International Journal of Research in Advent Technology, Vol.4, No.4, April 2016
E-ISSN: 2321-9637
Available online at www.ijrat.org

Speed Control of DC Motor Fed with Fuel Cell and Luo Converter Using PI and Fuzzy Controller

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Abstract- This paper proposes the stable and ripple free output voltage from the design of developed dc-dc converter topology. Dc voltage provided by battery contains high voltage ripples and it is not constant enough voltage, thus it is not applicable for most devices like electric-vehicle controller, dc-chargers, etc. Dc-dc converters are employed to attenuate the ripples regardless of change in the load voltage. In the existing method, the classical buck converter for electric vehicle applications does not meet the load requirement containing more ripples on the output voltage and parasitic effects. To overcome this problem the advanced developed dc-dc luo-converter technology was introduced. Luo converter is the developed converter derived from the buck-boost converter. In this proposed model the additional filter elements in the luo-converter eliminate the output ripples and effectively enhance the output voltage level. A computer simulation using matlab/simulink confirms the predicted results..

Keywords: dc-dc converter, electric vehicle, low pass filter, luo converter

1. INTRODUCTION

From the past few decades, the dc-dc conversion technology has been a major subject area in the field of power electronics and drives. Dc-dc converters application has increased widely especially in industrial applications and computer hardware circuits. The output voltage of pulse width modulation (PWM) based DC-DC converters can be changed by changing the duty cycle [1]-[2]. The conventional non-isolated dc-dc boosting converters are supposed to produce more output voltage ripples. For the purpose of ripple reduction traditional controllers are employed. The DC-DC luo converter can convert the source voltage into a higher output voltage with higher efficiency, high power density and simple structure [3]. Proportional Integral (PI) controller has been implemented for the proposed DC-DC converter. PI control techniques offer stability, large line and load variation robustness, good dynamic response. PI control is chosen to ensure fast dynamic response for line side and load side disturbances with output voltage regulation [4]-[6]. However, these controllers are very sensitive to circuit parameter variations, change in operating region, line and load voltage disturbances. A fuzzy logic controller (FLC) and sliding mode controller (SMC) for the conventional DC-DC converters has been reported in [7-8]. However, the FLC for all the converters has produced small output voltage start-up overshoots, high overshoots during the dynamic conditions and high output ripple voltage compared to PI controller [9]. The FLC based PID controller for the buck DC-DC converter has been reported [10].

2. ANALYSIS OF LUO CONVERTER:

The circuit diagram of the Buck-Boost output Luo converter is shown in Fig. 1. In the circuit, S is the power switch and D is the freewheeling diode

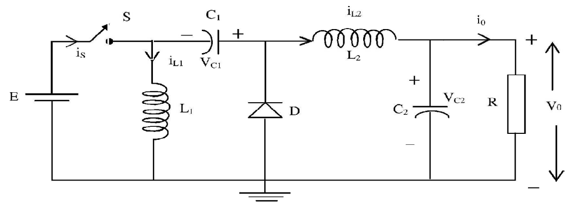

Fig 1: Luo converter

. The energy storage passive elements are inductors. L_1, L_2 and capacitors C_1, C_2, R is the load resistance. To analyse the operation of the Luo converter, the circuit can be divided into two modes. When the switch is ON, the inductor L_1 is charged by the supply voltage E. At the same time, the inductor L_2 absorbs the energy from source and the capacitor C_1. The load is supplied by the capacitor C_2. The equivalent circuit of Luo converter in mode 1 operation is shown in (a). During switch is in OFF state, and hence, the current is drawn from the source becomes zero, as shown in (b). Current i_{L1} flows through the freewheeling diode to charge the capacitor C_1. Current i_{L2} flows through C_2 –R circuit and the freewheeling diode D to keep itself continuous. If adding additional filter components like inductor and capacitor to reduce the harmonic levels of the output voltage

