REVIEW ARTICLE

Performance Analysis Review of Different Controllers Employed in Brushless DC Motor

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Received: 24 Jun 2023 Revised: 15 Nov 2023 Accepted: 29 Dec 2023

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ABSTRACT

This review document provides a brief overview of the performance analysis on different control techniques when applied to the brushless DC motor (BLDCM). These types of motors are non-linear in nature, therefore conventional controllers (PI, PID) do not achieve the desired steady-state performance. To achieve the control objective, intelligent controllers are presented with such a scheme according to various other control techniques such as (PI, PID, Fuzzy, ANN, Hybrid Adaptive Fuzzy, Neural-Fuzzy, Hybrid Neuro-Fuzzy, diffuse scrolling mode, MRAC, FPIDSMC and FSMC) were investigated by several researcher .These techniques differ in several ways, such as control architecture, controller adjustment method, dynamic and steady-state performance. The document presents a comparative review of the performance analysis of conventional and intelligent control techniques.

Keywords: BLDC motor, PI,PID, Fuzzy, ANN, Hybrid Adaptive Fuzzy, Neural-Fuzzy, Hybrid Neuro-Fuzzy, sliding mode fuzzy, MRAC, FPIDSMC and FSMC.

INTRODUCTION

A permanent magnet (PM) synchronous motor with trapezoidal induced voltage waveform is called a BLDC motor. A BLDC motor is activated electronically rather than mechanically based on feedback on the rotor position. The rotor of the BLDC motor contains permanent magnets and the stator has a winding. Rotor position detected by sensors positioned internally or externally. The BLDC motor is the most popular for various industrial applications (90% closed loop control with PI, PID thanks to the intrinsic advantage of simple structure and robust operation), robotics, avionics thanks to its high torque speed characteristics, less noise and less maintenance [1] Feedback is based on the sensor or not on the sensor. position sensors as feedback with this the parameter changes are temperature, pressure with the system with parameter changes are affected [2]. So the sensorless rotor position detection system [3] has received more and more attention. The sensorless method mainly includes the post EMF method, the Flux Linkage based method. But this controller is not suitable for the BLDC motor due to the non-linear behavior of the variations of the system parameters in different load conditions of the BLDC motor, the researcher proposed different techniques (hybrid, intelligent and robust controllers). The compensated system designed using the non-iterative controller design approach provides the desired specifications with greater precision for the different BLDC drive systems. The transient response of the compensated system is better than that obtained using the conventional design approach [4]. Fuzzy Sliding Mode Control with PID Compensator [5] introduced for BLDCM, this method features a robust control system with the Fuzzy Sliding Mode Controller and an additional compensator. FPIDSMC and FSMC controllers can provide robustness to external uncertainties and disturbances, FPIDSMC offers better performance than FSMC compared to the external load torque, vibrations are avoided and the system response is improved. Complete analysis of the fuzzy logic controller for PMBDCMD presented for a fast dynamic response such as speed and torque in a short time in case of sudden changes or load disturbances [6].

