Journal of Science, Computing and Engineering Research (JSCER)
Volume-7, Issue-11, November 2024.
DOI: *https://doi.org/10.46379/jscer.2023.071102*

Performance Measures of Speed Control for a DC Motor using LCMQR Controller Identification

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Article Information

Received	:	02 Nov 2024
Revised	:	06 Nov 2024
Accepted	:	10 Nov 2024
Published	:	14 Nov 2024

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Abstract— This paper contains, performance of fuzzy controllers which evaluated and compared. It also describes the speed control based on Linear Quadratic Regulator (LQR) technique. The comparison is based on their ability of controlling the speed of DC motor, which merely focuses on performance of the controllers, and also time domain specifications such as rise time, settling time and peak overshoot. The controller is designed using MATLAB software, the results shows that the fuzzy controllers are the good but it as higher overshoot in comparison with optimal LQR. Thus, the comparative study recommends LQR controller gives better performance than the other controllers.

Keywords: ***Fuzzy controllers, LQR, Performance index, Motor control, Performance specifications, servo control, Regulator control***

Citation: Pawan Kumar, Shefali Kanwar, "Performance Measures of Speed Control for a DC Motor using LCMQR Controller Identification", Journal of Science, Computing and Engineering Research, 7(11), November 2024.

I. INTRODUCTION

In control engineering, motor control plays a major role and is an unavoidable part, regardless of whether it is speed or position control. The effectiveness of a controller can be justified by performance objectives such as settling time, rise time, peak overshoot. Fuzzy control theory usually provides nonlinear controllers that are capable of performing different complex nonlinear control actions [1]. Due to the excellent speed control characteristics of a DC motor, it has been widely used in industry (such as cars, locomotives etc.) even though its maintenance costs are higher than the induction motor. As a result, authors have paid attention to position control of DC motor and prepared several methods to control speed of such motors. Proportional–Integral-Derivative (PID) controllers have been widely used for speed and position control [2]. A particle swarm optimization (PSO) instead of (GA).They presented a PID controller based on (PSO) method of tuning controller parameters. They modeled their PID-PSO controller in MATLAB environment and compare the results with fuzzy logic controller (FLC) using PSO. They found that PID-PSO controller gives better performance and minimal rise time than FLC-PSO controller [3] [6], presented a novel optimal PID controller using (LQR) methodology in tuning the parameters of PID controller. The new PID controller is applied to control the speed of brushless DC motor (BLDC). Finally, the computer simulation and experimental results showed that the proposed controller gives better performance than the traditional controller [7], presented and compared two types of controllers which are PID controller and optimal controller. The PID compensator is designed using (GA), while the other compensator is made optimal and integral state feedback controller with Kalman filter. Computer simulations have been carried out. Finally they found that the second controller gives less settling, less overshoot and better performance encountering with noise and disturbance parameters variations. [8], presented a novel PID dual loop controller for a solar photovoltaic (PV) powered industrial permanent magnet DC (PMDC) motor drive. MATLAB/SIMULINK was used in the analysis for the GUI environment[9], introduced the optimal strategies for speed control of permanent magnet synchronous motor (PMSM) through the linear quadratic regulator (LQR) and linear quadratic Gaussian (LQG) methodologies. In this paper the fuzzy control schemes are used to perform a comparative study with LQR. The candidate controller is fuzzy PID controllers. The detailed derivation of these fuzzy controllers is referred to [10]-[11].

II. RELATED WORKS DC MOTOR

Direct current (DC) motors have been widely used in many industrial applications such as electric vehicles, steel rolling mills, electric cranes, and robotic manipulators due to precise, wide, simple and continuous control characteristics. The development of high performance motor drives is very important in industrial as well as other purpose applications. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response. DC drives, because of their simplicity, ease of application, reliability and favorable cost have long been a backbone of industrial applications.