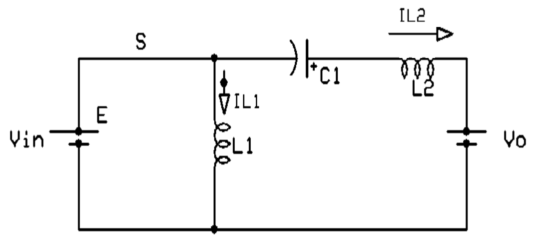

Fig 2: Luo converter with MOSFET ON condition

For closed loop simulation we go for state space transfer function. During MOSFET-ON

$$-V_{in}+L1\frac{dI_{L1}}{dt}=0\Rightarrow\frac{dI_{L1}}{dt}=\frac{V_{in}}{L1} \quad \ldots\ldots(1)$$

$$V_{C2}+L2\frac{dI_{L2}}{dt}=0\Rightarrow\frac{dI_{L2}}{dt}=-\frac{V_{C2}}{L2} \quad \ldots\ldots(2)$$

$$-I_{L1}+C1\frac{dV_{C1}}{dt}=0\Rightarrow\frac{dV_{C1}}{dt}=\frac{I_{L1}}{C1} \quad \ldots\ldots(3)$$

$$-I_{L1}+C2\frac{dV_{C2}}{dt}-I_{L2}+\frac{V_{C2}}{R}=0\Rightarrow\frac{dV_{C2}}{dt}=-\frac{V_{C2}}{RC2}+\frac{I_{L1}}{C2}+\frac{I_{L2}}{C2} \quad \ldots\ldots(4)$$

During MOSFET-OFF,

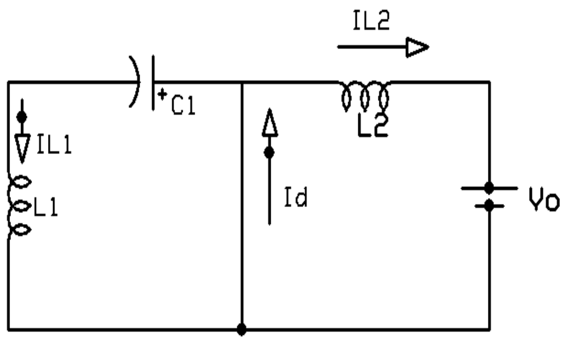

Fig 3: Luo converter with MOSFET OFF condition

$$-L1\frac{dI_{L1}}{dt}-V_{C1}=0\Rightarrow\frac{dI_{L1}}{dt}=\frac{V_{C1}}{L1} \quad \ldots\ldots(5)$$

$$L2\frac{dI_{L2}}{dt}+V_{C2}=0\Rightarrow\frac{dI_{L2}}{dt}=-\frac{V_{C2}}{L2} \quad \ldots\ldots(6)$$

$$C1\frac{dV_{C1}}{dt}-I_{L1}=0\Rightarrow\frac{dV_{C1}}{dt}=\frac{I_{L1}}{C1} \quad \ldots\ldots(7)$$

$$C2\frac{dV_{C2}}{dt}+\frac{V_{C2}}{R}=0\Rightarrow\frac{dV_{C2}}{dt}=-\frac{V_{C2}}{RC2} \quad \ldots\ldots(8)$$

Now, by writing into state space equations
MOSFET-ON

$$\begin{bmatrix}\frac{dI_{L1}}{dt}\\ \frac{dI_{L2}}{dt}\\ \frac{dV_{C1}}{dt}\\ \frac{dV_{C2}}{dt}\end{bmatrix}=\begin{bmatrix}0&0&0&0\\0&0&0&-\frac{1}{L2}\\ \frac{1}{C1}&0&0&0\\ \frac{1}{C2}&\frac{1}{C2}&0&-\frac{1}{R\,C2}\end{bmatrix}\begin{bmatrix}I_{L1}\\I_{L2}\\V_{C1}\\V_{C2}\end{bmatrix}+\begin{bmatrix}\frac{1}{L1}\\0\\0\\0\end{bmatrix}\left[V_{in}\right]$$

Where,

$$A_a=\begin{bmatrix}0&0&0&0\\0&0&0&-\frac{1}{L2}\\ \frac{1}{C1}&0&0&0\\ \frac{1}{C2}&\frac{1}{C2}&0&-\frac{1}{R\,C2}\end{bmatrix} \qquad B_a=\begin{bmatrix}\frac{1}{L1}\\0\\0\\0\end{bmatrix}$$

MOSFET-OFF

$$\begin{bmatrix}\frac{dI_{L1}}{dt}\\ \frac{dI_{L2}}{dt}\\ \frac{dV_{C1}}{dt}\\ \frac{dV_{C2}}{dt}\end{bmatrix}=\begin{bmatrix}0&0&\frac{1}{L1}&0\\0&0&0&-\frac{1}{L2}\\ \frac{1}{C1}&0&0&0\\0&0&0&-\frac{1}{R_LC2}\end{bmatrix}\begin{bmatrix}I_{L1}\\I_{L2}\\V_{C1}\\V_{C2}\end{bmatrix}$$

