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Closed Loop Fuzzy Logic Control of High Voltage Gain Interleaved Boost Converter fed 3-ϕ BLDC Motor Drive

TARUN KUMAR.MALLEMOGGALA [1], RAMA KUMAR.M.S[2] & BALA MURALI KRISHNA.V[3]

[1]M.Tech (P.E) Scholar, Dept of EEE, Swarnandra College of Engineering and Technology, JNTUK, A.P

[2]Associate Professor, Dept of EEE, Swarnandra College of Engineering and Technology, JNTUK, A.P

[3]Assistant Professor, Dept of EEE, Regency Institute of Technology, P.U, Pondicherry

Abstract: — This paper presents Brush Less DC Motor (BLCDM) driven by an efficient closed loop fuzzy logic based high voltage gain interleaved boost converter. The functioning of the high voltage gain interleaved boost converter proposed in this paper is to boosts an input DC voltage to required DC output voltage. The proposed converter performs the inverter operation to drive the BLCDM. For fine tuning the dynamic characteristics of BLDC, such as speed, torque, stator current and stator voltage an improved closed loop fuzzy logic control method is proposed in this paper. The control technique is modeled and simulated in MATLAB 2009a GUI environment using Simulink and Sim Power System set tool boxes. Finally the resultant simulation waveforms shows some more accuracy with the proposed closed loop fuzzy logic control technique as compared with conventional PID control technique. The control techniques are modeled and simulated in MATLAB 2009a GUI environment using Simulink and Sim Power System set tool boxes.

Keywords: Brush Less DC Motor (BLCDM), closed loop fuzzy logic control, Interleaved Boost Converter

I. INTRODUCTION

Brush Less DC Motor (BLCDM) has significant importance because of inherent properties like high efficiency, low noise operation, maintenance free, etc. .. BLDC motors are widely used for many applications in areas like automation, military, medical and for other appliances etc. Hence, it is important to design low cost and efficient speed controller for BLDCM.

Many techniques for BLDCM control have been developed such as PI, PID, fuzzy logic controller, adaptive fuzzy logic controller. Fuzzy logic is based on fuzzy set theory, which is used for many control applications. All controlling designs of BLDCM also be used for sensor less BLDCM control. In which back EMF waveform is observed and using different algorithms, speed of BLDC motor can be estimated, which is compared with reference speed[1].

In this paper the required input supply for the BLCDM provided by the high voltage gain interleaved boost converter, which performs the inverter operation and also boosts the input DC level to a maximum output D.C level. High voltage gain DC boost converter that proposed in this paper is a combination of two 2 phase interleaved boost converter, which is a non-isolated boost converter.[2]

The rest of this paper is organized as follows. In Section II, the designing aspects of the BLDCM, High voltage gain interleaved boost converter are given. In Section III, the closed loop fuzzy logic control technique is presented. In Section IV, the developed MATLAB-based simulation results are discussed. Finally, an appraisal of the proposed hybrid system is presented in the Section V.

II. DESIGNING ASPECTS

A. *Design of High Voltage Gain Interleaved DC Boost Converter :*

High voltage gain DC boost converter that proposed in this paper is a combination of two 2 phase interleaved boost converters and is shown by Fig.1 [2]. The four power electronic based switching devices used in the Fig.1 are controlled in 90 phase delay to each other's simultaneously (interleave technique method), in order to smooth output ripple current, raising power rating and efficiency[4].

For the Fig.1 , from KVL , voltage equation is given by equation(1)

$$V_o = V_{ca} + V_{cb} - V_s \qquad (1)$$

Where, V_s = Supply voltage

V_o = Output voltage

V_{ca} = Voltage across Capacitor "Ca"

V_{cb} = Voltage across Capacitor "Cb"

Voltage gain (G) for the Fig.1 is given by equation (2)

$$G = \frac{V_o}{V_s} = \frac{(1+D)}{(1-D)} \tag{2}$$

Where, D = Duty cycle.

