International Journal of Scientific Engineering and Applied Science (IJSEAS) - Volume-1, Issue-2, May 2015
ISSN: 2395-3470
www.ijseas.com

DSP Based Interleaved Boost Converter for Fuel Cell Distributed Generation System

Karthikeyan.P [1], Mrs K.preetha (Asst.prof)[2],
M.E (Power Electronics and Drives)[1 2],
Dhanalakshmi Srinivasan Engineering College, Perambalur.
\

Abstract— *Fuel Cell is low voltage and high current, a 2-phase Interleaved Boost Converter is designed to reduce the ripples in the output current. With thorough analysis of the operating principle of the converter, eight equivalent sub-circuits are described. According to the waveforms of the inductor current, the operation modes of the converter are classified to six kinds, including CCM(continuous conducting mode) and DCM(discontinuous conducting mode), and the uniform state-space averaged model of the converter in CCM and DCM are developed. Based on the transfer function, the controller is designed and a prototype of 1.2KW converter that is controlled by DSP-320F28027 is constructed. The hardware loop-in simulation results show that the converter has excellent electrical characteristics, and it can be applied in the Fuel Cell Distributed Generation system.*

I. INTRODUCTION

Distributed generation (DG) technologies can provide energy solutions to some customers that are more cost-effective , more environmentally friendly, or provide high power quality or reliability than conventional solutions. The application of fuel cell technologies to DG portends the most significant advancement in energy efficiency, conservation, and environmental protection. Proton Exchange Membrane Fuel Cell (PEMFC) are rapidly developed as the primary power source in movable power supplies and DG. The voltage of PEMFC stack decreases largely as the load current increase, and the voltage increases as the temperature increase at the same current. Therefore, DC-DC converter is needed to provide a constant voltage to other electrical apparatus. Besides, DC-DC converter plays an important role in the Energy Management System.

In this paper, the Interleaved Boost Converter for Fuel Cell is proposed, the operating principle of the converter is analysed thoroughly, and the uniform state-space averaged model of the converter in CCM is developed. Using DSP-320F28027 as main controller, a prototype of 1.2KW DC-DC converter is designed and some of the experimental results are discussed.

II. THE PRINCIPLE OF INTERLEAVED BOOST CONVERTER

In order to achieve the requirement of small volume, light weight and reliable properties, Interleaved Boost Converter is constructed, as shown in fig 1.

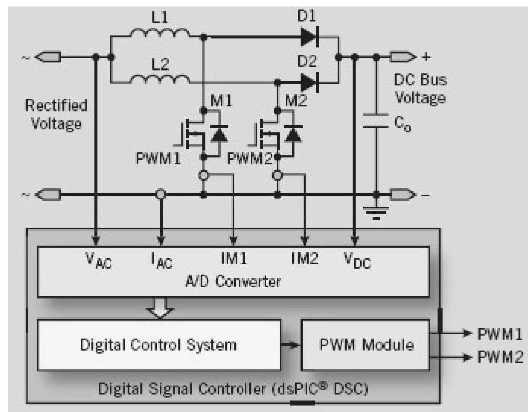


Fig 1. The topology of Interleaved Boost Converter

The principle of Interleaved Boost Converter as follows: each phase is a BOOST/BUCK DC-DC Converter, which is composed of a bridge of power switches and storage energy inductor. When S1u=S2u=OFF, S1d and S2d switch on and off, the system work in the BOOST mode.The power switched S1d and S2d have 180-degree phase difference of driving pulses in a cycle. The current fluctuation of input power supply is reduced greatly because the two 180-degree phase difference inductor currents minify the fluctuation of each other. In one switching cycle Ts, considering the commutation of power switched and diodes, there have eight kinds of running states.

The converter have eight equivalent sub-circuits of state 1-state 8, are shown below

