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Article

Robust Control of SEDCM by Fuzzy-PSO

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Abstract: Industries have many rotational operations that are used for design, transport, lift, drilling, rolling, robotics, and many other applications. These rotating applications require a proper controller for accurate control of the operation. Separately excited DC motors (SEDCMs) are versatile and have various industrial operations because of their specific speed control characteristics. So, for smooth and accurate operation of an SEDC motor, controllers should be used. PI and PID controllers are used in many cases, but they are ineffective for nonlinear load operation. A fuzzy controller is a heuristic controller and can provide automatic control of the operation. Its operation depends on the selection of the correct membership values. This work proposes a novel particle swarm optimization (PSO) technique that would provide the optimum value of the membership for fuzzy controllers for optimum control of the industrial processes. To obtain SEDC results, MATLAB simulation was performed, and the fuzzy controller with novel PSO was implemented. A fuzzy PSO controller used for motor speed control operation obtains a rise time of 0.00026 s, settling time of 0.000214 s, maximum overshoot of zero, and delay time of 0.016 s, which are the best values when compared to PID and PID-Fuzzy controllers. It is observed that the results obtained from the separately excited DC motor using a fuzzy PSO controller improve the dynamic behavior of the motor that so it smoothly tracks the required speed without any more overshoot or oscillation than the PID controller. Such dynamic, stable operation of the motor makes it perfect for industrial as well as household operations.

Keywords: SEDCM (separately excited DC motor); speed controlling; novel PSO (particle swarm optimization); fuzzy logic controller (FLC)

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1. Introduction

SEDC motors have many important characteristics, such as wide-range operation and continuous and accurate controlling, make it versatile and useful in many industrial applications. This motor is mostly used in traction systems, steel, and rolling mills where constant and smooth operation is required, such as those of electrical vehicles, electric cranes, and robotic operations. For performing any particular task, the motor operates in various modes of speed. So, the motor requires a controller that can control the motor's speed as per the desired application [1].

The controller's application collects the signals from the process, determines how much speed is required, and operates the motor at the desired speed. Using a feedback system, the controller collects the information regarding the actual rotating speed at real-time operation and compares it with reference values. If the speed decreases from the required value, it takes action and increases up to the desired speed value of the motor [2].

Classical controllers have been broadly suggested for the speed control of SEDCMs. The performance of these controllers mainly depends on the accuracy of a mathematical model of the motor for different industrial applications required to develop mathematical models subjected to variation in parameters. Article [3] used chopper control, PI controller suggested [4], phase locked loop method implemented in [5], propose classical controlling method such as field weakening [6], flyback converter [7] and internal model control used by [8].

When the motor is handling the nonlinear loads, the parameters such as friction and magnetic saturation of the load change continuously. Conventional controllers cannot maintain the motor's constant speed. Now, these controllers are replaced by artificial intelligence-based controllers for more intelligent control of the speed of SEDCMs. Researchers proposed some new controlling algorithms which are more effective than classical controllers, such as the fuzzy controller, fuzzy PI controller, and NN-fuzzy controller [9].

The fuzzy controller provides flexibility to design the controller for different motor applications using a set of fuzzy membership functions. It is very effective for the nonlinear operation of the motor and provides smooth and accurate operation. Table 1 presents the difference between FLC and conventional controllers.

Table 1. Comparison between classical and fuzzy controllers.

S. No.	Fuzzy Controller	Conventional Controller
1	It has a special future and universal structure so used for all plants	Its structure should be changed for the plant to plant
2	In the fuzzy controller, generally used plant dynamics and control strategies found by human knowledge and skill.	Here human's skill and knowledge not considered.
3	It can control the nonlinear operated load	It can use but is not effective
4	Its performance cannot be change if variable parameters are used	It is very sensitive for parameters variation
5	Smooth and accurate controlling possible	At the starting produce over damping

Digital controllers take action only when the input is "1", which means it is in an "ON" state for the digital controller (when the input is zero, it means it is in an "OFF" state). The fuzzy controller cannot work as a digital controller with zero and one, but it can work between zero and one. For example, imagine that someone is checking the height of the students in a class and takes a standard value such as 6 feet as the threshold for tallness, meaning that any student above 6 feet is tall and any student below 6 feet is short. If using a digital controller, when the input is 6 feet or more, it would give the result "Tall or 1", and when the input is below 6 feet, it would give the result "Short or 0". However, we can see that practically any student who has a height of around 5.99 feet is also tall, but the digital controller considered him or her short.

In the fuzzy controller, they are not considered tall or short, but they are assigned a membership function that is nearest to the results. The fuzzy controller creates fuzzy membership between zero and one for presenting the concepts of partial truth. In the fuzzy controller, the tallest student receives a maximum membership of "1", and the remaining student who has less height receives a decremented membership up to zero. It implements human thinking and experience for creating a control system. Fuzzy logic is considered to be like human thinking for practical work because the system does not consist of black and white but lies in grayness [10].

