Fuzzy Logic Controlled Based PFC of BLDC Drive using Bridgeless Luo Converter

M. DANIYELU¹, SK. MOHIDDIN²

¹PG Scholar, Dept of EEE, Lingayas Institute of Management & Technology, Nunna, Krishna (Dt), AP, India, E-mail: dani.maddala@gmail.com.
²HOD, Dept of EEE, Lingayas Institute of Management & Technology, Nunna, Krishna (Dt), AP, India, E-mail: shaik36mohiddin@gmail.com.

Abstract: This paper shows another PFC bridgeless (BL) - Luo converter for brushless direct current (BLDC) engine drive application in low-control applications. A Fuzzy logic execution in adaptable speed control of BLDC engine is done here. A methodology of rate control of the BLDC engine by controlling the dc bus voltage of the voltage source inverter (VSI) is utilized with a solitary voltage sensor. The controller is intended to track varieties of pace references and settles the yield velocity amid burden varieties. The BLDC has a few preferences contrast with the other kind of engines; however the nonlinearity of the BLDC engine drive attributes, in light of the fact that it is hard to handle by utilizing customary relative basic (PI) controller. The PFC BL-Luo converter has been designed to operate in DICM and to act as an inherent power factor pre regulator. An electronic commutation of the BLDC motor has been used which utilizes a low-frequency operation of VSI for reduced switching losses. The speed of the BLDC motor is controlled by an approach of variable dc-link voltage, which allows a low-frequency switching of the voltage source inverter for the electronic commutation of the BLDC motor, thus offering reduced switching losses. The proposed BLDC motor drive is designed to operate over a wide range of speed control with an improved power quality at ac mains. The simulation results are presented by using Mat lab/Simulink software.

Keywords: Bridgeless Luo (BL-Luo) Converter, Brushless Dc (BLDC) Motor, Power Factor Correction (PFC), Power Quality, Voltage Source Inverter (VSI).

I. INTRODUCTION

Since 1980's a new plan idea of changeless magnet brushless engines has been created. The Changeless magnet brushless engines are ordered into two sorts based upon the back EMF waveform, brushless Air conditioning (BLAC) and brushless DC (BLDC) engines [1-2]. BLDC engine has trapezoidal back EMF and semi rectangular current waveform. BLDC engines are quickly getting to be well known in businesses, for example, Appliances, HVAC industry, restorative, electric footing, car, airplanes, military gear, hard plate drive, mechanical computerization gear and instrumentation due to their high effectiveness, high power element, noiseless operation, minimized, dependability and low support [3-5]. To supplant the capacity of commutators and brushes, the BLDC engine requires an inverter and a position sensor that distinguishes rotor position for legitimate substitution of current. The revolution of the BLDC engine is in light of the criticism of rotor position which is gotten from the corridor sensors [6]. BLDC engine ordinarily employments three lobby sensors for deciding the recompense Grouping. In BLDC engine the force misfortunes are in the stator where warmth can be effectively exchanged through the edge or cooling frameworks are utilized as a part of expansive machines [7-8]. BLDC engines have numerous focal points over DC engines and prompting engines. Fig.1. Conventional PFC-based BLDC motor drive.

A percentage of the favorable circumstances are better speed versus torque qualities, high element reaction, high proficiency, long working life, quiet operation; higher pace ranges [9] as shown in Fig.1. Up to now, more than 80% of the controllers are PI (Relative and vital) controllers on the grounds that they are effortless and straightforward. The velocity controllers are the routine PI controllers and current controllers are the P controllers to accomplish superior commute [10]. Fuzzy Logic can be considered as scientific hypothesis joining multi esteemed rationale, likelihood hypothesis, and counterfeit consciousness to recreate the human approach in the arrangement of different issues by utilizing an estimated
thinking to relate diverse information sets and to make choices [11]. It has been accounted for that fluffy controllers are more powerful to plant parameter changes than traditional PI or controllers and have better clamor dismissal capacities [12]. This paper presents a BL Lou converter fed BLDC motor drive with variable dc link voltage of VSI for improved power quality at ac mains with reduced components and superior control [13].