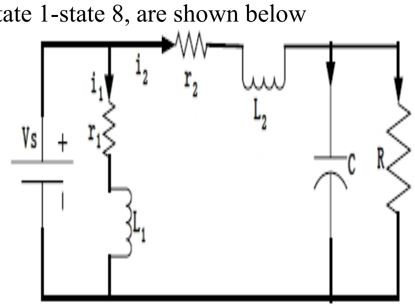


Fig 2a. The equivalent sub-circuits of state 1

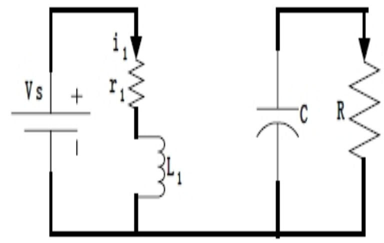


Fig 2b. The equivalent sub-circuits of state 2

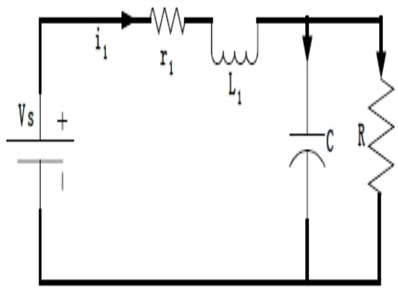


Fig 2c. The equivalent sub-circuits of state 3

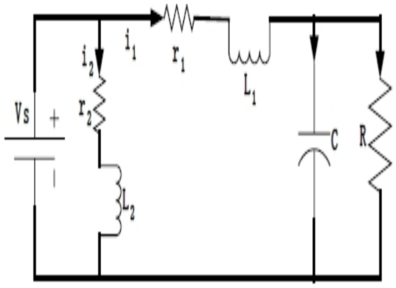


Fig 2d. The equivalent sub-circuits of state 4

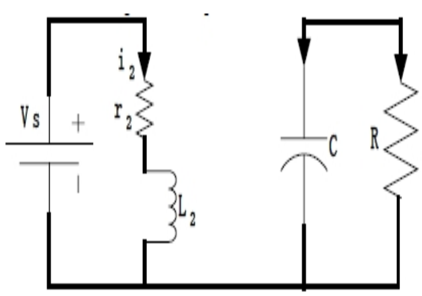


Fig 2e. The equivalent sub-circuits of state 5

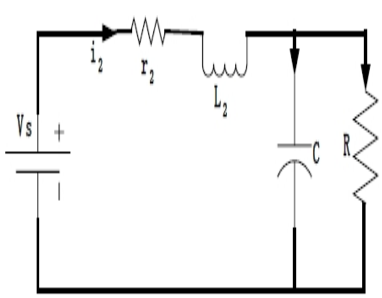


Fig 2f. The equivalent sub-circuits of state 6

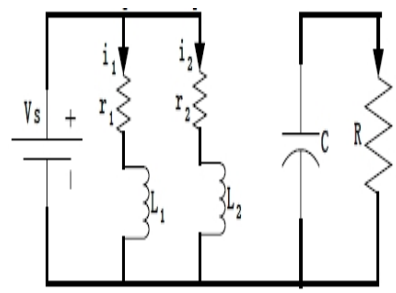


Fig 2g. The equivalent sub-circuits of state 7

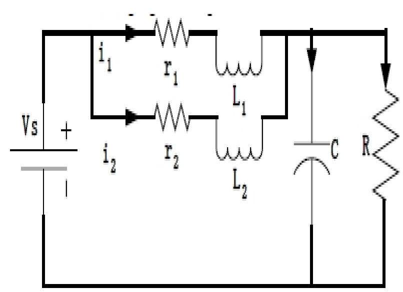


Fig 2h. The equivalent sub-circuits of state 8

III.STATE-SPACE AVERAGED SYSTEM MODEL

The state space equations are separately established according to the equivalent circuits in Fig 2. Supposing $\mathbf{i_1}, \mathbf{i_2}$, V_c as the state variables and V_s as the variable of the input voltage and V_0 as the variable of the output voltage. The state equation of the converter is :

$\dot{X} = A_n X + B_n V_s$......................during $d_{n*}\, T_s$

$V_0 = C_n X$

n=1, 2,3,4,5,6,7,8....................................... (1)

$$A_1 = \begin{bmatrix} \frac{-r_1}{L_1} & 0 & 0 \\ 0 & \frac{-r_2}{L_2} & \frac{-1}{L_2} \\ 0 & \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}; B_1 = \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix}; C_1 = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} \frac{-r_1}{L_1} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \frac{1}{RC} \end{bmatrix}; B_2 = \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \end{bmatrix}; C_2 = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

$$A_3=\begin{bmatrix} -\frac{r_1}{L_1} & 0 & -\frac{1}{L_1} \\ 0 & 0 & 0 \\ \frac{1}{C} & 0 & -\frac{1}{RC} \end{bmatrix};B_3=\begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \end{bmatrix};$$

$$C_3=\begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

$$A_4=\begin{bmatrix} -\frac{r_1}{L_1} & 0 & -\frac{1}{L_1} \\ 0 & -\frac{r_2}{L_2} & 0 \\ \frac{1}{C} & 0 & -\frac{1}{RC} \end{bmatrix};B_4=\begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix};C_4=$$