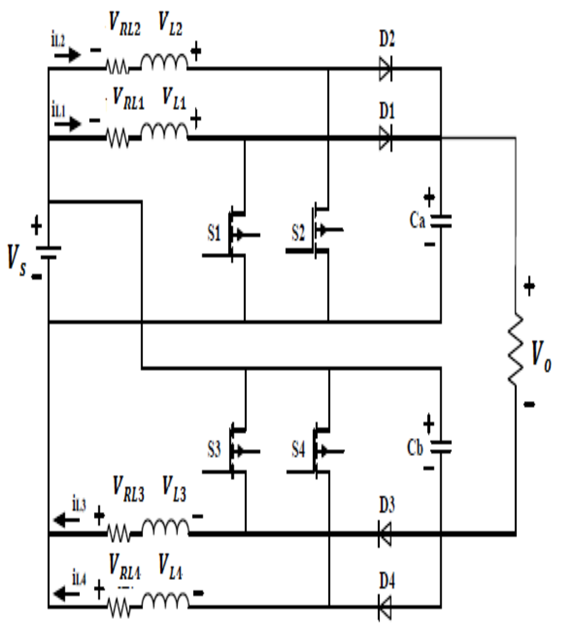

Fig.1. Proposed High voltage gain Interleaved DC boost converter

In the proposed high voltage gain interleaved DC boost converter, there is a considerable reduction in input current ripple and inductor size. The output voltage ripple of the circuit depends on the size of capacitor. The proposed converter should be operated in Continuous Conduction Mode (CCM). Based on the equations (3) & (4), the inductance & capacitance values respectively can be decided for the proposed converter.

$$L = \frac{D.V_S}{4.\Delta I_L.f_s} \tag{3}$$

$$C_{bus} = \frac{D.I_{out}}{2.\Delta V_{bus}.f_s} \tag{4}$$

Where, ΔI_L = Maximum current ripple

ΔV_{bus} = Output voltage ripple

I_{out} = Output current

f_s = Switching frequency

For the proposed converter, all the designed parameters are given by the Table.1. MATLAB based simulation diagram of proposed High voltage gain Interleaved DC boost converter is shown by Fig.2

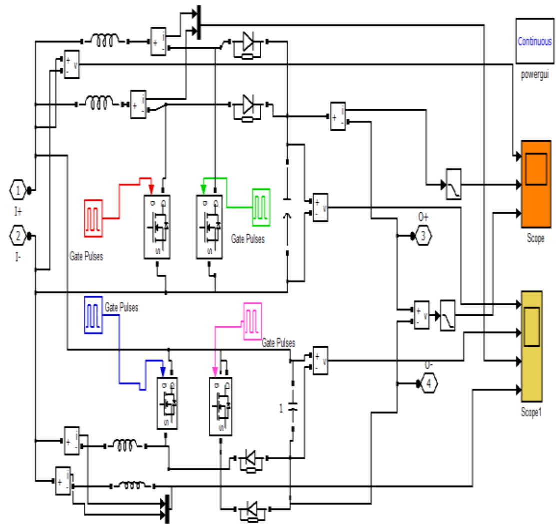

Fig.2. MATLAB based simulation diagram of proposed High voltage gain Interleaved DC boost converter

B. Design of Brush Less DC Motor (BLDCM) :

A BLDC Motor has three stator phase windings connected in a star manner. Fig.3. shows the equivalent circuit of a BLDCM.

