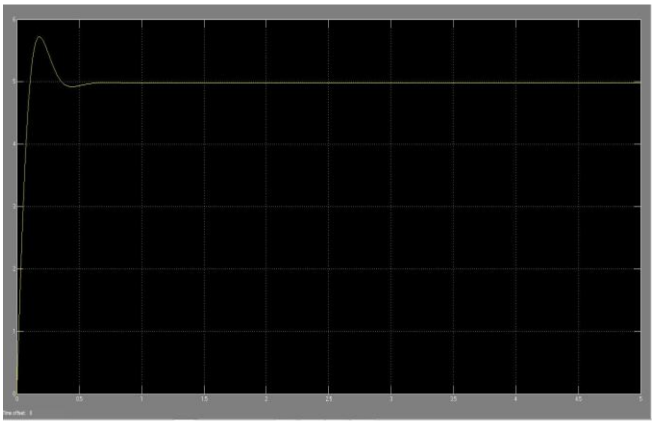


Fig 6-closeloop simulatedwaveform of buck boost converter

V. CO0NCLUSION

The lierature review shows that the controller which are being designed earlier for dc-dc high power converter has many disadvantages as compared to the proposed controller in prospective of time domain analysis. The proposed novel lag controller uses frequency domain analysis of buck-boost converter which in turn cosiders all the non-linearities into to be a best suitable controller than conventional PI controller. Close loop simulation of dc-dc high power buck-boost converter with Lag controller shows enhanced performance and optimum control than PI controller.

REFERENCES

1. Lee, Young-Joo, et al. "Digital combination of buck and boost converters to control a positive buck–boost converter and improve the output transients." IEEE Transactions on Power Electronics 24.5 (2009): 1267-1279.
2. Hwu, K. I., and T. J. Peng. "A novel buck–boost converter combining KY and buck converters." IEEE Transactions on power electronics 27.5 (2012): 2236-2241.
3. Lefeuvre, Elie, et al. "Buck-boost converter for sensorless power optimization of piezoelectric energy harvester." IEEE Transactions on Power Electronics 22.5 (2007): 2018-2025.
4. Benavides, Nicholas D., and Patrick L. Chapman. "Power budgeting of a multiple-input buck-boost converter." IEEE Transactions on Power Electronics 20.6 (2005): 1303-1309.
5. Chen, Jingquan, Dragan Maksimovic, and Robert W. Erickson. "Analysis and design of a low-stress buck-boost converter in universal-input PFC applications." IEEE Transactions on Power Electronics 21.2 (2006): 320-329.
6. . Buso, Simone. "Design of a robust voltage controller for a buck-boost converter using/spl mu/-synthesis." IEEE Transactions on Control Systems Technology 7.2 (1999): 222-229.
7. Hwang, Yuh-Shyan, et al. "A Fast Transient Response Flying-Capacitor Buck-Boost Converter Utilizing Pseudocurrent Dynamic Acceleration Techniques." IEEE Transactions on Very Large Scale Integration (VLSI) Systems 23.6 (2015): 1155-1159.
8. Reddy, B. Amarendra, and Mummadi Veerachary. "Robust multivariable controller design using H-infinity Loop shaping for TIFOI DC-DC converter." Electrical, Computer and Electronics Engineering (UPCON), 2016 IEEE Uttar Pradesh Section International Conference on. IEEE, 2016.
9. Yuan, Yubo, et al. "Design of a single-input fuzzy PID controller based on genetic optimization scheme for DC-DC buck converter." Next-Generation Electronics (ISNE), 2015 International Symposium on. IEEE, 2015.
10. Maali, Erfan, and Behrooz Vahidi. "Double-deck buck-boost converter with soft switching operation." IEEE Transactions on Power Electronics 31.6 (2016): 4324-4330.
11. Lu, Yangjun, et al. "A Family of Isolated Buck-Boost Converters Based on Semiactive Rectifiers for High-Output Voltage Applications." IEEE Transactions on Power Electronics 31.9 (2016): 6327-6340.
12. Chan, Ka-Fai, et al. "Generalized Type III controller design interface for DC-DC converters." TENCON 2015-2015 IEEE Region 10 Conference. IEEE, 2015.
13. Roy, T. K., et al. "Robust adaptive backstepping controller design for DC-DC buck converters with external disturbances." Industrial Electronics and Applications (ICIEA), 2016 IEEE 11th Conference on. IEEE, 2016.
14. Wu, Ding, Gerardo Calderon-Lopez, and Andrew John Forsyth. "Discontinuous conduction/current mode analysis of dual interleaved buck and boost converters with interphase transformer." IET Power Electronics 9.1 (2016): 31-41.
15. Roy, T. K., et al. "Nonlinear adaptive controller design for PWM based DC-DC boost converters using bank stepping control scheme." Informatics, Electronics and Vision (ICIEV), 2016 5th International Conference on. IEEE, 2016

AUTHORS PROFILE

Er. Bandan Kumar Panigrahi, is currently working as a faculty in the Dept. of Electrical Engineering in CAPGS, BPUT, Govt. of Odisha, India . He has done his B.Tech from PMEC,BPUT, Odisha, in the year 2010 and M.Tech. from BIT Mesra in 2017. He has a 02 years of experience in both teaching and research. He has published 05 no of papers in both national and international conferences.
Mail Id: panigrahi91@gmail.com
Mobile No: +91-6370873296

Dr Manoj Kumar Sahu, is currently working as a Associate Professor and Head of Dept. in the Dept. of Electrical Engineering in CAPGS, BPUT, Govt. of Odisha, India . He has done his B.Tech from UCE Burla, Odisha, and M.Tech. from KIIT University. He has done his Ph.D from Utkal University in the year 2014 He has a 20 years of experience in both teaching and research. He has published30 no of papers in both national and international conferences.
Mail Id: capgs.mksahu@bput.ac.in
Mobile No: +91-7978641040