Study on Application of AI controllers for speed control of motors

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***Abstract*—Building high-performance motor drives is vital for industrial uses. A high-performance motor drive system must be quick in terms of dynamic speed order monitoring and load regulating. The motor controllers can provide system protection by regulating or limiting torque, protecting against overloads, and safeguarding against mistakes. Many motor controllers include logic for managing applications as well as additional features like data recording and data collecting. The purpose is to study various tuning techniques for motor speed controllers using Artificial intelligence. The controllers such as proportional integral (PI) controller and proportional integral derivative (PID) controller have been considered here. Most frequently used Artificial intelligence (AI) methods such as Artificial Neural Networks (ANN), Fuzzy logic controller (FLC), Genetic Algorithm (GA), Bat Algorithm, Adaptive Tabu Search (ATS), Ant Colony Optimization (ACO), Ziegler and Nichols (ZN) Algorithm are considered by their decision-making capability. In the proposed work the rigorous literature review is done for analyzing the performance of AI based controllers. This will help other researchers to understand various aspects of the said controllers, particularly technology involved. In depth review and application of AI controllers are highlighted using various charts and graphs for easy understanding.**

Keywords*—AI motor controllers, Fuzzy Logic, PID controller, PI controller, Genetic algorithm, PSO algorithm, Ziegler and Nichols algorithm, Bat algorithm, Adaptive Tabu search algorithm.

I. INTRODUCTION

In our day today activities, we use electrical motor in the various machines, appliances, electric vehicles, large scale industries, medical sector, electric traction, robotics, air-crafts, military equipment, hard disk drive, etc. To get the efficient output from the motor shaft, the speed regulation of the motor must be reliable and robust at various conditions. For speed control of the motors Lately, numerous contemporary management methods have been put forth to regulate the motor's speed. The traditional PID controller, has a straightforward algorithm, that is simple to modify, operates steadily, and is more reliable. The majority of time, conventional PI and PID controllers are used to regulate motor speed. [1,2]. However, the majority of commercial processes use nonlinearities, parameter variations, and unsettled parameters. Due to the difficulty of tuning traditional controllers values under these circumstances, the total system's robustness is reduced.[3]. The effectiveness of the motor is diminishing in the case of the traditional PI controller as a result of rollover. Due to the saturation effect, rollover is an issue that occurs in traditional PI controllers. Saturation occurs when the processor receives steady input or when there is a significant amount of erroneous input.[4]. Therefore, for the entire system to operate reliably, an advanced control algorithm is required to regulate the motors' speed. These intelligent techniques, however, are more complicated and challenging to execute. [5].

To identify the most applied AI technique for speed control of the motor 40 research papers are studied related to application of AI controllers. Due to straightforward structure, conventional motor controllers or deterministic motor control techniques like PID (Proportional Integral Derivative) controllers are still extensively used. However, in order to use the previously stated controller to its full potential, the system's controller parameters must be precise and accurate (such as tuned Proportional, Integral, Derivative values, back electromotive force constant, armature and field coil impedance and inductance etc.) [6]. Additionally, the reason why traditional controllers, like the PI controller, have limited capability is because their overshoot from the set point is too high. Additionally, sudden changes in load torque and their sensitivity to controller gains Ki and Kp can cause delays in obtaining constant and weak responses. [7]. For the majority of complicated nonlinear systems with indeterminate mathematical analysis, appropriate control strategies can be developed by applying artificial intelligence methods. Smart controllers are preferred because they can be created for any mechanism without the need for a quantitative model, increasing the controller's effectiveness and dependability [8]. Controlling the speed of the motor as per the load requirements is quite a difficult task, but with the use of the right motor controller, getting desired speed requirements becomes easy.

The paper is ordered as following; types of conventional motor controllers in section II. The artificial intelligent controllers are described in section III. The observation and discussion of the study are presented in section IV. Finally, the summary is given in section V.

II. TYPES OF CONTROLLERS

A. Proportional Integral Controller:

The PI controller is currently widely used in commercial applications due to its simple setup, straightforward presentation, and affordable price. The block layout for a proportional-integral (PI) control system is shown in Fig. 1.

