Design of Fuzzy-Pid with Landsman Converter (LC) Fed BLDC Drive Using IFOC Controller

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Abstract. In this paper, fuzzy - PID control is designed to improve the settling time of DC link voltage of the Photovoltaic (PV) array fed landsman converter (LC). In all platforms such as medicals, automobile the utilization of variable speed drives is increased and which are directs to brushless DC motor demand in increasingly. Indirect Field Oriented Control is used to make precise and robust speed control with ripple minimization of torque. Back-EMF estimation method is contributing with IFOC control for obtaining accuracy speed in sensor-less approach and control the dynamic changes in speed. Dc link voltage of LC is maintained at constant using the Fuzzy-PID control which maintains the BLDC steady state condition while the motor speed at dynamic load as well as set point variation. The performance of IFOC based brushless DC motor is improved with high efficiency and in the MATLAB/Simulink platform the proposed system results are verified.

Keywords: Back EMF, BLDC Motor, Fuzzy-PID control, IFOC, LC converter, MPPT, PV.

1. Introduction
Daily life has become essential in using electric motors that are used in many applications such as electric vehicle, aerospace, air conditioning, and vacuum cleaner. Recently, the brushless direct current motor (BLDC) is highly preferred to employ in more applications due to less maintenance, compactness and high efficiency with low cost. This motor has accurate positions of rotor at high speed drive arrangements. The BLDC motor using electronic commutations technique and it is not requiring brushes for commutation. Normally, a DC motor is combined with friction of mechanical and erosions in electrical system but the brushless DC motor has defeat the aforementioned issues. The mentioned advantages are essential for preferring brushless DC motors in many platforms. In control of BLDC speed is accomplished using PI controller and the switching signals providing PWM. For obtaining better speed control with robust, the PID controller is used and to varied load conditions. In this brushless motors, the commutation error is found as a most concerning problem in high speed range drive system applications which are leads to overall performance of the system will be decreased. Since the commutations precision is impacted by the more non-ideal factors undesirably the elimination of commutation error is so hard. To compensate this issue, the sensor-less control based on 3rd-harmonic compensation method is developed and this control approach is also improving the presentation of drive system. The virtual 3rd harmonic is eliminated the commutation error and increase the effectiveness of the system performance. The output of the motor-fed system should be stable at varying operating conditions. This is done via the motor-connected drive arrangement converter system. The converters
of power electronics do the power conversion from the source. The power converters are made of power semiconductor components that can be used in low and high power applications. To improve the energy that fed from source, the power converters are used and doing performance such as dc-dc, ac-dc, ac-ac, etc. The conventional boost, buck-boost converters are used to improve the DC bus voltage due to low cost and simple in structure where the load connected with converter system. However, it does not achieve enough voltage gain for a high step-up application. The power converters are also having the problems such as less efficiency, large capacitor, and high number of passive elements. The landsman converter is better while compared with like SEPIC, ZETA, Cuk converters then it has reduced elements for operation and overcoming the fore mentioned issues. For obtaining high voltage gain from supply voltage, the power switches to be controlled by using control system. The conventional systems are controlled and regulated by using PWM, PI, and PID control to provide gate signals for the power switches with appropriate duty cycle.

The system stability is achieved through Fuzzy-PID control for landsman converter to improve DC link voltage and reduce settling time to maintain the input supply of voltage source converter (VSC) at constant. The Fuzzy-PID approach base implementation feeding power to IFOC control with back EMF estimation based BLDC motor. The power maximization technique of MPPT with Inc& con algorithm is proposed to PV system power extraction for landsman converter (LC) fed brushless BLDC motor. The proposed system is compared with the existing system of [8, 14] in term of DC link voltage improvement and reduced settling time.

