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CLOSED LOOP CONTROL OF NON ISOLATED POSITIVE OUTPUT BUCK BOOST DC-DC CONVERTER

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Abstract – *The closed loop control of a transformerless DC to DC Buck Boost converter with positive output has been achieved using Genetic Algorithm based PI controller for which the tuning of controller parameters is done using Integrated Time Absolute Error (ITAE).Though a wide variety of converter topologies have been proposed earlier, their applications are restricted due to limited voltage gain, topological complexity, cost, volume and losses .Compared with the traditional converters, the transformerless converter's voltage gain is high with non-inverted output. Simulation, state space modelling, derivation of transfer function and closed loop control will be performed to validate the effectiveness of the transformerless DC to DC converter.*

Key Words: DC to DC converter, PI controller, Genetic algorithm, Closed loop control, Non isolated converter, Transformerless converter, Positive output

1.INTRODUCTION

DC to DC converters are electronic circuits used for converting voltage of DC supply from one level to another, which may be higher or lower. They are used in a wide variety of applications such as discharge lamp ballasts for automobile headlamps, fuel-cell energy conversion systems, solar-cell energy conversion systems, and battery backup systems for uninterruptible power supplies. Though a wide variety of converter topologies have been proposed earlier, their applications are restricted due to limited voltage gain, topological complexity, cost, volume and losses .Compared with the traditional converters, the transformerless converter's voltage gain is high with non-inverted output.

1.1 Literature Survey

In 1998, A.J. Forsyth and S.V.Mollov has clearly explained the averaging and linearisation techniques used for state space modelling and derivation of transfer function of DC –DC Converters. DC-DC Converters can be provided with isolation using transformers and reduction of switching losses with the help of resonant techniques or soft switching. The three control methods namely Single loop control, Input voltage feed forward control , and current mode control are described with simulation block diagrams. The single loop control produces control signal with the help of error signal obtained by comparing output voltage with the reference signal . Input voltage feed forward control directly senses the voltage disturbances and provides the necessary correction. The current mode control is based on feedback of inductor current. These methods can be used for conventional DC-DC converters and other similar complex systems like the proposed model. Out of the three control methods, the current mode control gives a better performance comparatively in the case of source voltage disturbances and load transients. This article greatly aided in the case of simulation, state space modelling and derivation of transfer function to design a controller for the proposed model.

In 2008, Boris Axelrod, Yefim Berkovich have proposed hybrid converters with few simple structures formed by either two capacitors and two or three diodes /two inductors and two or three diodes with high step up/ step down conversion voltage ratio. For high volage conversion ratio , extreme duty cycle is necessary which in turn affects efficiency. Transformers are not used since it increases the cost , losses and the volume. Cascade and quadratic converters has their own disadvantages. Thus, simple switching structures are defined which can be inserted in classical buck, boost, buck-boost, cuk, sepic and zeta converters. These new hybrid converters reduces weight, size, cost , conduction losses and gives a better efficiency.

In 2009, Lung-Sheng Yang has proposed non isolated DC-DC converters with high voltage gain without high duty cycle which is limited due to the effect of power semiconductor switches, diodes, inductors and capacitors. The converter structure used is simple and the proposed DC-DC converters uses the switched inductor technique, where two inductors with same level of inductance are charged in parallel during the switch-on period and are discharged in series during the switch-off period, to get high step-up voltage gain without high duty ratio.

In 2011, K.I.Hwu and W.C.Tu have proposed three types of converters in order to achieve high voltage conversion ratios by pumping the energy stored in inductors and capacitors with the input voltage into output during off mode. These three converters have been addressed on the basis of circuit connection and control strategy. They are suitable for industrial applications as they provide good steady state and transient performances .Voltage stress are also reduced comapared to traditional buck boost converters.

In 2011,Wuhua Li has summarised the converter topologies for high step up, low cost and high efficiency DC to DC conversion as it is required for photovoltaic grid connected power system due to shortage of fossil fuel and modern world being energy saving conscious. It has been concluded that non isolated high step up converters can be preferred due to its low cost and improved efficiency. Increasing voltage gain, reducing stress across the switch are some of the challenges faced by non isolated high step up converters . These challenges will be overcome in this project.

1.2 Summary of Literature Survey

- Based on literature survey, a new transformerless DC to DC Buck Boost converter with positive output is to be proposed.
- High voltage gain with required duty cycle , high efficiency , less switching losses are to be achieved by facing and overcoming the difficulties as stated by many researches.
- Controller design and realisation of the converter greatly depends on state space modelling and derivation of transfer function.