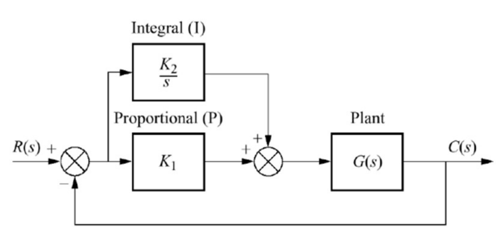

Fig. 1. Block diagram of Proportional Integral controller[7]

The PI controller receives the speed error EN between the motor's real speed N and the standard speed NR, and its proportionate end integral gains are K1 and K2 [9].

$$T = Kp\ e(t) + Ki \int e(t)\ dt \quad (1)$$

By using the gain Kp, the Proportional controller generates an output that is proportionate to the present error value. When the regulated system is highly complex and unpredictable, the PI controller fails. Integral action must be done in order to maintain the system's functioning. By using proportional action and delayed reaction, this integral mode is used to build steady state defect [9-10]. Almost any operation that could imagine has been controlled by PI-controllers, from aircraft to mobility management, from sluggish to rapid systems [10-11].

B. *Proportional Integral Derivative Controller:*

PID controllers are employed in a variety of commercial environments. PID controllers are used in closed loop functions in about 95% of the field. Proportional- Integral-Derivative, or PID, is a term. The combination of these three functions results in the production of a control signal [12]. To prevent overshoot and oscillations in the system's output response, the derivative gain component is additionally added to the PI controller within the PID controller. The result is formed by adding three terms—proportional, integral, and derivative terms. The controller provides high stability, no oscillations, quick response times, and 0% steady errors [13,14]. The following equation indicates the basic structure of a PID Control system:

$$y(t)=k_p\, e(t)+k_i \int e(t)+ k_d\frac{de(t)}{dt} \quad (2)$$

In which u(t) is the control variable, Kp is the proportionate gain, Ki is the integral gain, and Kd is the derivative gain, e(t) is the program error (change in between standard input and the process output) [14]. Although k_p , or the proportional constant, accounts for the error's current value, k_d or the derivative constant, accounts for the error's future value by taking into account its present rate of change. As an integral constant, k_i accounts for the error's past value [15-16]. Fig 2 shows the block diagram of the proportional integral derivative controller.

1) Proportional part: If a deviation is generated, the supervisor will attempt to decrease it using a proportionality link that reflects the deviation signal.
2) Integral component: primarily used to reduce static mistake and increase system reliability.
3) Differential part: can show the deviance signal's change tendency (change rate) and initiate a better preventive adjustment signal before the value of the deviation signal becomes excessive, accelerating system operation and cutting down on modifying time [17].

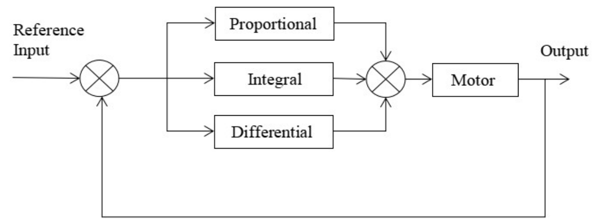

Fig. 2. Block diagram of PID controller [15]

III. ARTIFICIAL INTELLIGENT CONTROL TECHNIQUES

A. *Artificial Neural Network:*

In a traditional system, an ANN replaces a PI or PID control system. This can be used to export the motor's power, flux, or flux inclination at any moment in the past time or present time [18,19]. Here, the benefits of AI are quickly addressed. Examples include ANNs and fuzzy neural networks. An observed multi-stacked stream forward ANN can be trained using back-propagation (BPA) instruction to estimate the rotor location and rotor inclination. The square of the variance between the expected and real ANN output is reduced by using the back propogation. The real-time programs can make use of the trained ANN [20,21]. An ANN of this type includes concealed levels, an input, and an output. Though it should be noted as a rule that in electronic real apps, the depiction of concealed levels to be used is not recorded in preparation; this must be settled by experimentation. Additionally, the number of concealed elements in the hidden levels is also unknown beforehand and must once again be determined through experimentation and trial and error. The maestro levels for neural networks are shown in Figure 2 [22].

B. *Genetic Algorithm:*

GA is a technique of random worldwide responsive search algorithm. that is based on the workings of natural selection. In comparison to other optimization approaches, GA has recently come to be acknowledged as an effective and efficient tool for solving optimization issues [23]. Each chromosome in the initial population of the GA represents a different solution to the issue, and a optimization algorithm evaluates its effectiveness. GA's three main stages are evolution, crossing, and classification. These three basic techniques allow for the growth of new individuals who may surpass their forebears. After many iterations, the programme stops when it encounters the characters who best reflect the solution to the issue [24,25]. These more recent characters fare better than their forebears. Each chromosome in the initial population of the GA represents a different solution to the issue. It's employed to enhance the general efficiency of the system as well as other parameters like overshoot, rise time, and settling time. The choice of the goal feature (fitness) constitutes the most important stage [26,27]. Figure 3 displays the Genetic Algorithm Architecture.

