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Closed Loop Control of CSC converter Using PI and Fuzzy Logic Controllers for DC Motor Driven Applications

V.S. Prasadarao K.[1], G. Tabita[2] and P. Srihari[3]
[1]Assistant Professor, Department of Electrical and Electronics Engineering,
Shri Vishnu Engineering College for Women (Autonomous), Bhimavaram, (A.P.), INDIA
[2]AssistantProfessor,Department of Electrical and Electronics Engineering,
Laki Reddy Bali Reddy College of Engineering (Autonomous), Mylavaram (A.P.), INDIA
[3]Assistant Professor, Department of Electrical and Electronics Engineering,
Laki Reddy Bali Reddy College of Engineering (Autonomous), Mylavaram (A.P.), INDIA

(Corresponding author: K.V.S. Prasadarao)
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ABSTRACT: This paper presents the PI and fuzzy logic controller (FLC) based canonical switching cell converter (CSC) for DC motor driven applications like electric vehicles and agricultural pumping systems. Advantages of the CSC converters like nonpulsating input current, a lower requirement of components makes them more suitable for the above applications. The regulated output voltage of CSC converter can be obtained by using PI and fuzzy logic controllers. FLC further improves the dynamic performance of the CSC converter compared to the PI controller. A detailed analysis and working of the CSC converter are presented in this paper. The working of the CSC converter for DC motor driven applications has been verified with MATLAB/SIMULINK tool and the corresponding results are presented. Comparison between PI and FLC based CSC converter in terms of settling time is also presented in this paper.

Keywords: CSC Converter, DC motor, fuzzy logic controller, PI controller, Voltage controller.

Abbreviations: CSC, Canonical Switching Cell; EVs, Electrical Vehicles; FLC, Fuzzy Logic Controller; PMDC, Permanent Magnet DC Motor; RES, Renewable Energy Source.

I. INTRODUCTION

Depletion of fossil fuels and global warming effects driving the society towards ecofriendly technologies. One of such technologies in the transportation field is the replacement of conventional vehicles into renewable energy source (RES) [1-2] based electric vehicles (EVs). To operate such EVs in an efficient manner and also to harvest maximum energy from the RESs, suitable power electronic converters are needed. The low voltage obtained from the PV system is not adequate to drive the permanent magnet DC (PMDC) motor based EV. To enhance the low voltage of PV system and also to extract maximum power, a suitable DC-DC converter is needed. The basic DC-DC converter to increase the PV cell output voltage is boost converter. But it requires large capacitor to reduce the ripple in the output voltage [3-6]. To address the above problem, buck-boost converters like cuck, SEPIC are used to get the required output voltage with small size filter. But requirement of more number of components like capacitor and inductor, makes them bulky and costlier [7-10]. Authors in [11] proposed a KY converter with four power electronic switches, an inductor and a diode.

This paper presents the CSC converter with less number of components to enhance the low voltage PV system.

The other advantage of CSC converter is the requirement of low size filter at the input side because of non-pulsating input current. The above advantages of CSC converter lead to higher efficiency and compact size. To improve the dynamic response of the converter, PI controller and FLC [12-15] are used in this paper.

Finally, PV fed CSC converter is used to drive the PMDC motor based EV is developed and implemented in the MATLAB/SIMULINK environment and the corresponding results are presented. Comparison between different DC-DC converters is also presented to show the superiority of the CSC converter.

II. CSC CONVERTER FED DC MOTOR DRIVE

Figure 1 shows the overall system which is used in this paper to drive the dc motor.

To get the required output voltage of CSC converter, a closed loop control is implemented. The voltage controller used in this paper is PI controller and FLC. The input for the voltage controller is error between the desired voltage and actual voltage. The voltage controller processes the error signal and generates the reference signal. By comparing this reference signal and high frequency carrier signal using comparator, pulses are generated to control the switch (S) of the CSC converter to get the desired output voltage.