2. Literature Review

In [1] the author proposes the simulation model implementation that based on the BLDC motor which operated by four quadrant operation. In this method, the torque ripple of the BLDC drive is reduced. The model predictive controller is used to achieve the effective analysis and monitoring in the developed simulation model that enables control in speed and characteristics in the back EMF and torque. The controller is accomplished the four quadrant operation and there is no power loss. The implemented system is validated with the MPC control scheme and during the regenerative period the energy is conserved. In [2] author suggests a BLDC Zeta converter motor for industrial applications. The motor speed is tracked using a hysteresis controller on the back EMF. The proposed method is designed to achieve speed and reduce fluctuation in input voltage. It provides an improved capacity with a high voltage gain rate. It’s a zeta and quadratic boost conversion combination. In [3] the BLDC motor control is accomplished using the PI controller as well as the fuzzy logic control system for the control in speed. But in the PI controller based motor speed control has low performance and it has demerit of will not operate under the load disturbances in high degrees. The fuzzy logic controller based speed control has dynamic performance while compared with PI control. In [4] sensor less based BLDC motor is used for the water pump and the BLDC motor is powered from the solar system. The converter is providing DC link voltage with minimum and it is controlled by the fundamental pulse width technique so that the converter not able to provide constant DC supply to load. In [5] proposes the interleaved boost converter for achieving high voltage gain based on the fuel cell with controller of MPPT system. The interleaving converter system is increasing the passive elements and enhances the cost and size. In [6-7] that explain the electro mechanical braking system that based on the utilization of the BLDC motor which is controlled by the method of fuzzy based sliding mode controller. The distribution of the torque is controlled in this approach. In [8] describes the renewable energy based DC-DC converter is interfaced. To improve the input power supply, the MPPT controller used for the converter system. The interleaved boost converter is used for the minimization of the input current ripples in the converter. In [9] author proposes the maximum power tracking controller for the dc-dc converter which is interfaced with the photo voltaic system. The differential MPP is used to tracking the more power but which has more constraints when the low irradiance in solar system. In [10] the model reference adaptive control (MRAC) with compensator for the BLDC motor to achieve high performance. This paper considers the speed control achieving for various speed respect to the different times. But the method is affected by the variations in the parameters and load disturbances. In [11] the BLDC motor drive is used for the
solar based water pump load and the bidirectional power flow is enabled. To maintain the DC link voltage in constant the energy storage system of grid system is interfaced. In [12] explains the different strategies of the BLDC motor based speed and torque controls are determined. In [13] the both converters of DC-DC buck and boost converters are proposed for the PV system connected voltage source inverter to power the permanent magnet BLDC motor system. To attain the constant speed for the motor, the voltage from the boost converter to be maintained at constant in this paper but also the ripples and settling time is more.

3. Proposed system

In this proposed system, as shown in figure.1. PV source is providing direct current to LC fed brushless DC drive. This paper consists of BLDC motor, single diode PV array, landsman converter, and VSI. LC is regulating high voltage gain which is fed to BLDC connected VSI. By using LC with Fuzzy-PID control method is to accomplish high voltage. In this proposal, the settling time of LC output voltage and high voltage gain are accomplished by the Fuzzy-PID control method. To control the speed and ripple reduction of the BLDC motor, the IFOC with back EMF estimation method is used.

3.1. PV Energy Generation
Photo voltaic system has PV cells in parallel and series combination which is utilized to improve the power respectively. PV produces energy directly from solar system and according to solar irradiances as well as temperature it will be changed. The PV circuit of single diode model is shown in figure 2. In PV cells the sunlight is directly converted into dc power. According to photoelectric effect phenomenon the PV modules are worked. In PV system, the Maximum Power Point Tracking (MPPT) is very essential algorithm during operation which yields high energy from the source and to PV arrays operating point almost reaching the MPP. Generally, the MPPT is used to generate more power that can highly possible to achieve in an electronic system which functions the PV modules. In this paper, incremental and conductance base MPPT is employed.

The following equation shows that PV model’s current (I) and voltage (V) (I-V) characteristics: The following equation shows that PV model’s current (I) and voltage (V) (I-V) characteristics:

Where,

\[ I = \text{PV current (A)} \]
\[ K = \text{Boltzmann constant (J/K)} \]
\[ I_L = \text{Light generated current (A) in the PV module} \]
\[ V = \text{PV voltage (V)} \]
\[ R_s, R_{sh} = \text{series and shunt resistance of the single diode PV model} \]
\[ Q = \text{Electron Charge} \]
\[ I_0 = \text{saturation diode current} \]

![Figure 2. Circuit of single diode PV module](image)