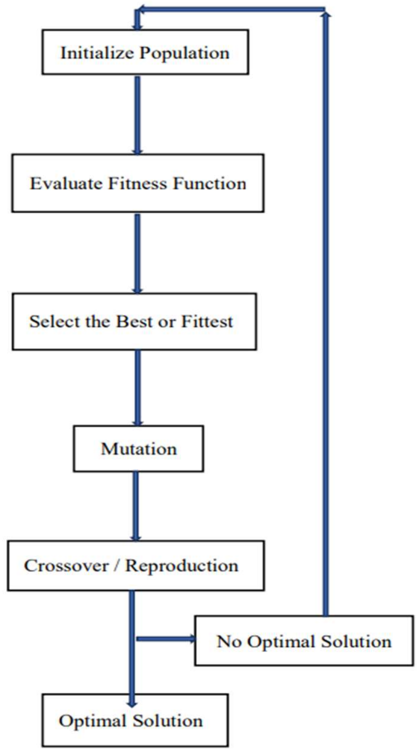

Fig. 3. Genetic Algorithm Flowchart[27]

C. Fuzzy Logic Controller:

The block diagram of the dc motor control system with a basic FLC is shown in Fig. 4. The basic FLC consists of the following four blocks:

- This fuzzy logic generator transforms the incoming data (error and error rate) into appropriate language values.
- The rationale employed in decision-making to choose the best course of action for control.
- The rationale employed in decision-making to choose the best course of action for control.
- Defuzzifier that generates an inferred fuzzy control action's membership function as a non-fuzzy control action [28,29].

Using the Center-of-gravity approach, defuzzification is carried out, and the inferred (numerical) value of the

$$u = \frac{\sum mi\, Ti}{\sum Ti}$$

where Ti is the corresponding degree of fulfilment and mi are the singletons.The regulated voltage supply, which transforms the incoming signal into an equal voltage to control the motor speed, is fed its output from the Fuzzy controller as its input [30,31]. The action of the flexible system frequency reaction is first studied to make it easier to incorporate knowledge and expertise into fuzzy control algorithms [32].

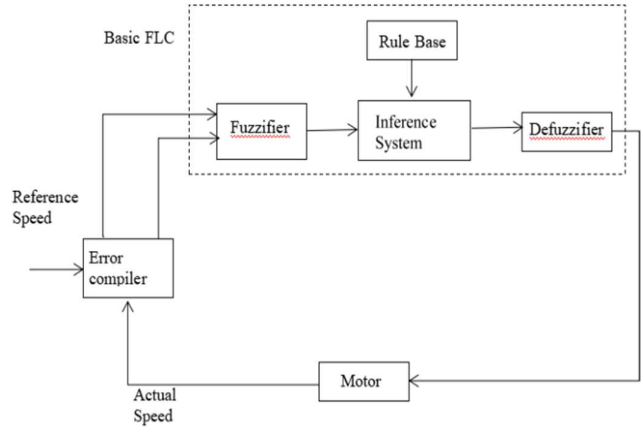

Fig. 4. Basic Function of Fuzzy Logic Controller [32]

D. Ziegler Nichols Method:

There are many approaches to adjust a PID and PI cycle. The most efficient techniques typically involve the creation of some type of system design, then P, I, and D are chosen according to the features of the dynamical system. especially if the circuits' response times are several minutes or greater, manual tuning techniques may not be adequate [33]. Ziegler and Nichols provided the finest PID controller tuning approach, which is now regarded as industry standard procedure in the field of control systems. Both methods make previous assertions about the system model, but they don't demand that these models be known in particular. Plant step reactions serve as the foundation for the Ziegler-Nichols equations used to define the controllers [34]. Tuning a controller means adjusting the gain setting to the correct amount. Any system's efficiency can be increased with the correct controller setting. If the gain settings of a controller are set at an incorrect number, the control signal deteriorates and becomes unreliable. As a result, appropriate controller tuning is required to obtain the intended result [34].