1.3 Objectives

The main objectives are the following:

- To achieve high voltage gain with required duty cycle using low cost, low weight, positive output Buck Boost converter
- Better efficiency compared to traditional converters
- Low conduction losses and switching losses compared to traditional converters

2. CIRCUIT DIAGRAM

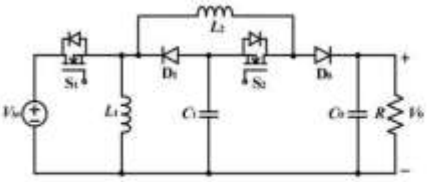


Figure 2.1 Circuit diagram

An additional switched network is added to the traditional buck-boost converter in which the two power switches are controlled synchronously. In the continuous conduction mode, the inductors are energised and capacitors (i.e. charge pump capacitor and output capacitor) are discharged when the power switches are turned on. When they are turned off, inductors are deenergised while the capacitors are charged.

2.1 Modes of operation

- On mode
- Off mode

2.1.1 On mode

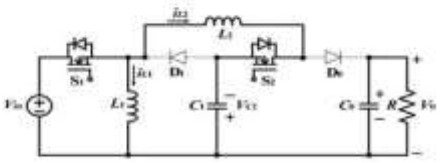


Figure 2.2 Circuit diagram during turn on period

In on mode i.e. during turn on period, the switches S1 and S2 are turned on.. The diodes D1 and D2 are reverse biased during this period and does not conduct as their anodes are at negative voltage compared to their cathodes.

The inductor L1 gets energised by the supply voltage and the current through the inductor increases from Imin to Imax due to which diode D1 is reverse biased. L2 gets energised by supply voltage and the charge pump capacitor C1 and the current through the inductor increases from Imin to I max due to which diode D2 is reverse biased. During this period, the charge pump capacitor C1 gets discharged energising the inductor L2 while output capacitor C0 gets discharged and supplies the output voltage.

2.1.2 Off mode

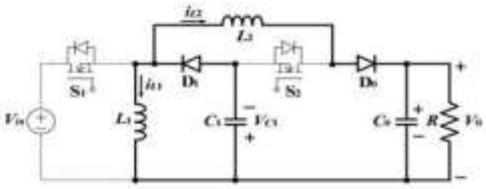


Figure 2.3 Circuit diagram during turn off period

In off mode i.e. during turn off period, the switches S1 and S2 are turned off. The diodes are forward biased during this period and it conducts as their anodes are at positive voltage compared to their cathodes. The inductors L1 and L2 get deenergised. The current through the inductors L1 and L2 decreases from Imin and Imax due to which the diodes D1 and D0 are forward biased. The stored energy in the inductors L1 charges the charge pump capacitor C1 via the diode D1 whereas the stored energy in the inductor L2 is released into the charge pump capacitor C1 , the output capacitor C0 and the resistive load R via the diodes D1 and D0. The switching operation of both the power semiconductor switches are synchronised i.e. they are turned on and off at the same time.

2.2 CALCULATION OF CONVERTER PARAMETERS

The converter parameters are calculated as follows:

V_{in} = 18 V, f_S = 20KHz, R = 30 Ohm, D = 0.6
ΔI_{L1} = 20% to 40% of I_{L1}
Assume,
ΔI_{L1} = 30% of I_{L1}

$$I_{L1} = \frac{Vin(2D-1)D^2}{R(1-D)^4}$$

Substituting the known values, we get,
I_{L1} = 0.995 A
ΔI_{L1} = 30% of 0.995 = 0.299 A

$$L_1 \geq \frac{Vin\,D}{\Delta I_{L1} f_S}$$

Substituting the known values, we get,

L_1 ≥ 1.81Mh

ΔI_{L2} = 20% to 40% of I_{L2}
Assume,
ΔI_{L2} = 30% of I_{L2}

$$I_{L2} = \frac{VinD^2}{R(1-D)^3}$$

Substituting the known values, we get, I_{L2} = 3.38 A
ΔI_{L2} = 30% of 0.995 = 1.01 A

$$L_2 \geq \frac{V_{in}D}{\Delta I_{L1} f_S}$$

Substituting the known values, we get,

$L_2 \geq$ 1.34mH

ΔV_{C1} = 1% to 5% of V_{C1}
Assume,
ΔV_{C1} = 1% of V_{C1}

$$V_{C1} = \frac{VinD}{1-D}$$

Substituting the known values, we get,
V_{C1} = 27 V
ΔV_{C1} = 1% of 27 = 0.27 V

$$C_1 \geq \frac{V_0 D}{\Delta V_{C1} f_S R(1-D)}$$

Here, $V_0 = V_{C0} = \frac{V_{in} D^2}{(1-D)^2}$ = 40.5 V
Substituting the known values, we get,