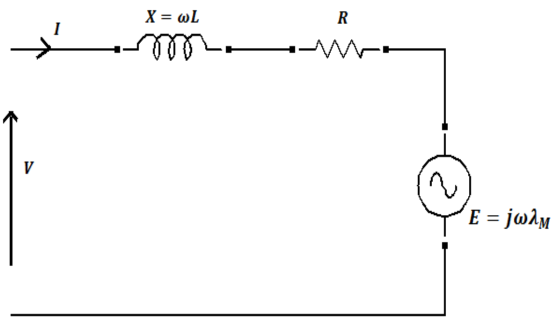

Fig.3. Equivalent circuit of a BLDC Motor

The windings of a BLDC Motor modelled as a series combination of RL and speed depends on the voltage source, which is known as the back EMF (E)[4]. The BLDCM has three phases and those phase voltages are given by the equations (5), (6) & (7).

$$V_A = R_S.I_A + \frac{d}{dt}F_A + E_A \tag{5}$$

$$V_B = R_S.I_B + \frac{d}{dt}F_B + E_B \tag{6}$$

$$V_C = R_S.I_C + \frac{d}{dt}F_C + E_C \tag{7}$$

Where, V_A= Phase "A" voltage

V_B= Phase "B" voltage

V_C= Phase "C" voltage

I_A = Phase "A" current

I_B = Phase "B" current

I_C = Phase "C" current

R_S = Stator resistance

F_A= Phase "A" stator flux linkages

F_B= Phase "B" stator flux linkages

F_C= Phase "C" stator flux linkages

E_A = Phase "A" back EMF

E_B = Phase "B" back EMF

E_C = Phase "C" back EMF

Fig. 4. Shows the relationship between the back EMF waveform of an ideal BLDC motor and the armature current (I). The shape of the currents should in rectangular waveform and must be inphase with the corresponding phase back EMF [4].

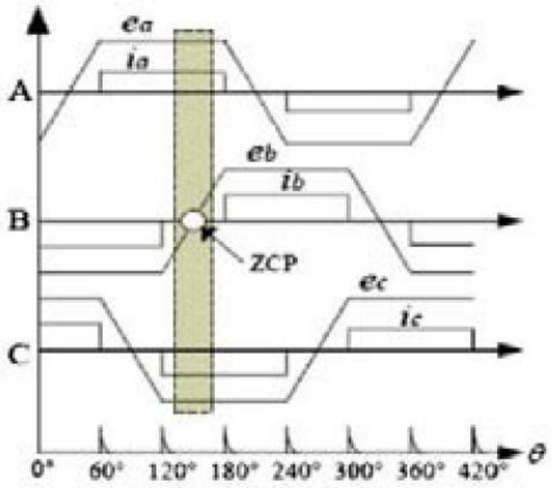

Fig.4. BLDCM Waveforms of ideal back EMF and phase current

If the self and mutual inductance around the air gap are consider to be constant, then there will be a direct relation between the applied source voltage to the phase terminals (V) and the induced back EMF (E) is given by equation(8) and the electromagnetic torque (Te) in N.M is given by equation (9)

$$E \propto V \qquad (8)$$

$$T_e = \frac{(E_A . I_A + E_B . I_B + E_C . I_C)}{\omega_r} \qquad (9)$$

Where, ω_r = Rotor mechanical speed

III. CONTROL ALGORITHM

This section mainly focused on the speed control technique for the BLDCM. Closed loop fuzzy logic control technique gives the better performance as compared with the conventional PID controller. The block diagram of the proposed control technique is shown in Fig.5

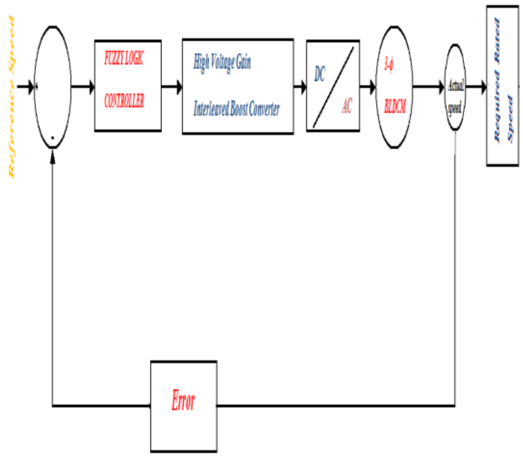

Fig.5. Proposed block diagram of closed loop fuzzy logic control technique fed to BLDCM

Fuzzy logic consist of three basic steps as fuzzification, decision making using knowledge base and defuzzification which is shown in Fig.6.