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

$$A_5=\begin{bmatrix} 0 & 0 & 0 \\ 0 & -\frac{r_2}{L_2} & 0 \\ 0 & 0 & -\frac{1}{RC} \end{bmatrix};B_5=\begin{bmatrix} 0 \\ \frac{1}{L_2} \\ 0 \end{bmatrix};C_5=$$

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

$$A_6=\begin{bmatrix} 0 & 0 & 0 \\ 0 & -\frac{r_2}{L_2} & -\frac{1}{L_2} \\ 0 & \frac{1}{C} & -\frac{1}{RC} \end{bmatrix};B_6=\begin{bmatrix} 0 \\ \frac{1}{L_2} \\ 0 \end{bmatrix};C_6=$$

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

$$A_7=\begin{bmatrix} -\frac{r_1}{L_1} & 0 & 0 \\ 0 & -\frac{r_2}{L_2} & 0 \\ 0 & 0 & -\frac{1}{RC} \end{bmatrix};B_7=\begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix};$$

$$C_7=\begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

$$A_8=\begin{bmatrix} -\frac{r_1}{L_1} & 0 & -\frac{1}{L_1} \\ 0 & -\frac{r_2}{L_2} & -\frac{1}{L_2} \\ \frac{1}{C} & \frac{1}{C} & -\frac{1}{RC} \end{bmatrix};B_8=\begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix};$$

$$C_8=\begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

AVERAGING: On the assumption that in one period T_s, the eight equivalent sub-circuits will run d_{n*} T_s respectively. The state-spaced equations of eight sub-circuits are time weighted and averaged over the switching period T_s. So the state-space averaged model of the whole system is:

$$\dot{X}=(A_1*d_1+A_2*d_2+A_3*d_3+A_4*d_4+A_5*d_5+A_6*d_6+A_7*d_7+A_8*d_8)X+(B_1*d_1+B_2*d_2+B_3*d_3+B_4*d_4+B_5*d_5+B_6*d_6+B_7*d_7+B_8*d_8)V_s$$

$$V_0=(C_1*d_1+C_2*d_2+C_3*d_3+C_4*d_4+C_5*d_5+C_6*d_6+C_7*d_7+C_8*d_8)$$

The interleaved Boost Converter can operate in three kinds of CCM, and the inductor current waveforms of the converter according to the duty of the PWM pulse(D),as shown in Fig3.

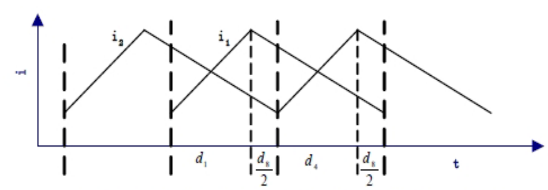


Fig 3a.The current of the two inductors,CCM(D<0.5)

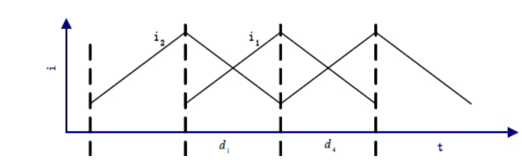


Fig 3b.The current of the two inductors, CCM (D=0.5)

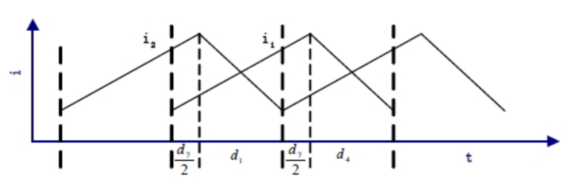


FIG 3C.THE CURRENT OF THE TWO INDUCTORS, CCM (D>0.5)

Define: D, rising time of the inductor current, D_p, Falling time of the inductor current.

1) **CCM(D<0.5):** The converter works in state1, state4 and state 8. Because there are two times of state8 in one period, the running time of the each state 8 is ½*d_8, as shown in Fig 3a.

2) **CCM(D=0.5):** The converter works in state1, state4 as shown in Fig 3b.

3) **CCM(D>0.5):** The converter works in state1, state4 and state7. Because there are two times of state in one period, the running time of the each state 7 is ½ *d_7, as show in Fig 3c.