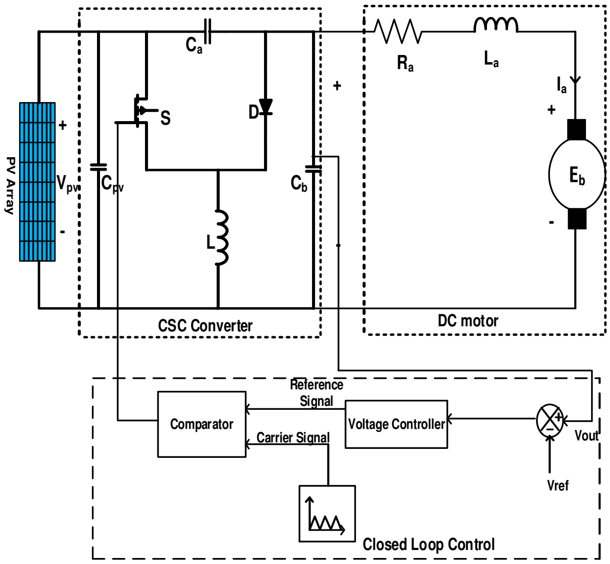

Fig. 1. Closed loop control of CSC for DC motor applications.

III. WORKING OF CSC CONVERTER

The following figure shows the circuit diagram of CSC converter.

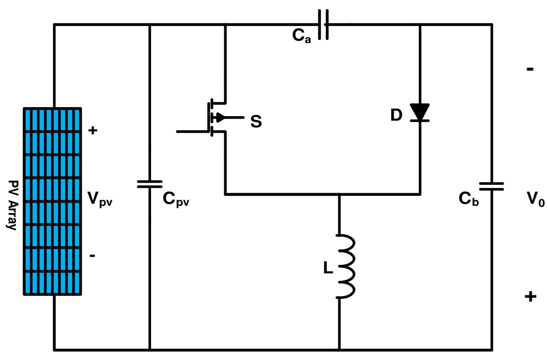

Fig. 2. Circuit Configuration of CSC Converter.

It consists of two capacitors (Ca and Cb), one switch (S), one diode (D) and an inductor (L) which are less compared conventional DC- DC converters. Due to this, CSC converter is having features like high efficiency, low cost and compact size. Due to the non-pulsating input current, the CSC converter requires low size filter at the input side. The two different working modes of the CSC converter are as follows.

Mode 1:

In this mode, switch S is closed turned ON. The corresponding circuit diagram for this mode is shown in figure 3.

Turning of switch (S) makes the diode reverse biases due to negative voltage applied across it. Due to this, inductor (L) is charged to Vpv and the capacitor is discharging the energy to Cb and load. That means, L and Cb are charging and Cb is discharging in this mode.

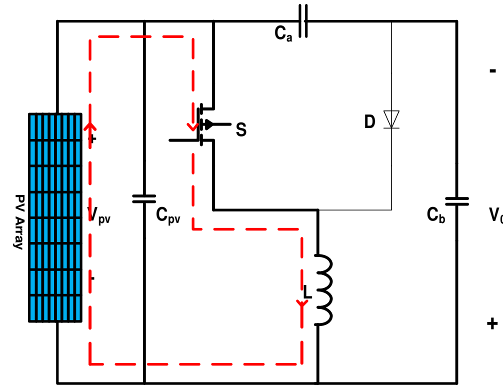

Fig. 3. Mode 1 of CSC Converter.

Mode 2:

In this mode, switch is turned OFF and the corresponding circuit is shown in figure 4. The energy stored in the inductor L is transferred to load is taking place in this mode. This makes the diode forward biased. In this mode, L, Cb are discharging while Ca is charging.

The output voltage expression is given by,

$$V_0 = \frac{d}{1-d} V_{pv} \tag{1}$$

Where V_0 = output voltage of the CSC Converter
Vpv = Input voltage
d = duty cycle

IV. PI AND FLC BASED CSC CONVERTER

To get the desired output voltage of CSC converter in order to drive the dc motor, a closed loop control is implemented. The actual output voltage of the CSC converter is sensed and subtracted from the desired value to get the voltage error. The error is given to the voltage controller to generates the reference signal which is compared with the carrier signal to produce the driving signal for the power electronic switch (S). The two voltage controllers (PI and FLC) are in this paper. The operation of the individual controllers is explained below.