The adaptive diffuse control method is used with sliding mode control algorithms. AFSMC performance is generating free phenomena and system stability will be improved compared to conventional sliding mode control to reduce the vibration of the nearby sliding surface [7]. The Intelligent Brain Emotional Learning Based Controller (BELBIC) is adapted for BLDCM. BELBIC's high level of precise self-learning offers fast and fast responses at transient speeds in a wide range of speeds from 20 to 300 rpm. Good monitoring has excellent control performance, good robustness and adaptability [8]. In [9] A comparison between DC motor position control by a PIDSMC fractional diffuse surface and a PIDSMC diffuse surface clearly shows that FPIDSMC offers better performance than PIDSMC compared to the external load torque. It is a robust controller and vibrations against external load torque are avoided. In [10] a fractional order derivative and a proportional controller (FOPD) is proposed for typical second order plants. The closed circuit system can achieve favorable dynamic performance and robustness compared to other techniques. A PI Fuzzy Gain Scheduling (FGSPIC) controller is proposed for BLDCM, three separate PI controllers for different low, medium and high speed sampling time intervals. , robust in a variable sampling situation (different loading conditions) [11]. A comparative study between PI, fuzzy and hybrid PI-Fuzzy controller (the hybrid controller has integrated both the diffuse controller and the PI controller) for speed control of the brushless DC motor (BLDC) ", a diffuse controller offers a better response starting speed while PI The controller has a good compliance with respect to the variation of the load torque, but the hybrid controller has the advantage of integrating the superiority of these two controllers to improve the performance of the control. The PI has a good load torque but a slow tuning response Shorter settling time The hybrid driver has integrated both the fuzzy driver and the PI driver During a high-speed error, the hybrid driver has improved the dynamic performance of the BLDC Motor [12] A speed controller intelligent for brushless DC motor with this PID method and PID controller of Fuse to control the BLDCM speed proposed FPID controller performs better than the conventional PID controller, when the engine undergoes sudden changes at ever higher speeds. The speed of the motor that must be kept constant during a sudden load varies with the fuzzy PID controller, but with the PID controller adjustment it is the problem that FPIDC can overcome [13].

In [14] the design of a BLDCM speed control using the PIC16F877A microcontroller. variation under load. By varying the PWM signal from the microcontroller to the motor controller, it is possible to control the motor speed and also the performance analysis of a BLDCM drive speed with PI and a diffuse-based controller. The dynamic behavior of the fuzzy logic controller provides a much better dynamic response and is robust. The fuzzy logic controller offers a better response than the PI controller. A cascade SMCNRPID controller for BLDCMD is proposed for better performance than the conventional PID controller. It reveals excellent performance in the treatment of overdrive, under drive and settling times, SMCNRPID reduces vibrations when the system is moved on a sliding surface [15]. A cascaded SMCNRPID controller shows a faster and vibration-free response to pitch disturbances, has more robust features than the conventional PID controller [16]. For BLDCM (BLDC motor) a robust diffuse neural control is proposed. the control signal includes diffuse neural control, supervised control and error states. The regulation laws for network parameters are from Lyapunov's theorem for network convergence and stability. The proposed controller was run on a TMS320F2812 DSP. It is feasible and effective even under variable load conditions [17]. In [18] a fuzzy estimator is proposed for driving the PMBLDC motor without reverse speed sensor. In this method the conventional sensorless method and the fuzzy estimate of electromagnetic fields are compared. The algorithm proposed using the fuzzy EMF estimator obtains robust control for the change of an external condition and continuously estimates the rotor speed in transient and steady state conditions. The proposed sensorless drive method without additional circuit has superior performance compared to conventional sensorless methods.

In [19] direct torque control based on the Fuzzy Logic Controller has been demonstrated. DTC has some advantages such as a simple and easy to implement algorithm, a faster torque response, a reduced torque fluctuation and a lower sensitivity to parameter changes, which is why the system has used DTC methods to eliminate the exceeding responses of speed and torque. PI controller compared to Fuzzy Logic controller. The effectiveness of the FLC controller is greater than other controllers. PI controller replaced by FLC. Using Fuzzy Logic Control, the starting current was reduced due to the reliability of the FLC controller. The effectiveness of the FLC controller was verified by simulation. In [20] Modeling and control of BLDC three-phase motors by means of PID with genetic algorithm for BLDCM. In this paper, conventionally tuned PID controllers and genetic algorithm are proposed as a global optimizer for finding optimized PID gains for BLDC motor position control. A comparative analysis with GA and ZIEGLER NICHOLS METHOD (ZNM). Controller performance with GA optimized gains are much more efficient than the ZN method in terms of rise time, settling time, overshoot and set point detection. But ZNM provides the initial values of the PID gains for GA optimization. [21] Modeling and simulation of BLDC motors in the MATLAB GUI presented for various types of BLDC motors that minimize torque ripple. Performance evaluation leads to very useful modeling to study the drive system before starting the design of the dedicated controller, taking into account the relevant dynamic motor parameters. [22] The BLDC motor drive system with sensorless control that uses the Adaptive Neuro Fuzzy Inference (ANFIS) system algorithm for BLDCM, the algorithm consists of the Least Squared method in its forward path while its feedback path uses the posterior propagation method. The modeled BLDC drive system was subjected to the NeuroFuzzy adaptive inference system (ANFIS) for sensorless estimation in closed loop operation. This document examines the sensorless control of the BLDC motor. ANFIS is a very powerful approach to building a complex and nonlinear relationship between a set of inputs and outputs. In [23] A DTC technique for BLDCM with non-sinusoidal rear EMF presented for high torque response and minimization of torque ripple to drive BLDCM.