II. PROPOSED PFC-BASED BLDC MOTOR DRIVE

Fig. 2 shows the proposed PFC-based bridgeless Luo (BL-Luo) converter-fed BLDC motor drive. A single phase supply followed by a filter and a BL-Luo converter is used to feed a VSI driving a BLDC motor. The BL-Luo converter is designed to operate in DICM to act as an inherent power factor preregulator. The speed of the BLDC motor is controlled by adjusting the dc-link voltage of VSI using a single voltage sensor. This allows VSI to operate at fundamental frequency switching (i.e., electronic commutation of the BLDC motor) and hence has low switching losses in it, which are considerably high in a PWM-based VSI feeding a BLDC motor. The proposed scheme is designed, and its performance is simulated for achieving an improved power quality at ac mains for a wide range of speed control and supply voltage variations. Finally, the simulated performance of the proposed drive is validated with test results on a developed prototype of the drive.

III. OPERATING PRINCIPLE OF PFC BL-LUO CONVERTER

The operation of the proposed PFC BL-Luo converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage [see Fig. 3(a)–(c) and (d)–(f)] and during the complete switching cycle.

A. Operation during Positive and Negative Half Cycles of Supply Voltage

Fig. 3(a)–(c) and (d)–(f) shows the operation of the PFC BL-Luo converter for positive and negative half cycles of supply voltage, respectively. The bridgeless converter is designed such that two different switches operate for positive and negative half cycles of supply voltages. As shown in Fig. 5(a), switch \( S_{w1}, \) inductors \( L_{i1} \) and \( L_{o1}, \) and diodes \( D_{p} \) and \( D_{p1} \) conduct during the positive half cycle of supply voltage. In a similar manner, switch \( S_{w2}, \) inductors \( L_{i2} \) and \( L_{o2}, \) and diodes \( D_{n} \) and \( D_{n1} \) conduct during the negative half cycle of supply voltage as shown in Fig. 5(d).

![Fig. 2. Proposed PFC BL-Luo converter-fed BLDC motor drive.](image-url)
Fuzzy Logic Controlled Based PFC of BLDC Drive using Bridgeless Luo Converter

![Diagram of PFC BL-Luo converter](image)

**Fig. 3.** Different modes of operation of the PFC BL-Luo converter during (a–c) positive and (d–f) negative half cycles of supply voltage. (a) Mode P-I. (b) Mode P-II. (c) Mode P-III. (d) Mode N-I. (e) Mode N-II. (f) Mode N-III.

**B. Operation During Complete Switching Cycle**

Fig. 4(b) shows the operation of the PFC BL-Luo converter during a complete switching period for a positive half cycle of supply voltage.

**Mode P-I:** As shown in Fig. 3(a), when switch $S_{w1}$ is turned on, the input side inductor ($L_{i1}$) stores energy, depending upon the current ($i_{L1}$) flowing through it and the inductor value ($L_{i1}$). Moreover, the energy stored in the intermediate capacitor ($C_{i1}$) is transferred to the dc-link capacitor ($C_{d}$) and the output side inductor ($L_{o1}$). Hence, the voltage across the intermediate capacitor ($V_{C1}$) decreases, whereas the current in the output inductor ($i_{L01}$) and the dc-link voltage ($V_{dc}$) are increased as shown in Fig. 4(b).

**Mode P-II:** As shown in Fig. 3(b), when switch $S_{w1}$ is turned off, the input side inductor ($L_{i1}$) transfers its energy to the intermediate capacitor ($C_{i1}$) via diode $D_{p1}$. Hence, the current $i_{L01}$ decreases until it reaches zero, whereas the voltage across the intermediate capacitor ($V_{C1}$) increases as shown in Fig. 4(b).