E. Adaptive Tabu Search:

The updated form of the Tabu Search is called the adaptive tabu search, or ATS. The ATS was introduced in 2004 and is based on an iterative neighbourhood search strategy. The ATS search process starts with a few early answers that are randomly selected and fall into a neighbourhood search space. Every answer in the local search area will be assessed using the objective function [35]. The answer providing the lowest goal cost is retained in the tabu list and set as the new starting point of the following search round (TL). The process flow of ATS is shown in Fig. 5.

The basis of ATS is a live neighbourhood search methodology for nonlinear and complex issues. The adjustable radius (AR) and backtracking are ATS methods (BT). AR technique is heavily used in the ATS search process to hasten it. The BT device can also be used to get out from under nearby obstacles [36,37]. One crucial component of this technique is the Tabu collection, which is used to keep track of resolution behavior and take a different course that can avoid a minimum error hazard. The ATS technique also includes two extra methods to improve convergence: retracing and responsive search range.

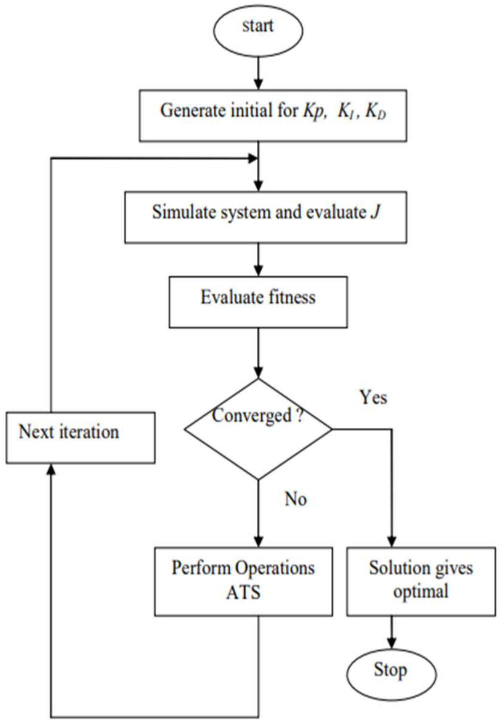

Fig. 5. Flowchart of Adaptive Tabu Search [37]

F. Bat Algorithm :

The echolocation technique used by bats is known as the bat algorithm. These bats use echolocation to produce a very high sound pulse and pay attention to the echo that is reflected back from nearby items. Species differences affect the transmission band-width of these organisms. Frequency, volume, and pulse release rate are all components of each sound pulse [38]. While the remainder use fixed-frequency signals, the majority of bats use signals with adjusting frequencies. These animals operate in the 25 kHz to 150 kHz frequency band. The following factors form the basis of the bat algorithm: echolocation, which all bats use, and the ability to tell a target from an obstacle. Bats travel at arbitrary speeds, in random places, and with varying frequencies, decibel levels, and pulse emission rates [39-44].

G. Ant Colony Optimization :

The theory behind Ant Colony Optimization is that ants can locate the quickest route from their home to a food location. In 1992, Marco Dorigo created the very first Ant Colony Optimization device. Both the cubic distribution issue and the roaming marketer challenge were addressed using ACO. Due to their innovative idea, ant strategies have received extensive study over the recent few years, and their uses have been expanded to include inflation issues, network invasion, information extraction, etc [40]. ACO has several benefits over other optimization methods, including appropriated computation, a positive responses mechanism, optimistic scanning, and improved extensibility. Its drawbacks include a bottleneck and a lengthy scanning duration. However, the symmetry can somewhat compensate for these drawbacks [45-49].

IV. Discussion

From the study of the mentioned AI controllers it is observed that all the Artificial controllers are robust and perform with high accuracy for the speed control of the motors. The AI control techniques and their hybridization with conventional controllers and the application for different motors are mentioned in the TABLE I.

TABLE I. APPLICATION OF AI CONTROLLERS FOR SPEED CONTROL

Sr. No.	Name of the Technique	PID	PI	AC motor	DC motor
1	Genetic Algorithm	4	2	2	5
2	Particle swarm optimization	3	0	0	3
3	Adaptive Tabu Search	2	0	0	3
4	Ziegler and Nichols	3	2	0	4
5	Bat Algorithm	1	1	0	2
6	Ant Colony Algorithm	2	0	0	3
7	Artificial Neural Network	2	1	4	3
8	Fuzzy Logic	5	8	7	10

A. AI Application on PID Controller:

The application of AI techniques for controlling speed of the motors have shown in the pie charts and bar graph below. From the pie chart Fig 6, it is observed that, most of the research has been done on the Fuzzy Logic PID Controller and Artificial neural network controller. Implementation on these AI techniques is much easier than the rest of the mentioned AI techniques.