A slide observer design was proposed to estimate the trapezoidal EMF of a BLDC motor. It is robust due to the uncertainties of the parameters, it can be used to estimate the subsequent EMF and generate the torque. It is used to estimate the non-sinusoidal posterior EMF waveform in a BLDCM using only stator current measurements. A modified version of the non-dominated genetic classification algorithm (NSGA-II) is used as an effective optimization tool to adjust the speed controller PID controller parameters and the selection of four slider observer gains. The relationship between the PID controller and sliding mode is also satisfied with NSGA-II. The effectiveness of the proposed system was validated by the simulation results. In [24] The design of the Fuzzy PID controller for brushless DC motor has proposed lower, higher and constant speeds even when the load varies. a comparative study of the integral integral proportional controller (PID) and the integral integral proportional Fuzzy controller of the three-phase BLDC motor. The widespread PID controller has better control performance than the conventional PID controller when sudden load disturbance occurs. Conventional PID controller difficult to adjust parameters. Because Fuzzy tuning has the ability to satisfy control characteristics and is easy to calculate. The improved Fuzzy PID controller has superior PID control over the conventional.

In [25] Conventional and fuzzy PID controller with field programmable matrix (FPGA) proposed for BLDCM speed control. It was simulated and synthesized using the Xilinx Foundation package and implemented in the Xilinx XC3S400 FPGA. The dynamic response of the system using the proposed controller is better than a conventional controller. The proposed method provides several BLDCM speed commands with correct speed regulation. In [26], hybrid fuzzy control solutions for BLDC units with variable moment of inertia offer four Takagi-Sugeno hybrid fuzzy controllers consisting of two Neuro-diffuse PI hybrid controllers and two adaptive fuzzy sliding controllers. two hybrid PI-NFCs based on an online adaptation of a PI-FC and two ASMFCs based on online adaptation of the switching gain. First, the VMI is characteristic for many servo applications, it may be necessary to use controllers adapted to the operating point. Second, fuzzy control can offer advantageous nonlinear control solutions compared to other BLDCM control solutions. These control techniques and design methods expand the industrial application areas of BLDCM drives and are also implemented for other control applications. The control structures have robustness, system stability and offer constant performance in the presence of model uncertainties. In [27] a comparison of the performance of the PMBLDCM drive with the speed controller PI and FLC is proposed. FLC offers good results in terms of torque ripples and current control limits for windings. Low starting current is achieved if FLC is used, leading to a low cost reversing switch. the starting torque is reduced compared to the use of the PI controller, but does not cause starting problems. It can be easily applied to industrial applications where reliable and inexpensive operation of the BLOC motor drive is required. In [28], the conventional Slip Mode Observer (CSMO) and Enhanced Slip Mode Observer (ISMO) are proposed for BLDCM. The improved scroll mode observer eliminates the problem of unwanted vibrations in the conventional scroll mode observer. ISMO stability was verified by Lyapunov's stability analysis. The use of the sigmoid function in Sliding Mode Observer (SMO) allows to estimate the position of the rotor with high precision and to obtain a faster response. Enhanced Slider Mode Observer (ISMO) has good convergence and solid observer performance. In [29], the sensorless control of BLDC motors uses the closed circuit PWM controller.