**Mode P-III:** As shown in Fig. 3(c), no energy is left in the input inductor ($L_{i1}$), i.e.,

![Waveforms of BL-Luo converter](image)

**Fig. 4.** Waveforms of BL-Luo converter during its operation for (a) complete line cycle and (b) complete switching cycle.

Fig. 4(b). The dc-link capacitor ($C_{d}$) provides the required energy to the load; hence, the dc-link voltage $V_{dc}$ reduces in this mode of operation. Mode P-III: As shown in Fig. 3(c), no energy is left in the input inductor ($L_{i1}$), i.e.,
current \(i_{L1}\) becomes zero and enters the discontinuous conduction mode of operation. The intermediate capacitor \(C1\) and output inductor \(L_{o1}\) are discharged; hence, current \(i_{L1}\) and voltage \(V_{C1}\) are reduced, and dc-link voltage \(V_{dc}\) increases in this mode of operation as shown in Fig. 4(b). The operation is repeated when switch \(S_{w1}\) is turned on again. In a similar way, for a negative half cycle of supply voltage, the inductor’s \(L_{i2}\) and \(L_{o2}\), diode \(D_{a1}\), and intermediate capacitor \(C_{2}\) conduct to achieve a desired operation.

IV. CONTROL OF PFC BL-LUO CONVERTER-FED BLDC MOTOR DRIVE

The control of the PFC BL-Luo converter-fed BLDC motor drive is classified into two parts as follows.

A. Control of Front-End PFC Converter: Voltage Follower Approach

The control of the front-end PFC converter generates the PWM pulses for the PFC converter switches \((S_{w1} \text{ and } S_{w2})\) for dc-link voltage control with PFC operation. A single voltage control loop (voltage follower approach) is utilized for the PFC BL-Luo converter operating in DICM. A reference dc-link voltage \(V_{dc}^*\) is generated as

\[
V_{dc}^* = k_v \omega^*
\]

Where \(k_v\) and \(\omega^*\) are the motor’s voltage constant and reference speed.

The reference dc-link voltage \((V_{dc}^*)\) is compared with the sensed dc-link voltage \((V_{dc})\) to generate the voltage error signal \((V_{e})\) given as

\[
V_{e}(k) = V_{dc}^*(k) - V_{dc}(k)
\]

Where \(k\) represents the kth sampling instant.

This error–voltage signal \((V_{e})\) is given to the voltage proportional–integral (PI) controller to generate a controlled output voltage \((V_{c})\) as

\[
V_{c}(k) = V_{c}(k-1) + k_p (V_{e}(k) - V_{c}(k-1)) + k_i V_{e}(k)
\]

Where \(k_p\) and \(k_i\) are the proportional and integral gains of the voltage PI controller.

Finally, the output of the voltage controller is compared with a high frequency saw tooth signal \((md)\) to generate the PWM pulses as

\[
\begin{align*}
\text{if } m_d(t) < V_{cc}(t) & \text{ then } S_{w1} = S_{w2} = "ON" \\
\text{if } m_d(t) > V_{cc}(t) & \text{ then } S_{w1} = "OFF" \\
\end{align*}
\]

Where \(S_{w1}\) and \(S_{w2}\) represent the switching signals to the switches of the PFC converter. The modeling and stability issue of the proposed converter are discussed in the Appendix.

B. Control of BLDC Motor: Electronic Commutation

An electronic commutation of the BLDC motor includes the proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc-link capacitor for 120° and placed symmetrically at the center of each phase. A rotor position on a span of 60° is required for electronic commutation, which is sensed by Hall Effect position sensors. The conduction states of two switches (\(S1\) and \(S4\)) are shown in Fig. 5. A line current \(iab\) is drawn from the dc-link capacitor, whose magnitude depends on the applied dc-link voltage \((V_{dc})\), back electromotive forces (EMFs) \((e_{an}\) and \(e_{bn}\)), resistance \((R_a\) and \(R_b\)), and self- and mutual inductances \((L_a, L_b, \text{ and } M)\) of the stator windings. Table I shows the governing switching states of the VSI feeding a BLDC motor based on the Hall Effect position signals \((Ha-He)\).