DC drives are less complex with a single power conversion from AC to DC. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition of use as adjustable speed machines and a wide range of options

have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. The speed control stands for intentional change of the drive speed to a value required for performing the specific work process. Speed control is either done manually by the operator or by means of some automatic control device .The expression of speed Control dc motor is given as, □ □$=V-IaRa\ k\varphi$ …… (1) This Equation show that the speed is dep

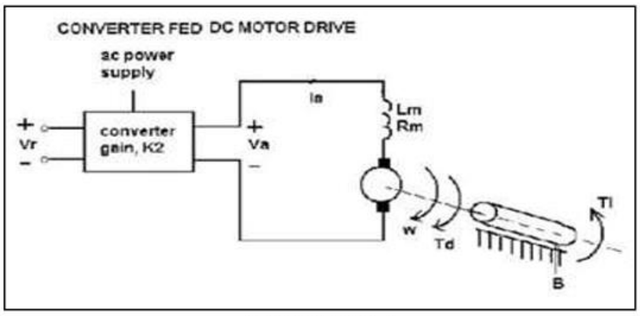

Fig. 1: DC Motor

III. STUDY MATHEMATICAL MODELING OF DC SHUNT MOTOR

We consider a DC shunt motors. In DC shunt motors the field coil in parallel (shunt) with the armature. The current in the field coil and the armature a independent of one another. As a result, these motors have excellent position control. Hence DC shunt motors are typically used applications that require five or more horse power. The equations describing the dynamic behavior of the DC motor are given by the following equations

$$\frac{d\,i_a}{dt} = -\frac{R_a}{L_a} i_a - \frac{K_b}{L_a}\dot{\theta} + \frac{Va}{L_a} \tag{2}$$

$$\frac{d\theta}{dt} = \frac{K_T}{J} i_a - \frac{Bm}{J}\dot{\theta} \tag{3}$$

Assuming the above equations, the steady state representation can be obtained as,

$$\begin{bmatrix} \frac{di_a}{dt} \\ \frac{d\theta}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R_a}{L_a} & \frac{-K_b}{L_a} \\ \frac{K_T}{J} & \frac{-Bm}{J} \end{bmatrix} \begin{bmatrix} i_a \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{1}{L_a} \\ 0 \end{bmatrix} [V_a] \tag{4}$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ \dot{\theta} \end{bmatrix} \tag{5}$$

The transfer function of the motor using the state space model by formula

$$G(s) = C\,(s\,I - A)^{-1}\,B$$

From equation (2) and (3) we can obtain equation (6)

$$\frac{\dot{\theta}\,(s)}{v(s)} = \frac{K_m}{(L_m S+R_m)(JS+b)+K_m^2} \tag{6}$$

The overall transfer functions of the system.

The circuit diagram of the single tail comparator shown in Fig 3. The single tail comparator circuit operation is given below. When CLK=0 the circuit works in reset phase so the Mtail NMOS transistor is in off position and the reset transistors M7 and M8 PMOS transistors are in on position now the output at OUTN and OUTP will be VDD. When CLK= VDD , Mtail NMOS transistor is in ON position and M7 and M8 PMOS transistors are in OFF position now the OUTN and OUTP urrent to keep the differential amplifiers in weak condition so a large current required enabling fast regeneration in the circuit.

IV. FUZZY LOGIC CONTROLLER

Fuzzy logic began with the 1965 proposal of fuzzy set theory by Lotfi Al Zadeh. It has been applied to many fields, from control theory to artificial intelligence. Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. Fuzzy logic control technology has been widely and successfully utilized in industrial applications. Fuzzy Logic is a multi-valued logic, that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low and emerged as a tool to deal with uncertain, imprecise, or qualitative decision making problems. Fuzzy logic is a way to make machines more intelligent to reason in a fuzzy manner like humans. A fuzzy logic model is a logical-mathematical procedure based on an “IF-THEN” rule system that mimics the human way if thinking in computational form. Generally, a fuzzy rule system has four modules. The establishment of fuzzy logic is based on the simulation of people's perception and opinions to control any required system. One of the methods to make simpler complex systems is to accept to uncertainty, vagueness, and precision up to some extent. FC (fuzzy control) is provides a actually simple way to draw specific conclusions from vague ambiguous or imprecise information. FL is suitable for applications like the speed control of dc motor which has non-linear characteristics. A FLC system is a system in which a analyzes the mathematical system that analog input

values in terms of logical variables that obtain on constant values between 1 and 0, in contrast to classical or digital logic, which operates on discrete values of either 0 or 1 (false or true, respectively). FLC provides simple way to appear at a definite conclusion based upon ambiguous, noisy, vague, or missing input information. Fuzzy logic’s come close to to control problems mimics how a person makes decisions, much faster. Function of fuzziness is connected with the degree to which events arise rather than possibility of their occurrence. FL (Fuzzy Logic) has some advantages compared to other controller like: low cost and the possibility to design without knowing the precise mathematical model of the process. Fuzzy Logic (FL) incorporates another way of thinking which allows complex design systems using superior level of abstraction originating from the knowledge and experience. The general structure of fuzzy logic controller is given in Fig 2.