The effectiveness of the fuzzy controller can be improved if the optimum value of the selected membership functions is used. PSO is the optimization technique to determine the optimum value of a linear or nonlinear set of data. This work used a fuzzy PSO controller to obtain the optimum speed control of an SEDC motor. This controller is also effective even if the load is changing. Simulation results were obtained by the fuzzy PSO controller compared with the results obtained by the PID controller. In the results section, a deep discussion is given.

Literature Review

The following paragraphs discuss the work conducted by various researchers on the speed control of DC motors. NARMA L2 suggested speed regulation of SEDCM which can handle the nonlinearity operation [1]. A microcontroller used an eight-bit C505C-L for control of speed in both directions. Moreover, the proposed real-time controller approach is based on the closed-loop feedback error principle, unlike the existing open-loop designs [2].

A class chopper is tasked with designing and implementing a speed controller to control the separately excited DC motor speed. The speed of the separately excited DC motor is controlled to a maximum of its rated speed using a chopper as a converter. The speed controller used is the PI controller, which reduces steady-state error and provides fast control [3].

A fuzzy controller for the control of the shaft position of the DC motor is suggested in reference [10]. They designed a fuzzy controller for ten fuzzy members and optimized it using a genetic algorithm. Article [11] proposed a fuzzy controller and provided a digital signal using digital signal processing units to operate different modes of DC motors.

Article [12] also proposed a fuzzy controller that helps tune PI controllers for the stable operation of DC motors. They also implemented a PLC control system to make the automatic operation of the controller. A new hybrid system called Neuro-Fuzzy was used in article [9] for the smooth operation of a DC motor. A fuzzy based controller proposed for the control of operation of the servomotor [13].

A self-tuned PID controller with a fuzzy logic controller is proposed by [14], which has self-tuning parameters provided online for real-time control of the operation. Articles [15,16] proposed a fuzzy logic controller, which is also effective if the parameters' value changes during the operation of the motor.

A PLL control system with inputs of IGBT for speed control of SEDC motors was suggested in article [5]. PLL controllers are used for constant frequency control of the motor. The NN-fuzzy hybrid system has been suggested for speed control of a separately excited DC motor. This method tries to control the fractional part of PID parameters for fine control of motor operation [17].

SEDC motors operated in a high-speed field-weakening regime controlled by using a nonlinear multiple-input multiple-output feedback linearization technique [6]. The adaptive load approach used a sensor-less control system to impart the motor's dynamic performance. Online tuning of PID controller parameters with the help of the recursive least square algorithm was suggested in articles [18–20].

A DC-to-DC buck converter was suggested for DC motor control by [21], and for a permanent magnet with a DC motor, the authors of [22] suggested the predictive control algorithm with a Discrete-Time Reduced-Order GPIO.

For the selection of the optimum side for the charging stations, the authors of [23] proposed an MCDA approach based on GIS. They suggested genetic optimization techniques for the selection of the optimum location of the charging stations.

For the analysis of indirect flat-panel evaporative coolers, the authors of [24] proposed the mechanism and theory of operation based on X-analysis. Flat-plate heat exchanger entropy is calculated based on the second law of thermodynamics.

A pinch technique was proposed in article [25] which optimizes the consumption of energy in the process of milk powder production. For the analysis of economic and technical aspects, the stream information data were optimized by an Aspen Energy Analyzer.

From the above discussion, it is clear that a separately excited DC motor is very useful for industrial and domestic work if its speed can be controlled at the desired value. When using classical controllers for the control of the SEDC motor, they face problems during the change in the load. If the load varies with time, motor speed controlling at a steady state is a very difficult task.

Classical controllers such as PI and PID can provide speed control, but they need continuous tuning of the control parameters, which is a very difficult task during the operation. The fuzzy controller is very versatile and used for speed control of the DC motor in industrial as well as domestic applications. However, fuzzy controllers also need to use the correct value of the membership; otherwise, we have to use the trial and hidden method and find out the correct value of membership. This work uses a novel PSO to find out the optimum value of the membership function according to the error that arises from the output of the motor. So, there is no need to use trial and hidden methods, and it can save our time and improve the control action of the fuzzy controller.

2. Mathematical Model of SEDM Motor

Optimum control of the SEDC motor requires a compact mathematical representation of different parameters used in the stator and rotor. For mathematical modeling of the SEDC motor used Figure 1, which depicts it connecting with the rotating load. In an SEDCM, armature and field voltage can be controlled separately [26]. SEDCM mechanical and electrical operations are given in Equations (1) and (2), respectively.

$$J_m \frac{d\omega_m}{dt} = T_m - b\omega_m - T_L \quad (1)$$

$$L_a \frac{di_a}{dt} = V_a - R_a i_a - K_b \Phi \omega_m \quad (2)$$

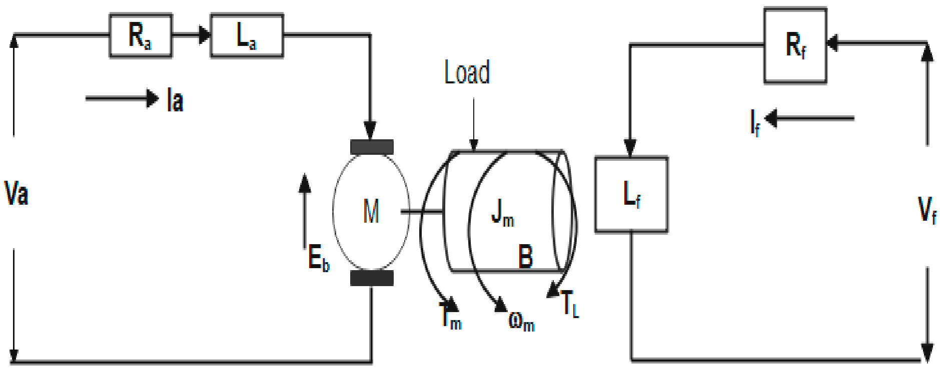

Figure 1. Circuit diagram of SEDC.