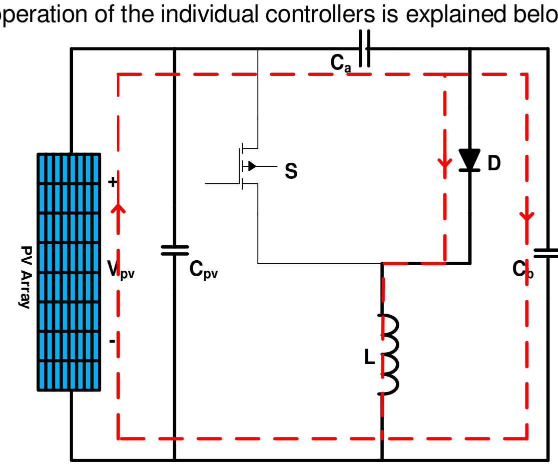

Fig. 4. Mode 2 of CSC Converter.

A. PI controller

The PI controller is used to control the output voltage and improve the transient response of the CSC converter. The proper selection of PI gains (Kp and Ki) gives the better response. The transfer function the PI controller is given as,

$$T.F = K_P + \frac{K_i}{S} \quad (2)$$

B. Fuzzy Logic Controller (FLC)

To further improving the response of CSC converter, FLC is used in this paper. The input variable for this controller are voltage error (ΔV) and change in voltage error $\frac{d}{dt}(\Delta V)$ and the output variable is duty cycle (d). The membership functions for the above variables are shown in below figures. The basic 7X7 fuzzy set rules shown in table 1 are considered in this paper. The terms related to the rules [12-13] are NL: Negative large, NM: Negative Medium, NS: Negative Small, ZE; Zero, PS: Positive Small, PM: Positive Medium, and PL: Positive Large.

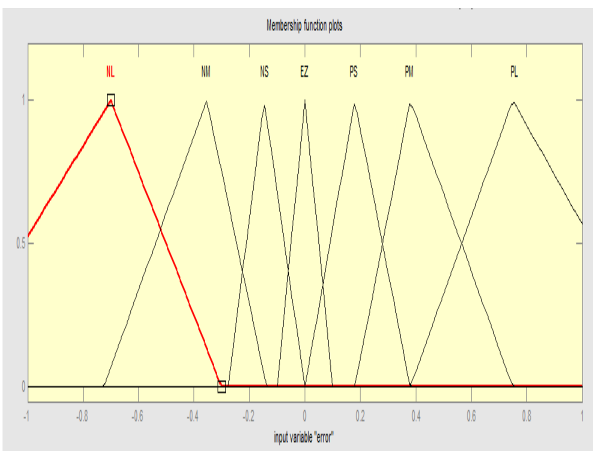

Fig. 5. Membership function of voltage error.

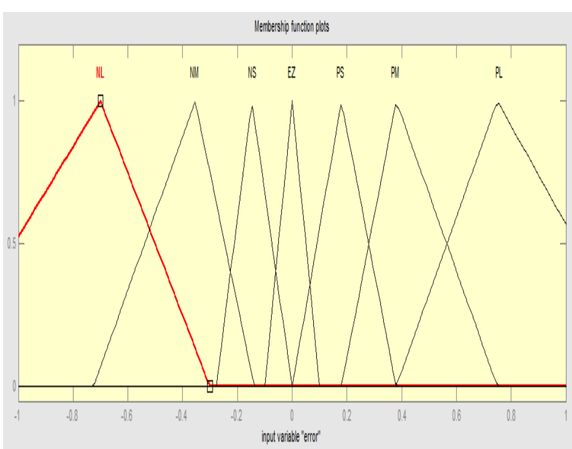

Fig. 6. Membership function of change in error.

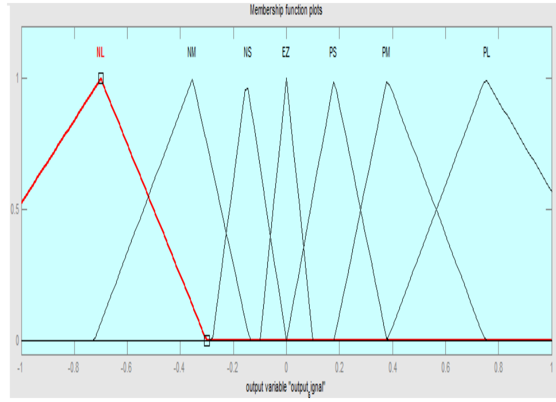

Fig. 7. Membership function of output (duty cycle).