On the assumption that the two phase circuits is symmetrical, so $L_1= L_2$,$r_1= r_2$,$d_1=d_4$, $d_2=d_5$, $d_3=d_6$.

The uniform state-space averaged model of the whole system in CCM and DCM will be gained.

$$A=\begin{bmatrix} -\frac{r_1}{L_1} & 0 & -\frac{(1-D)}{L_1} \\ 0 & -\frac{r_2}{L_2} & -\frac{(1-D)}{L_2} \\ \frac{(1-D)}{C} & \frac{(1-D)}{C} & -\frac{1}{RC} \end{bmatrix}$$

$$B=\begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix}$$

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

STEADY-STATE:

$X=-A^{-1}BV_S$
$V_0=-CA^{-1}BV_S$

The steady state characteristics of the converter are as follows:

$$M=\frac{V_0}{V_S}=\frac{1}{1-D}$$

$$I_1=I_2=\frac{V_s}{(1-D)}\ \frac{V_s}{2R(1-D)^2}$$

$$V_0=\frac{V_s}{(1-D)}$$

IV.THE DESIGN OF THE CONTROLLER

A. System Transfer function

The dynamic characteristics of the converter:

When $r_1= r2\approx 0$, the order of the state equation will be descend to two.

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

$$B=\begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$$

$$C=\frac{-LV_0/D*s+V_0RD}{RLC*s^2+L*s+RD}$$

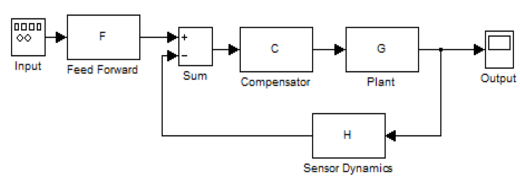
The transfer function of the converter derived from the above reduced state equation is

$$G_{vd}(s)=\frac{-LV_0/D*s+V_0RD}{RLC*s^2+L*s+RD}$$

B. Design of the Controller

Based on the transfer function above the values of the variables, the BODE PLOT can be drawn and the digital controller is designed. The control system of this converter is voltage controlled loop and is fully digitalized with DSP,

The voltage control loop is shown in below figure.



The voltage compensator is designed for the desired crossover frequency and phase margin and it is observed from the bode plot the loop is stable.

V.SIMULATION RESULT

Based on the analysis above, using DSP-320F28027 as main controller, a prototype of a hardware loop-in simulation was constructed with its basic technical specification as follows: P=1.2KW, $30<V_s<50V$, $V_0=72V$. The proposed converter have one third of the volume and weight than single phase BOOST converter, moreover, the fluctuation of currents is less than 10%.

Figures4. are the waveforms of the Interleaved Boost Converter working at 1.2KW. Fig 4a are the driving signals of the two phase IGBT switches, which have a

180-degree phase difference. Fig 4b is the waveforms of its output voltage, which shows that the voltage fluctuation is less than 1%. Figs 4c are the waveforms of the inductor current and its voltage of one phase. Fig 4d is the step response for the transfer function of the converter. Figs 4e. are the Bode Plot of the converter model and it shows the converter is stable. Fig 4f. are the response without and with step change in load.