An FPGA-based implementation of the BLDC FSTP unit that uses PWM control and real-time experiment. Hardware implementation is performed using the SPARTAN-3 processor. The VHDL (Very High Speed Description Language) program is developed in XILINX to generate the PWM pulses controlled to control the system. In [30] a sliding mode control algorithm (SMCA) is proposed for controlling the speed and current of a BLDC motor. The exponential approach of the flow law was used to design the flow laws for the mathematical model of the BLDC engine developed. An SMCA compared to an integral proportional controller (PIC). The scroll mode control offers much better performance in terms of steady state error, faster settling time, excessive speed response and elimination of the best noise rejection capabilities. but there is the Chattering effect. In [31] Reduction of torque ripple and increase of the torque capacity proposed for the BLDC motor. To increase the torque, the BLDC 9-phase motor model was studied and its efficiency and ripple reduction were tested by simulation. The comparison between the three-phase, 5-phase and 7-phase and 9-phase BLDCM models discussed and the effect of the increase in the number of phases shows that the starting torque of the motor will increase and the efficiency of the motor will also increase slightly. the torque ripple will decrease.

In [32] A Neuro-Fuzzy Hybrid (N.F.) - P.I. Proposed controller powered to control the speed of BLDC motors. A solid S.S.E.E. (removal of steady state errors) to enrich the entire control process. The hybrid system, P.I. N.F.C. is the main loop of the controller while the integral S.S.E.E. The controller reimburses steady state errors. In this he proposed the BLDC unit's capabilities for fast tracking, small steady-state errors and high stability despite all the load and parameter changes compared to other conventional controllers. In [33] Model of adaptive reference controller (MRAC) that uses an artificial neural network controller (ANN) proposed for brushless DC motors (BLDC). The MRAC-based model is capable of monitoring speed and reducing the effect of parameter changes under different conditions. BLDCM suitable for applications such as robotics and position detection. The MRAC-based model is able to monitor the speed and effect of parameter changes compared to the performance of the traditional PID controller. The proposed RNA-based control scheme is robust, efficient and easy to implement.

In [34] the anti-roll PI controller and the fuzzy controller proposed for BLDC motor speed control. The comparison with the PI controller. Conventional PI controllers are slower than popular, anti-winding controllers. From the simulation results, it is clear that for the load variation, the PI windproof controller gave a better response than the conventional PI and the widespread controller. Therefore, the anti-roll PI controller proves more suitable to drive the BLDC motor during load variation. In [35], fuzzy tuning in PID sliding mode is proposed for the BLDCM drive system. The PIDSMFC-based BLDC motor drive system tracks the error and causes the actual speed to follow the reference speed when the system is subject to a gradual change in the reference speed, sudden load disturbance and parameter changes. The comparison between BLDC motor speed control from PIDSMFC and SMFC, that PIDSMFC offers better performance than SMFC compared to external load disturbances, so the controller is a robust controller, vibrations are avoided and the system response against load from external impact.

In [36] Fractional Order PI Controller (FOPI) proposed for BLDC Motor Drive. It is done with the Oustaloup filter. The desired response obtained by adjusting in 1 / S ^ . The FOPI controller tested on the BLDC motor for various operating modes and performance compared to the conventional PI controller. The performance of the FOPI controller is quite good with constant speed and constant torque mode compared to the conventional PI controller. In [37] The fractional order fuzzy logic controller (FOFLC) proposed for the BLDC motor. Controller performance tested under different operating conditions and sudden load disturbance. The performance of the FOFLC controller compared to the FOPI controller and the conventional PI controller. Torque, speed response are faster and smoother than the FOPI and PI controllers in terms of rise time, maximum exceedance and stabilization time. In [38] a sliding mode controller (FOSMC) was proposed to improve the dynamic performance of a BLDC motor.