$C_1 \geq$ 375μF

ΔV_{C0}= 1% of 40.5= 0.405 V

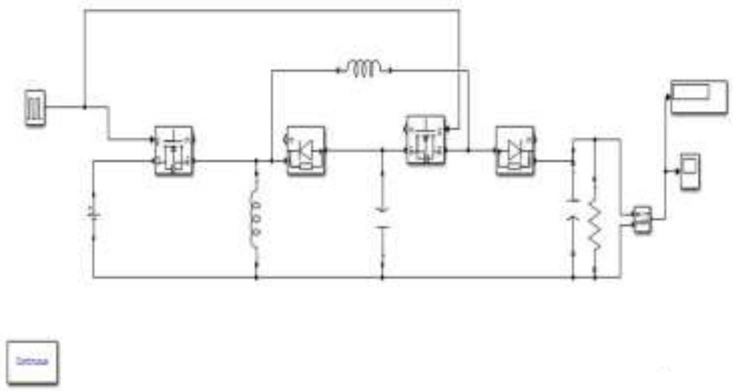
$$C_0 \geq \frac{V_0 D}{\Delta V_{C0} f_S R}$$

Substituting the known values, we get,

$C_0 \geq$ 100μF

3 OPEN LOOP SIMULATIONS

3.1 Without disturbance

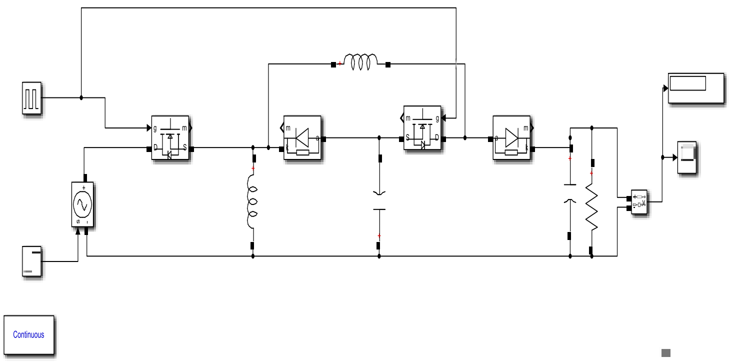


3.1 Open loop simulation without

Table 3.1 Simulation results without disturbance

PULSE WIDTH(% OF PERIOD)	OUTPUT VOLTAGE(V_0) (Theoretical)	OUTPUT VOLTAGE(V_0) (Practical)
10	0.22	0.141
20	1.125	1.958
30	3.33	6.093
40	8.08	13.33
50	18	25.84
60	40.5	47.57
70	97.72	84.70
80	288	128.40
90	1458	131.80

3.2 With disturbance



3.2 Open loop simulation with disturbance

Table 3.2 Simulation results with disturbance

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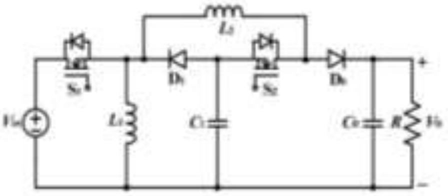
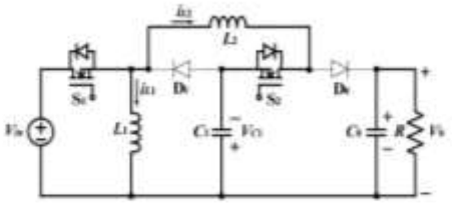
4. STATE SPACE MODELLING



I_{L1} ,I_{L2} , V_{C1} , V_{C1} are the state variables and V_{in} is the input variable.