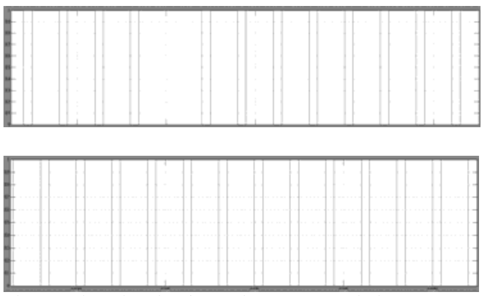


Fig 4a.Drive Signals of two phase IGBT switches

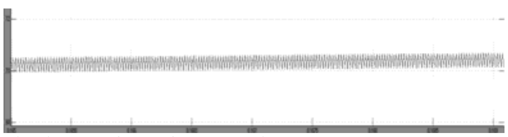


Fig 4b.Wave form of output Voltage

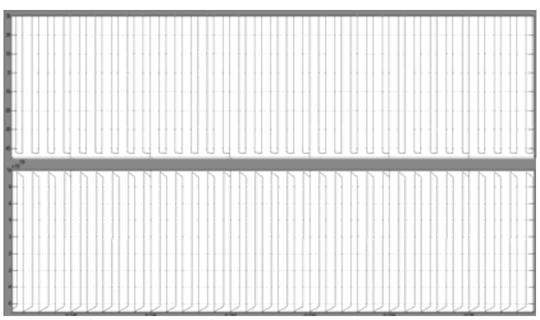


Fig 4c. Waveforms of the inductor current and its voltage of one phase

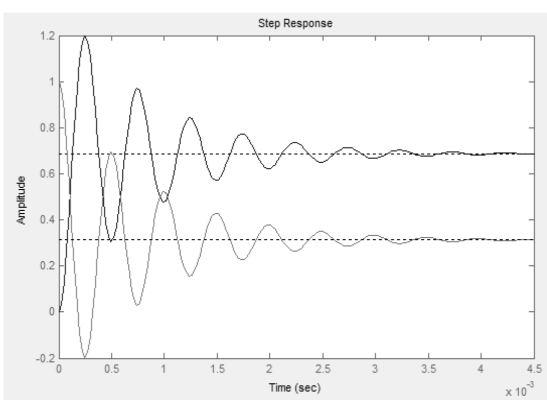


Fig 4d. Step Response for the transfer function of the converter

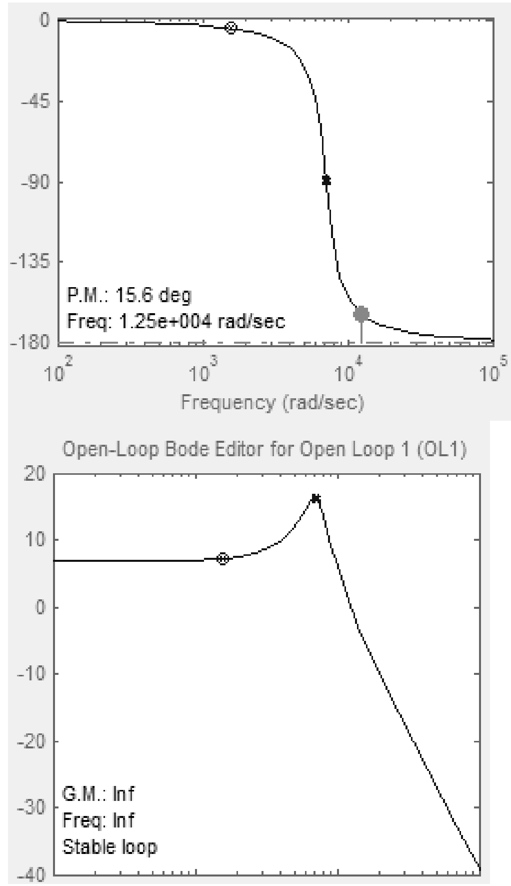


Fig 4e.Bode Plot of the converter model

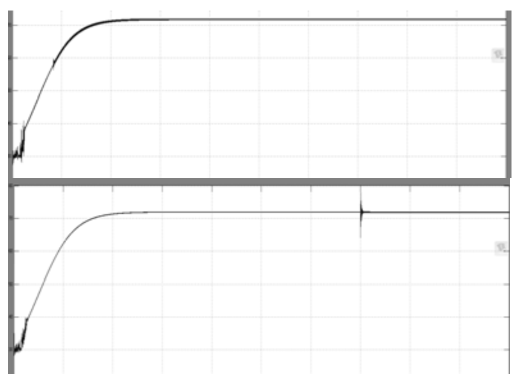


Fig 4f. Response of the converter with step change in load

VI. CONCLUSIONS

The Interleaved Boost Converter for Fuel Cell and the state-space averaged model of the converter are simulated in MATLAB and it is verified by hardware loop-in simulation using ELVIS kit. Owing to the digital control, its dynamic and static characteristics are excellent. Therefore, the Interleaved Boost Converter is suitable for Fuel Cell Distributed Generation System.

REFERENCES

1.Xu Yang,Yanping Ying,Wenjie Chen " A Novel Interleaving Control Scheme for Boost Converters Operating in Critical Conduction Mode "Journal of Power Electronics, 2010

2. Jie Shen,Klauss Rigber,Rik W.De Doncker "A Novel Phase-Interleaving Algorithm for Multiterminal Systems" IEEE,Power Electronics,2010

3. Gustavo henn,A.L.Silva,Paulo P.Praca,Luiz H.S.C Barreto "Interleaved Boost Converter With High Voltage Gain " IEEE,Power Electronics,2010

4. Xudong Huang,Xingyi Xu,Lizhi Zhu" A DSP Based Controller for High-Power InterleavedBoost Converters " IEEE,2003

*****