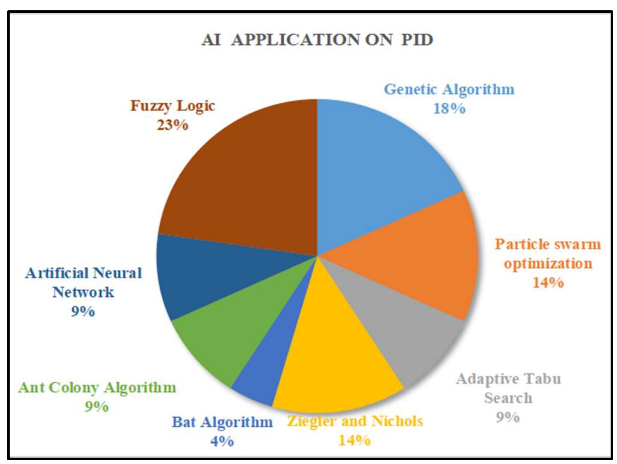

Fig. 6. AI applications on PID controller

Due to which more research is done on the Fuzzy logic PID controller and Artificial neural network PID controller.

The new hybrid AI methodologies are compared with conventional Ziegler & Nichols tuning method. And by the comparison table it is shown that new hybrid AI techniques are much efficient and widely used in speed control of motor application.

B. *AI Application on PI Controller:*

By studying research on various AI techniques, it is observed that, most of the research has been done on the Fuzzy Logic PI Controller and genetic algorithm based controller. Implementation of these AI techniques is much easier than the rest of the mentioned AI techniques. Due to which more research is done on the Fuzzy logic and Artificial neural network techniques. The new hybrid AI methodologies are compared with conventional PI controller. And by the comparison, it is shown that new hybrid AI techniques are much efficient and results zero steady state error. The AI techniques like Firefly Algorithm, Bat Algorithm, Ant colony Algorithm are used less because of their complex structure as well as complication in implementation. Tuning of PI controller by these AI techniques is not as simple as PID controller because of the output parameters. Therefore there are less papers available on Bat algorithm, Firefly and Ant colony algorithm. The application of AI techniques and research papers availability is shown by the pie chart diagram in Fig. 7.

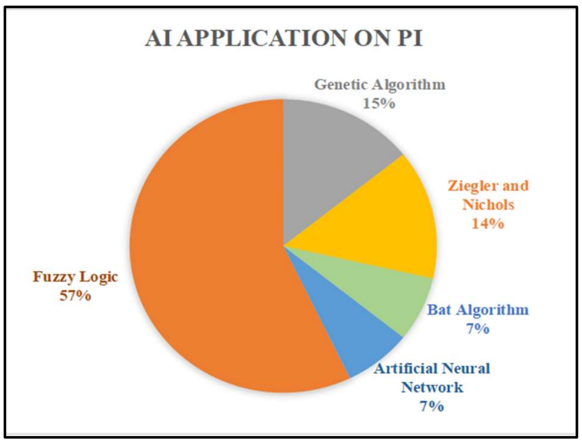

Fig. 7. AI applications on PI controller

All the AI methodologies are applicable on different motors as shown in Fig. 8. The bar chart shows that mainly most of the research of AI speed control techniques are done on the DC motors because of its robustness and ease of implementation. The AI methodologies discussed are mostly applied on the DC motors. The use of DC motors is much wider in various small day today applications. The use of AC motors is mainly applicable for industries and heavy duty operations. Therefore, the speed control methodologies are mostly experimented on DC motors.

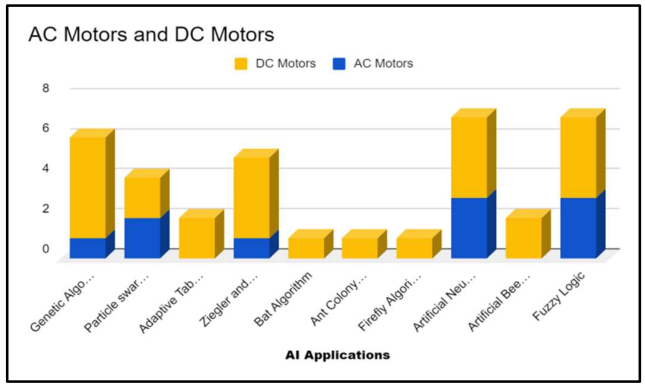

Fig. 8. AI applications on AC Motors and DC Motors

In TABLE II. letter 'Y' indicates consideration of that particular methodology.