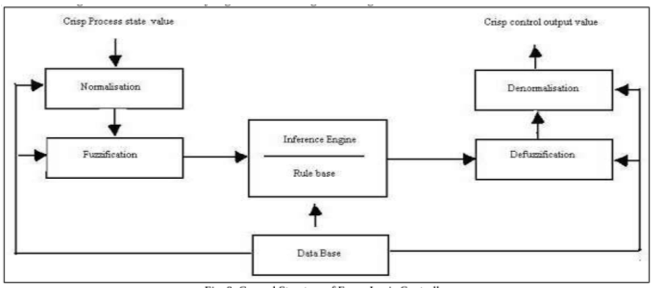

Fig. 2: General Structure of Fuzzy Logic Controller

Fuzzy Logic Toolbox There are five primary graphical user interface (GUI) tools for building, editing and observing fuzzy inference systems in the toolbox. Types of Fuzzy logic toolbox – Fuzzy Inference System (FIS) editor – Membership Function editor – Rule Editor – Rule Viewer – Surface Viewer

This structure has the power consumption 20.49 nW and circuit delay is 38.83 ps. Circuit diagram of the conventional double tail comparator shown in Fig 4. This structure has low static power consumption and operates at lower supply voltages compare to the single tail comparator. The working of this comparator is given below.

When CLK=0 the to discharge with different charging rates. Due to these

V. DESIGN OF THE LQR CONTROLLER

Linear quadratic regulator design technique is well known in modern optimal control theory and has been widely used in many applications. The standard theory of the optimal control is presented in [17]-[20]. Under the assumption that all state variables are available for feedback, the LQR controller design method starts with a defined set of states which are to be controlled. In general, the system model can be written in state space equation as follows: □ □$=Ax+Bu$ (7) Where $x \in Rn$ and $u \in Rm$ denote the state variable, and control input vector, respectively. A is the state matrix of order nxn; B is the control matrix of order nxm. Also, the pair (A, B) is assumed to be such that the system is controllable. The linear quadratic regulator controller design is a method of reducing the performance index to a minimize value. The minimization of it is just the means to the end of achieving acceptable performance of the system. For the design of a linear quadratic regulator controller, the performance index (J) is given by: □ □ = ∫ (∞ 0 □ □$TQx+uTRu)dt$ (8) Where Q is symmetric positive semidefinite (≥0) state weighting matrix of order nXn, and R is symmetric positive definite (> 0) control weighting matrix of order mXm. The choice of the element Q and R allows the relative weighting of individual state variables and individual control inputs as well as relative weighting state vector and control vector against each other. The weighting matrices Q and R are important components of an LQR optimization process. The compositions of Q and R elements have great influences of system performance. The designer is free to choose the matrices Q and R, but the selection of matrices Q and R is normally based on an iterative procedure using experience and physical understanding of the problems involved.