4.1 On mode



By applying Kirchoff's voltage law and current law,

$$\frac{di_{L_1}}{dt} = \frac{v_{in}}{L_1} \dots\dots\dots\dots\dots\dots \text{(1)}$$

$$\frac{di_{L_2}}{dt} = \frac{(v_{in}+v_{C_1})}{L_1} \dots\dots\dots\dots\dots\dots \text{(2)}$$

$$\frac{dv_{C_1}}{dt} = \frac{-iL_2}{C_1} \dots\dots\dots\dots\dots\dots \text{(3)}$$

$$\frac{dv_{C_0}}{dt} = \frac{-v_{C_0}}{RC_0} \dots\dots\dots\dots\dots\dots \text{(4)}$$

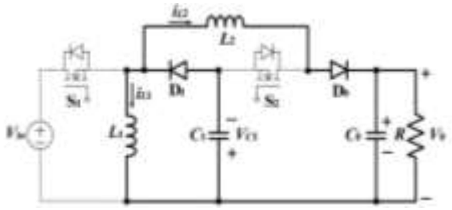
x'(t) = A_1x(t) +B_1u(t)

$$\begin{bmatrix} \frac{di_{L_1}}{dt} \\ \frac{di_{L_2}}{dt} \\ \frac{dv_{C_1}}{dt} \\ \frac{dv_{C_0}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L_2} & 0 \\ 0 & \frac{-1}{C_1} & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{RC_0} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_0} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \\ 0 \end{bmatrix} [v_{in}]$$

y(t) = C_1x(t) +D_1u(t)

$$[v_0] = [0 \quad 0 \quad 0 \quad 1] \begin{bmatrix} iL_1 \\ iL_2 \\ vC_1 \\ vC_0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} [v_{in}]$$

4.2 Off mode



By applying Kirchoff's voltage law and current law,

$$\frac{diL_1}{dt} = \frac{-vC_1}{L_1} \dots\dots\dots\dots\dots\dots \text{(5)}$$

$$\frac{diL_2}{dt} = \frac{-(vC_0+vC_1)}{L_2} \dots\dots\dots\dots\dots\dots \text{(6)}$$

$$\frac{dvC_1}{dt} = \frac{(iL_1+iL_2)}{C_1} \dots\dots\dots\dots\dots\dots \text{(7)}$$

$$\frac{dvC_0}{dt} = \frac{iL_2-\frac{vC_0}{R}}{C_0} \dots\dots\dots\dots\dots\dots \text{(8)}$$

x'(t) = A_2x(t) +B_2u(t)

$$\begin{bmatrix} \frac{diL_1}{dt} \\ \frac{diL_2}{dt} \\ \frac{dvC_1}{dt} \\ \frac{dvC_0}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-1}{L_1} & 0 \\ 0 & 0 & \frac{-1}{L_2} & \frac{-1}{L_2} \\ \frac{1}{C_1} & \frac{1}{C_1} & 0 & 0 \\ 0 & \frac{1}{C_0} & 0 & \frac{-1}{RC_0} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_0} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} [v_{in}]$$

y(t) = C_2x(t) +D_2u(t)

$$[v_o] = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_o} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} [v_{in}]$$

5. DERIVATION OF TRANSFER FUNCTION

Input voltage=18 V, L1=1.81mH, L2=1.34mH, C1=375 microFarad, C2=100 microFarad, R=30ohm, d=0.6

$$A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 746.27 & 0 \\ 0 & -2666.67 & 0 & 0 \\ 0 & 0 & 0 & 333.33 \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 552.49 \\ 746.27 \\ 0 \\ 0 \end{bmatrix}$$

$$C_1 = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}$$

$$D_1 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 0 & 0 & -552.49 & 0 \\ 0 & 0 & -746.27 & -746.27 \\ 2666.67 & 2666.67 & 0 & 0 \\ 0 & 10000 & 0 & 333.33 \end{bmatrix}$$

$$B_2 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$C_2 = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}$$

$$D_2 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$A = A_1d+A_2(1-d)$

$$A = \begin{bmatrix} 0 & 0 & -220.996 & 0 \\ 0 & 0 & 149.252 & -298.508 \\ 1066.668 & 1066.668 & 0 & 0 \\ 0 & 4000 & 0 & 133.332 \end{bmatrix}$$

$B = B_1d+B_2(1-d)$

$$B = \begin{bmatrix} 331.494 \\ 447.762 \\ 0 \\ 0 \end{bmatrix}$$

$C = C_1d+C_2(1-d)$

$$C = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}$$

$D = D_1d+D_2(1-d)$

$$D = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Transfer function = C*[sI-A]^-1*B+D

The transfer function has been derived using matlab.