The incremental and conductance (IC) algorithm is overcoming the demerits of perturb and observe method in case of the failure in tracking peak power at atmospheric condition under fast variation. In this method, when the MPP is reached then the operating point disturbing comes to stop. The disturbance of operating point is calculated using the following relationship in between \( \frac{dI}{dV} \) and I-V characteristics. While MPP is in right side for MPPT, this is negative and which is from \( \frac{dP}{dV} \) and when it is to the left of the MPP, It is positive. This IC has merits over the conventional system because the oscillations are occurred in MPP when the MPPT method is achieving the maximum operating point. The basic incremental and conductance equations are shown in below,

\[
\frac{dI}{dV} = -\frac{I}{V_{at\ MPP}} \quad (1)
\]
\[
\frac{dI}{dV} > -\frac{I}{V_{left\ of\ MPP}} \quad (2)
\]
\[
\frac{dI}{dV} < -\frac{I}{V_{right\ of\ MPP}} \quad (3)
\]

The MPPT improves the Fuzzy –PID control based PWM signal of landsman converter dc-dc converter. The flowchart of IC technique base MPPT is shown in figure 3.
3.2. Proposed LC system
The LC is dc-dc converter and it is designed to improve the photo voltaic (PV) power and to function in CCM depends on the deviation level of irradiance. Proposed LC is providing improved voltage with less settling time to brushless DC motor. The PV array output voltage is optimized using proposed LC to perform noiseless, safe and better running of the BLDC motor. The DC bus voltage of the proposed BLDC system is regulating and achieving enhanced voltage gain by the function of LC converter. LC comprises of two capacitors (C1, C2), inductors (L1, L2), and diode with the power switch (Sw). The proposed landsman converter is represented in figure 4 generally; LC converter is designed to work in two operation modes such CCM and DCM. In continuous conduction mode, when the power switch is ‘ON’ state, the voltage in the capacitor C1 is direct to diode (D) gets reverse biased. The inductor current is supplied through the power switch. The voltage across C1 is larger than the result voltage Vdc, here L receiving the energy from the C1 that discharges and the power fed to output. Because of this, the inductor current IL is increased and the voltage across the intermediate C1 decreases. In discontinuous continuous conduction mode, when the switch is in OFF state, the diode operation is biased in forward as well as the IL is flowing through the forward biased diode D. Through the D, the output energy is transferred that stored energy in inductor. At the same time, intermediate capacitor is charged from both input supply and inductor L.
4. Proposed system control methods

In this paper, the proposed PV fed landsman converter contains a power switch (S) which is controlled by using Fuzzy-PID controller. In this proposed system, the Fuzzy-PID control designed to achieve high voltage gain for landsman converter fed brushless DC motor based photo voltaic system. The proposed control is returning the desired reference value even the variation in the set points. This control design is including both fuzzy logic and PID controllers. Normally a PID controller has three parameters values such as proportional, Integral, and Derivative. In this controller design the oscillations can be reduced and the system steady state error is controlled. When the dynamic condition in both load and set point, the proposed Fuzzy-PID controller is used to optimizing and provide switching signals for the proposed converter power switch. In this system, Kp, Ki, and Kd, parameters are determined by using fuzzy logics. The input of the proposed controller Fuzzy-PID consists of two inputs that delta error and error, and three Kp, Ki, and Kd, outputs. The Fuzzy-PID controller used and the settling time is reduced. The input source of the voltage source inverter is increased using by the designed Fuzzy-PID controller. The block diagram of the proposed Fuzzy-PID controller design for proposed dc-dc landsman converter is shown in figure.5. In this system, the Fuzzy logic rules are reducing the error signal and provide three PID parameters to PID controller after that it is fed to plant.

4.1. Back EMF and IFOC system

In The DC link voltage which is improved using landsman converter is fed to three phase voltage source inverter. In this proposed method, the requirement of adding the injection of high frequency signal is not necessary to obtain the position of rotor that achieved using from stator currents and voltages. This sensor-less back EMF is widely applied successfully to more applications which are requiring starting control with simple. To make signals of back EMF, the stator voltages and mathematical model as well as stator command currents are used. The back EMF signals are used to observe the position and speed of the rotor and the sensor-less drive performance is directly influenced by the accuracy of proposed
back EMF estimator. From the observed values, the line currents and voltages are can be calculated. By equation (3) the back EMF is calculated that leads to obtain rotor speed. In figure .6 the Back EMF method is shown.