On the basis of study of the research papers available on AI techniques for speed control of motors. The research done is classified by the year of research published with the author's name and on which specific AI technique the experiment is done with particular motor used for experiment is mentioned. As per the information gathered in the table, it is observed that the research done on Fuzzy logic and genetic algorithm on DC motor is more than the research done on rest of the AI techniques and on AC motors. In case of the research on tuning method for PID controllers, the most conventional Ziegler & Nichols technique is utilized for the comparison purpose. All other AI techniques results significant rather than the conventional control technique. In some of the researches AI tuning techniques are directly applied on the motor input parameters.

TABLE II. APPLICATION OF AI TECHNIQUES ON MOTOR CONTROLLERS FOR SPEED CONTROL

Public-ation year	*Author*	*AI Control Techniques*								*Controllers*		*Motors*	
		GA	*PSO*	*ATS*	*ZN*	*Bat Algorithm*	*ACA*	*ANN*	*Fuzzy Logic*	*PID*	*PI*	*AC motor*	*DC motor*
2009	Yang. Yi							Y				Y	
2009	K. Ang, G. Chong									Y			Y
2010	Changliang Xia						Y		Y				Y
2010	Atef Saleh Othman									Y			Y
2010	Adel A. A. El-Gammal		Y							Y			Y
2011	Hassan. M. Kamel								Y		Y	Y	
2011	Mohanasundaram K.								Y		Y	Y	
2012	E. Daryabeigi									Y			Y
2012	J. L. F. Daya								Y		Y	Y	
2012	Tan Chee Siong								Y		Y		Y
2013	Rohit G. Kanojiya				Y					Y	Y		Y
2013	H. Aloui								Y			Y	
2013	Walaa M. Elsrogy							Y	Y	Y			Y

2013	Yogesh Mohan								Y		Y		Y
2014	Dhivya.N.M							Y				Y	
2014	S. Mishra							Y			Y	Y	
2014	Amir Ahmed	Y							Y				Y
2014	Ch. Bhanu Prakash	Y								Y			Y
2015	Pranoti K. Khanke								Y		Y		Y
2015	Olivier Munyaneza								Y	Y			
2015	K. Premkumar		Y			Y			Y	Y			Y
2016	Sajid Ali Bhatti				Y						Y		Y
2016	Essamudin A. Ebrahim						Y			Y			Y
2017	Sushma J Patil								Y		Y	Y	
2017	Ansar Rizal							Y					Y
2017	Meena D. K.	Y			Y					Y			Y
2017	Yasser Ali Almatheel								Y	Y			Y
2017	P. Suganthi								Y	Y			Y
2017	Thanet Ketthong			Y						Y			Y
2018	Abasin Ulasyar									Y			Y
2018	S.Sakunthala							Y	Y			Y	
2018	Gamze Demir	Y									Y	Y	
2019	Archana Mamadapur							Y		Y			Y
2019	Vishal Verma									Y	Y		Y
2019	Era Purwanto	Y										Y	
2019	Amer Mohammad Jarjees			Y					Y				Y
2019	Manoon Boonpramuk1	Y		Y	Y					Y			Y
2020	S. Balamurugan									Y			Y
2020	Kiran Gadekar									Y	Y		Y
2020	Paliwal D.					Y					Y		Y
2022	Sandeep Yadav	Y	Y				Y			Y			Y

CONCLUSION

In this study, research papers on 'AI techniques for speed control of the motors' are considered for the identification of robust and easily applicable methodology for speed control of the motors. On the basis of the study we can say that, most applied AI techniques for the speed control of the motors are fuzzy logic and Genetic Algorithm. From the all studied research papers, for PID controller there are 23 percent papers available on fuzzy logic and 18 percent on genetic algorithm. Which are major among all the AI techniques. For PI controller, 57 and 15 percent papers are available on fuzzy logic and genetic algorithm respectively. The aforementioned AI techniques are mostly applied on the PID controller than the PI controller. As well as the implementation is mainly done on the DC motors rather than the AC motors. In future, more combinations of these AI techniques can be used to control speed of the motors in much efficient way.

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