5.1 MATLAB program

```
A=[0 0 -220.996 0;0 0 149.252 -298.508;1066.668 -533.334
0 0;0 4000 0 333.331];
B=[331.494;447.762;0;0];
C=[0 0 0 1];
D=0;
sys=ss(A,B,C,D);
tf(sys)
```

5.2 Output

```
 1.791e06 s^2 + 2.111e11
 ------------------------------------------------------
s^4 – 333.3s^3 + 1.35e06 s^2 – 5.204e07 s + 2.815e11
```

Continuous-time transfer function.

6. TUNING OF PI CONTROLLER PARAMETERS USING GENETIC ALGORITHM

Genetic Algorithm based PI controller is used for closed loop control of the proposed DC to DC converter for which the tuning of controller parameters is done using Integrated Time Absolute Error (ITAE).The stability analysis is done using bode plot. The simulation of the closed loop control of the proposed converter is used to obtain the desired output and satisfactory performance.

6.1 MATLAB program

```
function [J] = pi_optim(x)
s = tf('s');
plant = (2667*s^2 + 4.268e07)/(s^4 + 0.668*s^3 + 8.667e04*s^2 + 5.077e04*s + 6.827e08);
Kp = x(1)
Ki = x(2)
cont = Kp + Ki/s ;
step(feedback(plant*cont,1));
dt = 0.01;
t = 0:dt:1;
e = 1 - step(feedback(plant*cont,1),t);
J = sum(t'.*abs(e)*dt);
```

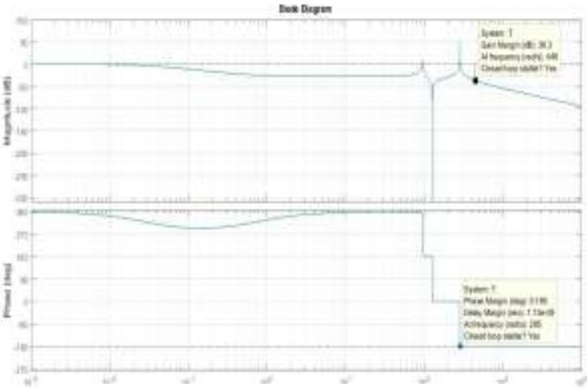
6.2 Output

After 117 iterations, KP = 0.8838 and KI = 0.00008

7. STABILITY ANALYSIS

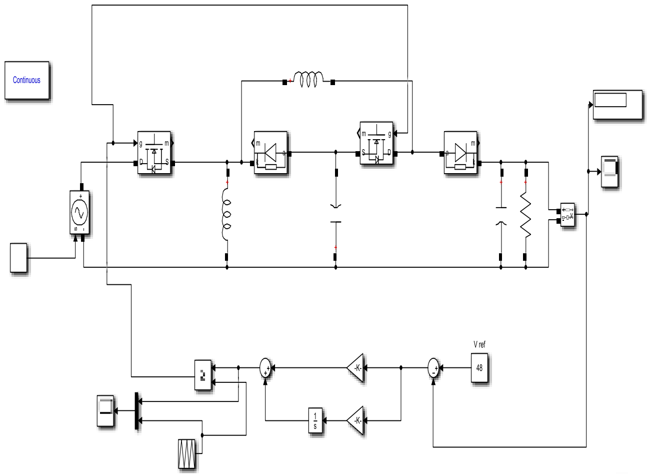
7.1 MATLAB program

```
syms s;
G=tf([1.76e06 2.111e11],[1 -333.3 1.35e06 -5.204e07 2.815e11]);
K=tf([0.8838 0.00008],[1 0]);
L=feedback(K*G,1);
pole(L)
bode(L),grid
```



7.1 Bode plot (closed loop – stable)

8. CLOSED LOOP SIMULATION



8.1 Closed loop simulation

By simulating the above model, the desired output is obtained.

9. CONCLUSION

The simulation, state space modelling and derivation of transfer function has been used to validate the effectiveness of the proposed positive output DC-DC Buck Boost converter. The state space modelling has been used to derive the closed loop transfer function using MATLAB. The PI controller parameters has been tuned by using Genetic Algorithm (i.e. Integrated Time Absolute Error function) in MATLAB. The stability analysis and closed loop simulation has been used to obtain satisfactory performance from the proposed positive output DC-DC Buck Boost converter. This proposed model will overcome the disadvantages of traditional converters and is suitable for industrial applications.

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