Where,

$$A_b=\begin{bmatrix}0&0&\frac{1}{L1}&0\\0&0&0&-\frac{1}{L2}\\ \frac{1}{C1}&0&0&0\\0&0&0&-\frac{1}{R\,C2}\end{bmatrix}$$

$$V_{OUT} = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{C1} \\ V_{C2} \end{bmatrix}$$

For state space average model we have to consider,

$$A = DA_a + (1-D)A_b$$
$$B = DB_a + (1-D)B_b$$

For LUO the input to output relationship and associated signal state relationship can be represented as,

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

Input to output relationship can be expressed as,

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

$$\frac{V_{out}}{V_{in}}(S) = \frac{Y_1 S^2 + Y_2}{Y_3 S^4 + Y_4 S^3 + Y_5 S^2 + Y_6 S + Y_7}$$

Where,

$$Y_1 = L2C1R\ (1-D) = 3.4591*10^{-14}$$
$$Y_2 = D(1-D)\ R = 2.451$$
$$Y_3 = L1C1L2C2R = 6.4716*10^{-28}$$
$$Y_4 = L1C1L2 = 2.2042*10^{-18}$$
$$Y_6 = L1D^2 + L2(1-D)^2 = 2.74*10^{-4}$$
$$Y_7 = R\ (1-D)^2 = 1.849$$

By substituting the L1, L2, C1, C2, Rand D values we can get that input to output relationship,

$$\frac{V_{out}}{V_{in}}(S) = \frac{3.4591*10^{-14} S^2 + 2.451}{6.4716*10^{-28} S^4 + 2.2042*10^{-18} S^3 + 7.0759*10^{-14} S^2 + 2.74*10^{-4} S + 1.849} \quad \text{. . . . (9)}$$

3.PI CONTROLLER

The actual armature voltage of a dc motor is compared with reference voltage and error so obtained is processed by PI controller. The main function of PI controller is to reduce the peak overshoot and make steady state error zero. With the transfer function mentioned above, by using pole placement technique, the PI controller is obtained as

$$C = 46.572 * \frac{2.42*10^{-6} S^2 + 0.0033 S + 1}{1.7*10^{-7} S^2 + S} \quad \text{. . . . . (10)}$$

By using controller transfer function, Kd, Kp, Ki values are obtained.

Kd=2.42e-6 Kp=0.0033 Ki=1

4.FUZZY CONTROLLER

The output voltage of the Luo converter is compared with reference voltage by the comparator and the output of converter is error signal which is fed to the Fuzzy controller along with the change in error signal. The output of controller is dc signal which is superimposed on a sawtooth signal to produce a switching signal to the converter as shown in Figure 5.

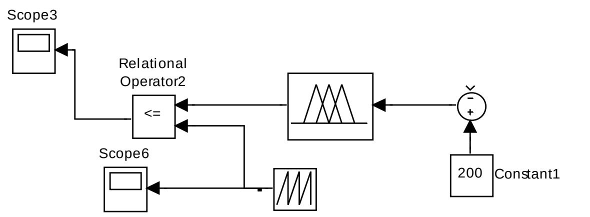

Fig 4: Fuzzy PI controller

5.SIMULATION AND RESULTS

The proposed circuit with fuel cell feeding to Luo converter with dc motor load is shown in fig .

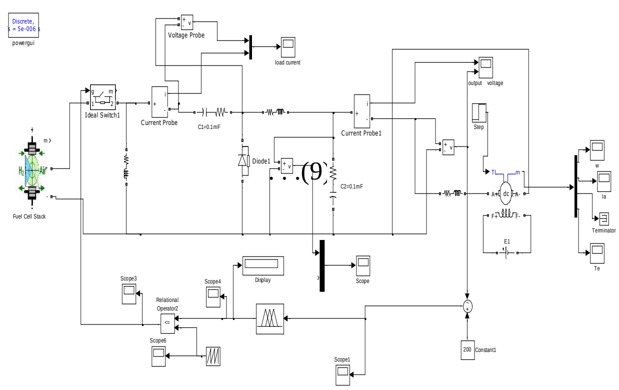

Fig 5: Proposed circuit-Fuel cell-Luo converter fed dc drive

Fuel cell is modeled to produce a dc voltage of 100V. Luo converter steps up this voltage to suitable voltage required to rotate dc motor with desired speed. The test parameters are given below