![Flowchart of Speed Estimation Method](image)

**Figure 6.** Speed Estimation Method flow chart

In

\[ I_{ref} = \frac{T_{ref}}{2 \cdot P \cdot \phi} \]  

(4)

Where  \( V_a, V_b, V_c \) - phase voltages  
\( I_a, I_b, I_c \) - phase currents  
\( e_a, e_b, e_c \) - BLDC motor back EMF  
\( \omega_r \) - speed of rotor  
\( P \) - Number of pole pairs  
\( \phi \) - Flux

The proposed streamlined IFOC scheme is to measure the speed of the BLDC engine, which is calculated using the EMF prediction process behind it. Submit to the PI controller after determining the speed error between approximate speed and reference speed and act as a speed regulator. To produce switching signals by the HC, the hall signal of the BLDC motor is to be computed and is combined with reference current. The estimation of Inc& Con is used to extract the intense power from the source and the path of the period of duty is calculated from the MPPT algorithm balances of the current reference value.
4.2. Hysteresis controller
Present controller function well only because we are correctly characterizing the two party viz. Present error is fed as controller input and produces gate signals when error is below the limit of the hysteresis band or when the pulse reaches the limit of the band it induces gate signals which are low to power switches. As shown in figure 7 if the band limit is preferred band limit will be held at a lower significance because the pulse's high switching frequency is also high, resulting in high power electronic switching losses.

![Hysteresis current controller](image)

**Figure 7.** Hysteresis current controller

5. Simulation and Results
Proposed simulink model of the Fuzzy-PID with LC converter which is powered by renewable PV array fed BLDC motor. Low generated energy from the PV module is supplied to landsman converter to achieve high DC link voltage is controlled. Output DC voltage of the PV fed converter is feeding to VSI which is generating three phase voltages for BLDC motor operation. In this proposed system, the main Fuzzy-PID controller has proposed to manage the response of LC converter DC link voltage and reduce the settling time. The proposed system simulink model is shown in figure 8 The MPPT is used to produce maximum power through the proposed controller which is control the response of the converter. As shown in figure 9, the DC link bus voltage of the proposed LC based on Fuzzy-PID controller is achieving 82 V and settling time is 0.08 sec which is high obtained results while compared with the [8] explains.

![Overall Simulink Model of the Landsman Converter (LC) Fed BLDC motor](image)

**Figure 8.** Overall Simulink Model of the Landsman Converter (LC) Fed BLDC motor

The switching signals are generated using the HC which is based on the hall signal valuation from the proposed drive rotor angle. The sensor-less based back EMF method is used to detect the voltage and current of the brushless dc motor stator. From this estimation the proposed system speed and torque can be controlled. The rotor speed as well as the position of the rotor is observed with accuracy using
proposed estimation method. The speed of the BLDC has controlled using IFOC control which is performing under the estimation of the back EMF based sensor-less method. In the PI controller the set point or reference torque is generated by reduce the error in the feedback of the proposed system.

![Figure 9. DC link voltage](image)

The Stator current of the proposed BLDC drive is illustrated in figure.10. By using the IFOC and back EMF based sensor-less control. System actual speed is shown in figure.11. The proposed drive system torque is shown in figure.12. Speed that is obtaining using IFOC control method is shown in figure. 13. The actual speed and estimated controlled speed are compared as shown in figure. 14.

![Figure 10. DC link voltage](image)

The cascaded multilevel inverter is used to produce levels for achieving the harmonics reduction in form carrier arrangement with control technique of APOD control for the generating switching signals for the proposed cascaded MLI. The proposed system inverter is achieving 11 levels with 230V for the induction motor as shown in fig based system to reduce the inrush current which is done by the control method of the direct torque and flux control. The speed of the proposed DTFC based IM accomplished the speed of 1600rpm which is settled in the time of 0.4 sec as shown in figure.15.
**Figure 11.** Stator Current of the BLDC motor

**Figure 12.** Proposed System Actual speed

**Figure 13.** Proposed System torque
6. Conclusion
The PV fed brushless DC motor drive is implemented and through the proposed landsman converter (LC) the DC bus voltage is achieved its high voltage gain and the reduced ripples in the output voltage and settling time reduction. These are accomplished by the proposed Fuzzy-PID controller. The stator voltage and currents are observed and the speed of the BLDC drive is controlled by using back EMF estimator and indirect field orient control (IFOC) are respectively. In this paper, the LC is achieved high DC bus voltage and the reduced settling time is 0.07 sec achieved. The ripples in the BLDC drive speed are reduced with efficient control of proposed system.

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Figure 14. Proposed System speed control with reduced ripple

Figure 15. Comparison of actual speed and estimation speed
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