The FOSMC has a robustness against external load disturbances, so the controller is a robust controller, without vibrations in case of sudden load variations. In various operating modes constant torque mode, constant speed mode such as engine in running conditions, generation and reverse condition. In all these operating modes, the dynamic response of the BLDC motor observes dynamic parameters of rise time, peak overflow and BLDCM settling time. The engine is quite good with FOSMC compared to the PI controller. The performance of the BLDC motor with the FOSMC methodology provides a smooth and faster torque speed response than the normal PI controller. In [39] Fractional order based super torque algorithm (FOSTA) proposed for controlling the BLDC motor under various operating conditions. Simulations are performed in various operating modes and controller performance is tested on the BLDC dynamic motor model using matlab-simulink. FOSTA performances are compared with the normal PI controller. FOSTA has a good dynamic response compared to the PI controller.

BLDC Motor Mathematical Modelling

State space representation of BLDC motor is represented[40]

$$\dot{X}=AX+BX \quad (1)$$

$$X=[I_d I_q \ \ \omega \ \ \theta]^T$$

$$\frac{dI_a}{dt}=\frac{V_d}{L}-\frac{I_d}{\tau}+\omega I_q \quad (2)$$

$$\frac{dI_q}{dt}=\frac{V_q}{L}-\frac{I_q}{\tau}-\omega I_d-\frac{K_e}{L}\omega \quad (3)$$

$$\frac{d\omega}{dt}=\frac{PK_e}{J}I_q-\frac{f}{J}\omega-\frac{P}{J}T_L \quad (4)$$

$$\frac{d\theta}{dt}=\omega$$

The output equation is given by

$$Y=CX,\ Y=[I_d I_q]^T \quad (5)$$

$$\mathbf{C}=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{bmatrix}$$

V_d, V_q,I_d,$I_q$are voltages and currents on a (d,q) frame,

T_L=Load torque, ω- electrical angular velocity,

K_e=factor torque, L-inductance, R-resistance,

τ = Electric time constant.

$$\underline{v}=[\mathbf{R}]\underline{i}+[\mathrm{L}]\frac{di}{dt}+\underline{e} \quad (6)$$

Where R is the stator resistance per phase

$$\boldsymbol{R}=\begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}$$

L is the matrix of inductance interims of self and mutual inductance, L_s, M

$$\boldsymbol{L}=\begin{bmatrix} L_s & -M & -M \\ -M & L_s & -M \\ -M & 0 & L_s \end{bmatrix}$$

$\underline{e} = [e_a\, e_b\, e_c]^T$ is the vector of the trapezoidal back EMF

$$\frac{d}{dt}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} \frac{1}{L_T} & 0 & 0 \\ 0 & \frac{1}{L_T} & 0 \\ 0 & 0 & \frac{1}{L_T} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} - \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} - \begin{bmatrix} e_{an} \\ e_{bn} \\ e_{cn} \end{bmatrix} \quad (7)$$

$L_T = L_s + M$

The equation of motion is

$$J\frac{d\omega_r}{dt} = T_{em} - T_L - f\omega_r \quad (8)$$

$$T_{em} = \frac{1}{\omega_r}(e_{an} i_a + e_{bn} i_b + e_{cn} i_c), \quad (9)$$

ω_r-mechanical speed [rad/s], T_l– load torque [N m] , J - motor shaft and load inertias [kg m^2]

F –frictional damping coefficient [N m s/rad m],

T_{em} - electromagnetic torque [N].

CONCLUSION

The Performance review of different control strategies for BLDC Motor are conventional controllers(PIC,PIDC), intelligent controllers are (FLC, ANN, FLCANN, HybridFuzzy, NF, VHDL, FPGA, NSGA-II, ZNM, BELBIC) and robust controllers are sliding mode controller as(PIDSMC,FPIDSMC,SMFLC,SMO,ISMO,CSMO) and finally Fractional order controllers are (FOPI, FOFLC, FOSMC, FOSTA) based control scheme is presented in this paper. During the study it was observed that, although fractional order controller displayed improvement in dynamic performance of BLDC motor operating parameters but still it could not establish its superiority indisputably in terms of steady state performance of the system. Various different control scheme were also combined with FOPI controller, FOFL Controller, FOSM Controller and FOSTA to further improve upon its limitation.

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