<table>
<thead>
<tr>
<th>(\theta(\degree))</th>
<th>Hall Signals</th>
<th>Switching States</th>
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<tbody>
<tr>
<td>NA</td>
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<tr>
<td>0-60</td>
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</tr>
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<td>120-180</td>
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<td>0 0 1 0 0 1</td>
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<tr>
<td>180-240</td>
<td>1 0 0 0</td>
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<td>240-300</td>
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<tr>
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V. FUZZY LOGIC CONTROL

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of compensator. The basic scheme of a fuzzy logic controller is shown in Fig.6 and consists of four principal components such as: a fuzzyification interface,
which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a defuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

Fig. 6. Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter.

Fig. 7. Membership functions for Input, Change in input, Output.

**Rule Base:** the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input/output variables; in the steady state, small errors need fine control, which requires fine input/output variables as shown in Figs. 7 and 8. Based on this the elements of the rule table are obtained as shown in Table, with ‘\(V_{dc}\)’ and ‘\(V_{dc-ref}\)’ as inputs.

**TABLE I: Rule Table**

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<tr>
<th>(\Delta e)</th>
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<th>EZ</th>
<th>PS</th>
<th>PM</th>
<th>PL</th>
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**V. MATLAB/SIMULATION RESULTS**

Simulation results of this paper is as shown in bellow Figs. 9 to 15.

Fig. 9. Test results of proposed BLDC motor drive At rated load torque on BLDC motor with \(V_{dc} = 50\) V and \(Vs = 220\) V.

Fig. 10. Test results of proposed BLDC motor drive At rated load torque on BLDC motor with \(V_{dc} = 200\) V and \(Vs = 220\) V.
Fig. 11. Test results of proposed BLDC motor drive showing dynamic performance during starting at 50 V.

Fig. 12. Test results of proposed BLDC motor drive showing dynamic performance during change in dc-link voltage from 100 to 150 V.

Fig. 13. Test results of proposed BLDC motor drive showing dynamic performance during change in supply voltage from 250 to 180 V.

Fig. 14. Input Current THD with PI Controller.

Fig. 15. Input Current THD with Fuzzy logic Controller.
VI. CONCLUSION

A PFC BL-Lou converter-based VSI-fed BLDC motor drive has been proposed targeting low-power applications. A new method of speed control has been utilized by controlling the voltage at dc bus and operating the VSI at fundamental frequency for the electronic commutation of the BLDC motor for reducing the switching losses in VSI. The front-end BL Lou converter has been operated in DICM for achieving an inherent power factor correction at ac mains. Moreover, voltage and current stresses on the fuzzy based PFC switch have been evaluated for determining the practical application of the proposed scheme. Finally, a simulation of the proposed drive has been developed to validate the performance of the proposed BLDC motor drive under speed control with improved power quality at ac mains. The proposed scheme has shown satisfactory performance, and it is a recommended solution applicable to low-power BLDC motor drives.

VII. REFERENCES


Author’s Profile:

Mr. M. Daniyelu is a student of EEE department in Lingayas Institute of Management and Technology in Madalavarigudem, Nunna, Vijayawada. He is presently pursuing MTech degree from JNTU Kakinada. He has obtained B.Tech degree from Dhanekula Institute of Management and Technology JNTU Kakinada.

Mr. S. Mohiddin is presently working as HOD in EEE department Lingayas Institute of Management and Technology Madalavarigudem, Nunna, Vijayawada. He has obtained B.Tech degree in NIMRA College of Engineering and Technology Ibrahimpatnam, Krishna District and MTech degree from NIMRA College of Engineering and Technology Ibrahimpatnam Krishna District. He has published three research papers in International Journals One Paper in Conference.