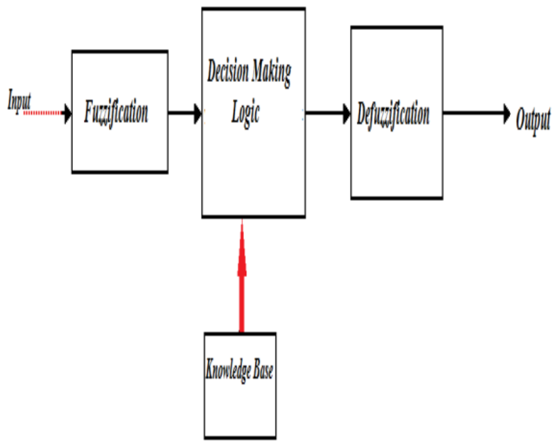

Fig.6.Basic idea block diagram of fuzzy logic control technique

Inputs error and change in error are fuzzified using fuzzy set theory and fuzzification process. Fuzzy set is represented by a membership function defined on universe of discourse. Universe of discourse is space where fuzzy variables are defined. In the proposed system, error and change in error are the two inputs to the fuzzy logic controller (FLC) and a single output exists. 9 membership functions are defined for inputs and outputs. Using rule editor window as shown in Fig. 7, if-then rules are defined for relation of inputs and output. By using two inputs to obtain the single out 81 rules are used in the proposed controller. Fuzzy rules are given by the Fig.8. For this system, 9 different variables will be defined are NB- Negative Big, NM- Negative Medium, NS- Negative Small, Z- Zero, PS- Positive Small, PM- Positive Medium and PB- Positive Big. Defuzzzification is process in which fuzzy variables are again translated into regular format. The MATLAB based simulation diagram of proposed closed loop fuzzy logic controller is given by Fig.9.

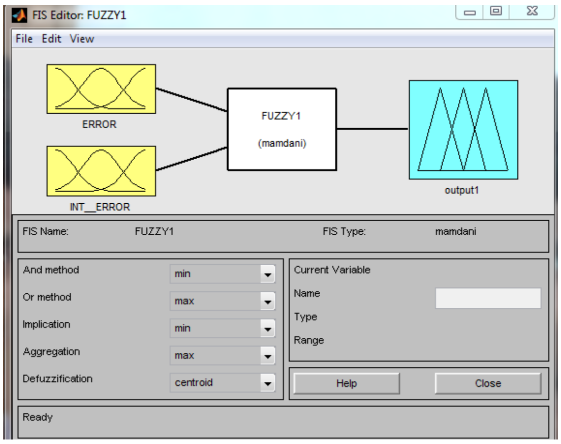

Fig.7. Window diagram of FIS Editor

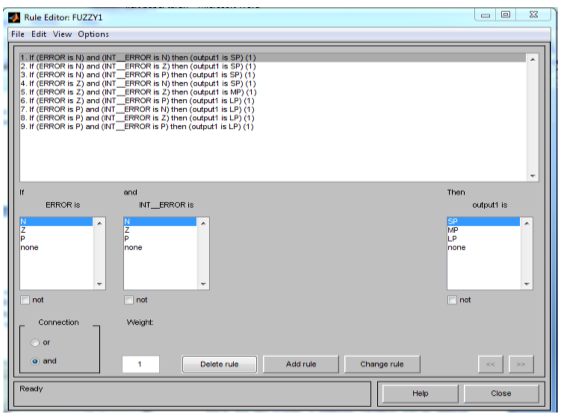

Fig.8. Window diagram of Fuzzy Rule Editor

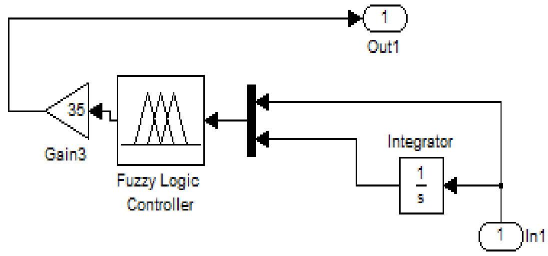

Fig.9. MATLAB based simulation diagram of proposed closed loop fuzzy logic controller

Fig.10. shows the input voltage to the proposed high voltage gain interleaved boost converter , its value is nearly 17.4 V and theo utput from the converter is nearly 248 V . Hence the proposed high voltage gain interleaved boost converter boosts the low level input DC value to a maximum output DC value.