Table 1: Fuzzy rule set for FLC.

Duty Cycle (d)		Voltage Error						
		NL	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
Change in Voltage Error	**NL**	NL	NL	NL	NL	NM	NS	ZE
	NM	NL	NL	NL	NM	NS	ZE	PS
	NS	NL	NL	NM	NS	ZE	PS	PM
	ZE	NL	NM	NS	ZE	Ps	PM	PL
	PS	NM	NS	ZE	PS	PM	PL	PL
	PM	NS	ZE	PS	PM	PL	PL	PL
	PL	ZE	PS	PM	PL	PL	PL	PL

V. RESULTS AND DISCUSSON

The feasibility of the proposed system is verified with the help of MATLAB/SIMULINK software. The performance of the system is carried for three cases.

Case (i) ***Open loop Control:*** In this case, the CSC converter directly connected to the PMDC motor without using any closed loop controller. The following figure shows different waveform waveforms of the proposed system.

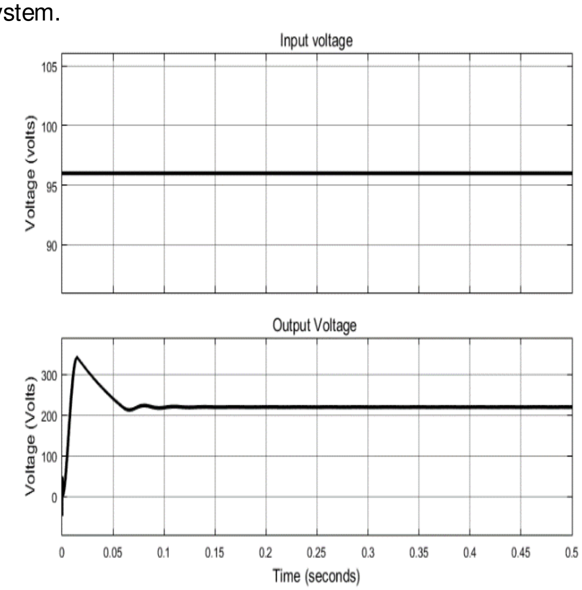

Fig. 8. Input and output voltages of the CSC converter under open loop control.

From Fig. 8, the CSC converter converts the PV system voltage of 96V into 220V required for the PMDC motor. But the time taken to reach steady state is about 0.2 Seconds.

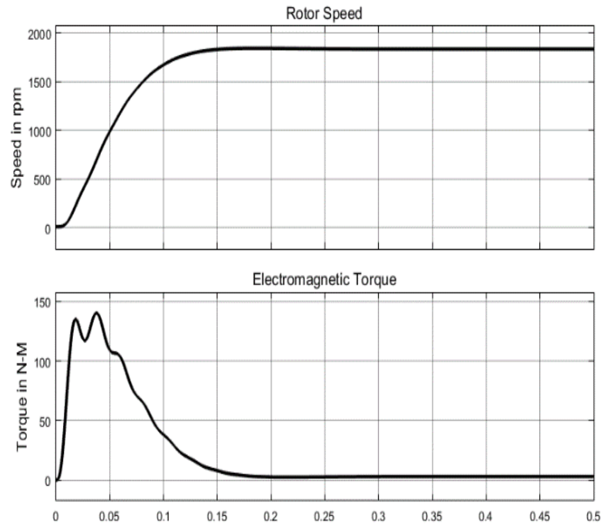

Fig. 9. Speed and Torque developed by the PMDC motor.

Case (ii) ***Closed loop Control with PI controller:*** By selecting the proper values of Kp and Ki gains of PI controller the desired response can be obtained. The following figure 10 and 11 shows the response of CSC converter and PMDC motor with closed loop control. In this paper Kp = 0.5 and Ki = 0.01 are chosen such that it gives the desired response with less time (0.1 Seconds) to reach steady state compared to case (i).