Commonly, a trial and error method has been used to construct the matrices Q and R elements. This method is very simple and very familiar in linear quadratic regulator application. However, it takes long time to choose the best values for matrices Q and R. The number of matrices Q and R elements are dependent on the number of state variable (n) and the number of input variable (m), respectively. The diagonal-off elements of these matrices are zero for simplicity. If diagonal matrices are selected, the quadratic performance index is simply a weighted integral of the squared error of the states and inputs. The term in the brackets in equation (7) above are called quadratic forms and are quite common in matrix algebra. Also, the performance index will always be a scalar quantity, whatever the size of Q and R matrices. The conventional linear quadratic regulator problem is to find the optimal control input law u that minimizes the performance index under the constraints of Q and R matrices. The closed loop optimal control law is defined as: u= - Kx (9) Where K is the optimal feedback gain matrix, and determines the proper placement of closed loop poles to minimize the performance index. The feedback gain matrix K depends on the matrices A, B, Q, and R. There are two main equations which have to be calculated to achieve the feedback gain matrix K. Where P is a symmetric and positive definite matrix obtained by solution of the ARE is defined as: □ □$TP+PA-PBR-1BTP+Q$ =0 Then the feedback gain matrix K is given By □ □ $=R-1BT$ Substituting the above equation (11) into equation (7) gives: □ □$=Ax-BKx=(A-BK)x$ (10) (11) (12) If the eigen values of the matrix (A-BK) have negative real parts, such a positive definite solution P always exits. Linear quadratic regulator design technique is well known in modern optimal control theory and has been widely used in many applications. LQR control that designed is classified as optimal control systems. This is an important function of control engineering. It has a very nice robustness property. This attractive property appeals to the practicing engineers. Thus, the linear quadratic regulator theory has received considerable attention since 1950s. LQR is a method in modern control theory that used state-space approach to analyses such a system. Using state space methods it is relatively simple to work with Multi- Input Multi-Output (MIMO) system. Linear- Quadratic Regulator (LQR) optimal control problems have been widely investigated in the literature. The performance measure is a quadratic function composed of state vector and control input.. If the linear time invariant system is controllable, the optimal control law will be obtained via solving the algebraic Ricci equation optimal control. The function of Linear Quadratic

Regulator (LQR) is to minimize the deviation of the speed of the motor. The speed of the motor is specifying that will be the input voltage of the motor and the output will be compare with the input. VI. RESULT AND DISCUSSION Analysis of Result of dc motor, the performance of linear quadratic regulator controller has been investigated and compared with the fuzzy logic controller. The parameters of dc motor show in table 1. Table – 1 Parameter of DC Motor Parameter Armature Resistance Ra Value Armature Inductance 11.2 Ω Rotor Inertia Im 0.1215 H 0.02215 kgm Viscous friction coefficient Bm 0.002953 Nms/rad Torque Constant Kt Back Emf Constant Kb 1.28Nm/A 1.28 Vs/rad The control objective is to keep the various performance specifications such as rise time tr, settling time ts, maximum overshoot Mp within desirable limits. Fig 3 shows the response of LQR controller for a DC motor whose parameters are given in table 1.The optimal LQR controller controlled response of the system has considerably reduced settling time and reduced overshoot values than fuzzy logic controller.

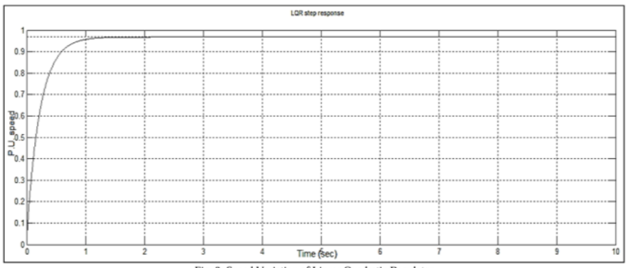

Fig. 3: Speed Variation of Linear Quadratic Regulator

Table – 2

Comparison of results of LQR controller and fuzzy logic controller is shown in table 2

Controller / *Time characteristics (sec)*	*Fuzzy Logic Controller*	*LQR*
Rise time	*0.7600*	*0.498*
Settling time	*2.6200*	*0.881*
Overshoot	*0.008264%*	*0%*

All the circuits are designed by using Cadence Virtuoso tool and simulated in 90 nm CMOS technology with the supply voltage of 0.6V. The output waveform of comparator shown in Fig 8. Power waveform of the single tail comparator is shown in Fig 9.

VI. CONCLUSION

DC separately excited motor the optimization of speed control and comparison between the speed control of the separately excited DC motor by linear quadratic regulator technique and fuzzy logic controller. It clearly shows that the linear quadratic regulator technique gives better performances than fuzzy logic controller against parameter variations. The results so obtained show that the Tuning controller LQR controller gives better result. We observe overshoot and settling time and rise time and final value are improved in proposed controller of LQR. The separately excited DC motor with a rapid settling time, no overshoot, and zero steady state error. The fuzzy controllers for DC motor speed controller have been designed using MATLAB software. When applied fuzzy controller, the system performance has been improved. It concluded that when compared fuzzy controller with the LQR controller, LQR controller has better performance in both transient and steady state response, it also has better dynamic response curve, shorter response time, small steady state error (SSE) and high precision compare to the fuzzy logic controller.

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