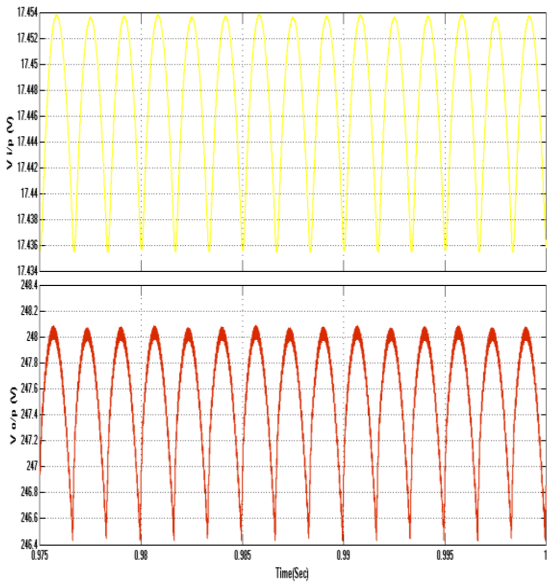

Fig.10. MATLAB based simulation input & output wave forms of proposed high voltage gain interleaved boost converter

Fig.11 shows the phase A stator current (I_A) and E_A Phase "A" back EMF (E_A) of the BLDC Motor.

Fig.12. Stands for MATLAB based simulation waveforms of Electromagnetic torque (Te) in N.M and Rotor speed (N) in rpm of the BLDC Motor with Conventional PID controller. Here, Settling time (T_S) is 0.1 Seconds for both the "Te" and "N".

Fig.13. Stands for MATLAB based simulation waveforms of Electromagnetic torque, "Te" in N.M of the BLDC Motor with proposed closed loop

fuzzy logic controller. Here, T_S is 0.05 Seconds for the "Te".

Fig.14. Stands for MATLAB based simulation waveforms of Rotor speed, "N" in rpm of the BLDC Motor with proposed closed loop fuzzy logic controller. Here, T_S is 0.05 Seconds for the "N"