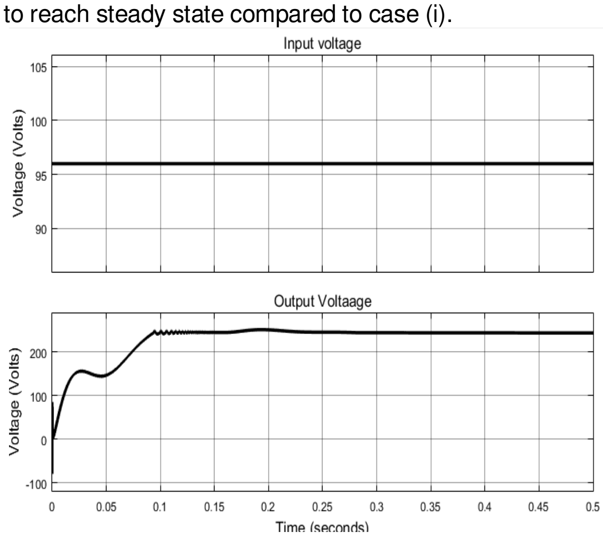

Fig. 10. Input and output voltages of the CSC converter with PI controller.

Case (iii) Closed loop Control with FLC controller:

Incorporation of fuzzy logic controller in the closed loop system further improves the performance of the system which is shown in figure 12. In this case the system takes very less time (0.02 seconds) to reach steady state.

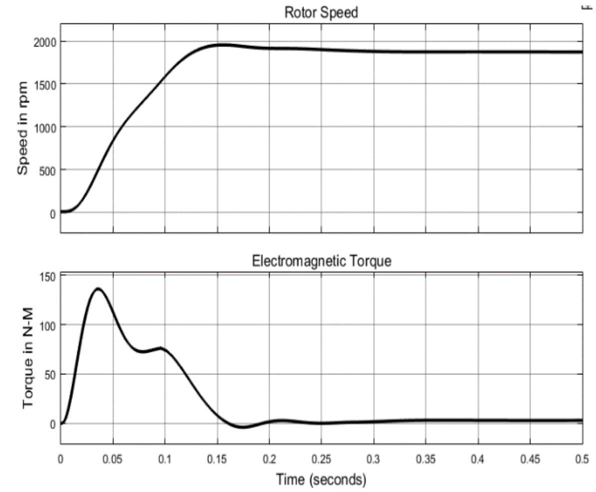

Fig. 11. Speed and Torque developed by the PMDC motor with PI controller.

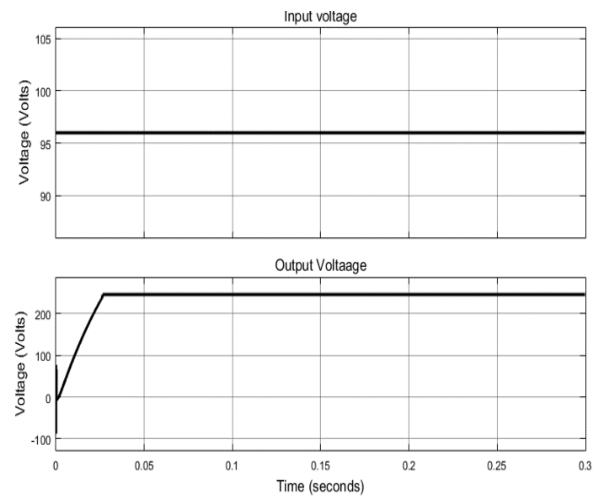

Fig. 12. Input and output voltages of the CSC converter with FLC.

The following table 2 shows the settling time required by the different controllers for the proposed system.

Table 2: Comparison of different controllers.

Parameter	Without Controller	PI Controller	Fuzzy Logic Controller (FLC)
Settling Time (Seconds)	0.2	0.1	0.02

From the above table, the settling time for the FLC is very low compared to other controllers which improves the dynamic performance of the system.

VI. CONCLUSION

Closed loop control of CSC fed PMDC motor through PI and FLC is presented in this paper. The CSC converter enhance the low voltage input into high voltage with less number of components which can drive the PMDC motor for various applications like EVs. The dynamic performance of the CSC converter is improved by using PI and FLC. The feasibility of the proposed system is confirmed through simulation studies and corresponding results are presented. Finally, the comparison between different controllers used for closed loop system is also presented in this paper. Fuzzy logic controller makes the system faster compared to other controllers.

Conflict of Interest. The authors declare no conflict of interest.

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