Table 1: Test Parameters

Fuel cell		
	DC voltage	100
	DC current	50A
Luo Converter		
	R_1, L_1	1Ω, 20mH
	R_2, C_1	1Ω, 20uF
	R_3, L_2	1Ω, 20mH
	R_4, C_2	1Ω, 2000uF
DC Motor		
	R_a, L_a	2.58 Ω, 0.028 Ω
	R_f, L_f	281.3 Ω, 3.156 Ω

With the above test parameters and reference voltage of 200V dc, the fig shows the output speed of converter fed dc drive using PI & fuzzy controller. The wave form is free from fluctuations, but settling time is little bit more; the output is following the input.

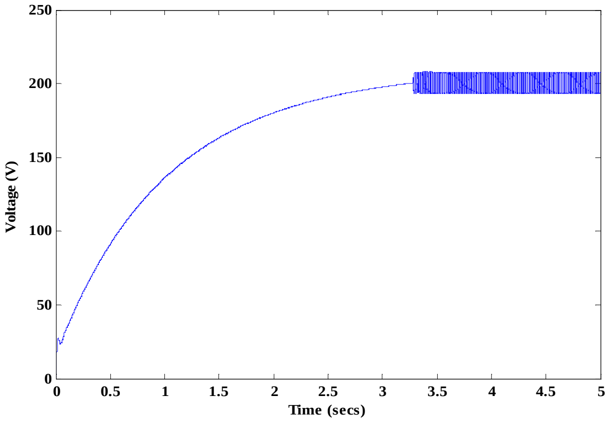

Fig 6: Armature voltage with reference voltage of 200V

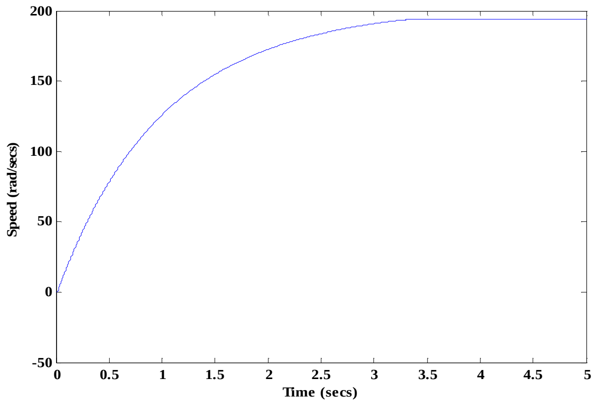

Fig 7: DC motor speed with reference voltage of 200V

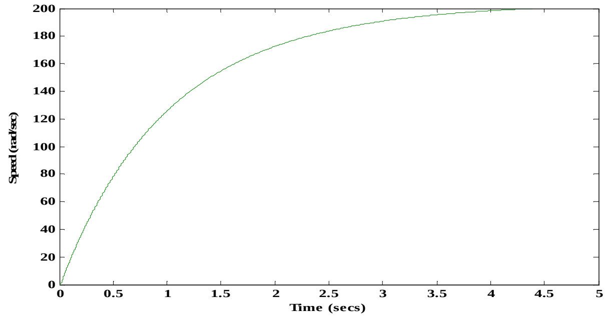

Fig 8: Speed with fuzzy controller

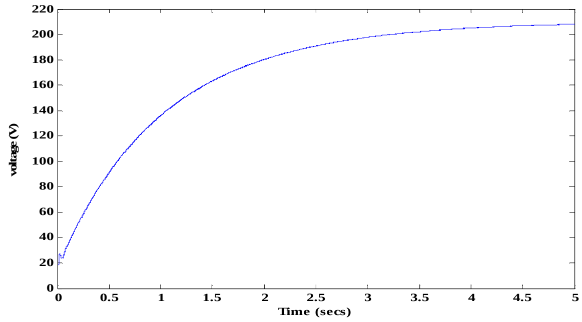

Fig 9: Armature voltage with fuzzy controller

6. CONCLUSION

The paper has presented dc motor speed control fed with Fuel cell and Luo converter. The modeling of Luo converter is described briefly. The transfer function derivation is presented for the calculation of PI controller and fuzzy controller. With PI controller, the drive is able to follow the input; but fluctuations are observed in an armature voltage. With fuzzy controller, armature voltage observed to be very smooth and free from fluctuations.

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