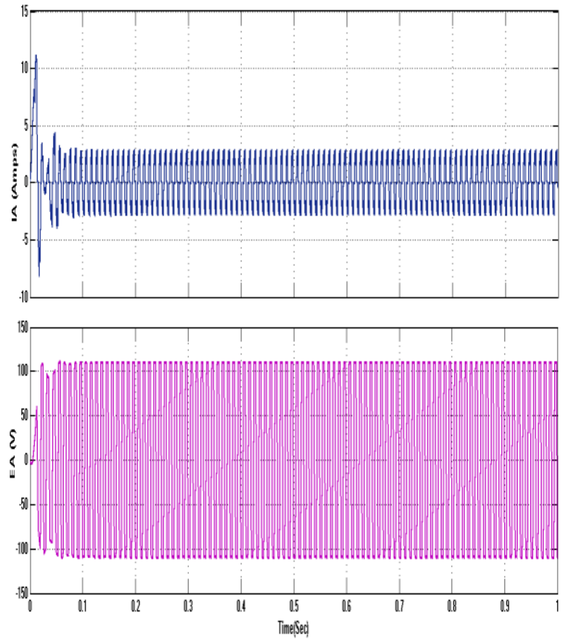

Fig.11. MATLAB based simulation I_A and E_A wave forms of the BLDC Motor

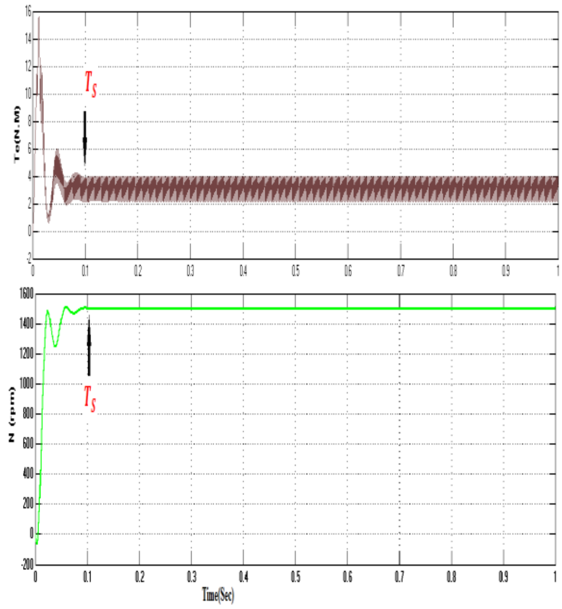

Fig.12. MATLAB based simulation waveforms of BLDC Motor "Te" and "N" with PID Controller

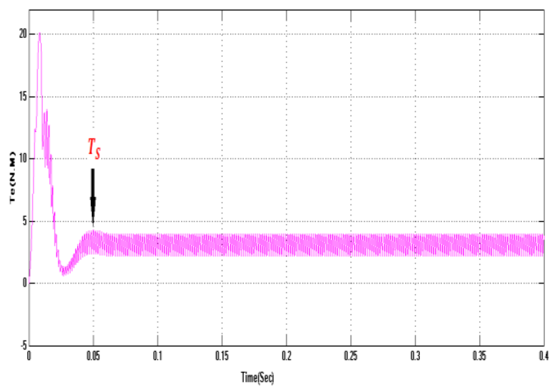

Fig.13. MATLAB based simulation waveforms of BLDC Motor "Te" with proposed closed loop fuzzy logic Controller

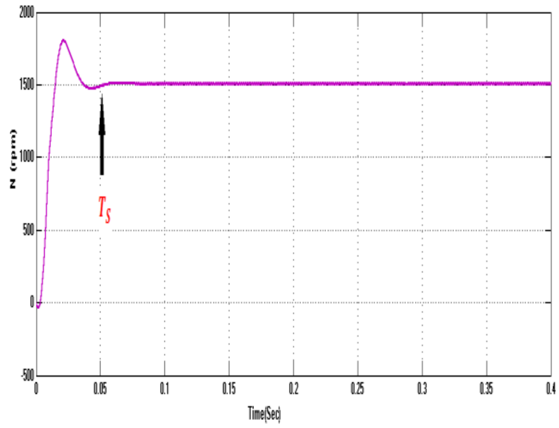

Fig.14. MATLAB based simulation waveforms of BLDC Motor "N" with proposed closed loop fuzzy logic Controller

TABLE.I.SIMULATION PARAMETERS

PARAMETER	RATING
BLDC Motor R_S	2.8750 Ω
BLDC Motor stator inductance L_S	8.5mH
PID controller , Kp	0.004
PID controller , Ki	0.7
PID controller , Kd	0.001
Boost converter capacitance C	470µF
Boost converter inductance L	840 µH
BLDCM rated speed N	1500 rpm

IV.CONCLUSION

Brush Less DC Motor (BLCDM) driven by an efficient closed loop fuzzy logic based high voltage gain interleaved boost converter modeled and simulated in MATLAB2009a GUI environment using ode23tb solver. The proposed closed loop fuzzy logic controller gives the better accuracy as compared with the conventional PID controller and is proved by the Fig.13, Fig.14 & Fig.15. Settling time for PID Controller is 0.1 Secs and it is with proposed closed loop fuzzy logic controller is 0.05 Secs . Hence dynamic response of the overall system improved with the proposed closed loop fuzzy logic controller.

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