An applied voltage of the motor in the armature is given as Equation (3):

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + E_b \quad (3)$$

where E_b is the back emf of the motor and is given as:

$$E_b = k\Phi\omega \quad (4)$$

Instantaneous field voltage in the field winding is given by Equation (5):

$$V_f = R_f i_f + L_f \frac{di_f}{dt} \quad (5)$$

The torque developed on the motor is given by Equation (6):

$$T_m = K_m i_a \quad (6)$$

$$T_m = j.\frac{d\omega_m(t)}{dt} + b\omega_m + E_b \quad (7)$$

Using Equations (5) and (6), the toque is replaced by the armature current, as given in Equation (8):

$$K_m I_a = j.\frac{d\omega_m}{dt} + b\omega_m + k\Phi\omega \quad (8)$$

Now, the speed of the SEDC motor in terms of rotor voltage and current, as well as field current, is obtained through Equation (9):

$$\omega_m = \frac{V_a - I_a R_a}{K_v I_f} \quad (9)$$

The speed of the motor is directly propositional to the applied voltage for the motor. The same concept is used in this work for the speed control of the proposed motor.

2.1. Double Feedback Control of the SEDC Motor

This work used a double feedback system, speed, and armature current. The principle of such double feedback for SEDCMs is shown in Figure 2. This control scheme has an outer control loop for rotational speed and an inner control loop for current. The controlling scheme is based on the motor's operation behavior when the reference value is changed. The basic requirement of the control system is to follow the reference value and operate at the desired speed. If any disturbances arise in the system, the current and speed of the motor cannot match the reference value. So, when one error arises in the system, the controller tries to remove this error and again matches the motor's output speed with the reference speed [9].

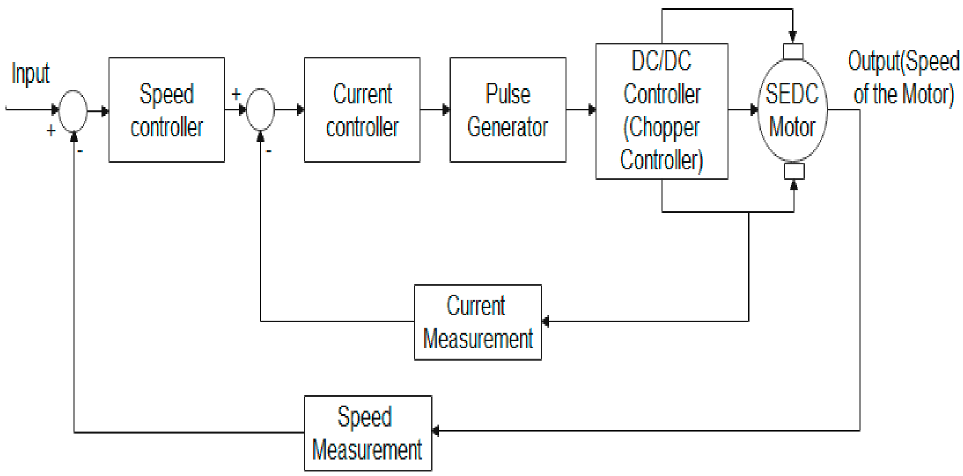

Figure 2. Double feedback control system of SEDC motors.

The symmetry of the system is changed if the disturbance quantity changes. The goal is that, after a disturbance, the output quantity is restored to its original value as soon as possible. In addition, it is required that there is a pure integrator or very large time constants in the system. The speed control loop is typically designed through the symmetry criterion since the speed controller shall restore the speed after disturbances caused by changes in the load torque [13].

2.2. Chopper-Fed PID Controller for Speed Governing of SEDC Motors

Operating a DC motor at a variable speed requires a variable voltage supply; generally, DC motors only have a fixed voltage supply system. A chopper is a power electronic device that can help to provide a variable DC supply [15]. Using such a variable-controlled supply governs the speed of the DC motor as per the desired application. The variable voltage, which is used for speed control of SEDCM, is given in Equation (10):

$$V_{avg} = \frac{1}{T}\int_0^T V(t)dt \quad (10)$$

PID controllers' parameters are selected as per the given limits in Table 2, and during the simulation, the best results were found at $K_P = 1.588$, $K_I = 23.89$, and $K_D = 0.024$. The PID controller's parameters are selected on trial and hidden bases.

Table 2. Parameters of PID controller.

S. No.	Parameters	Tuning Range of the Parameters	Final Values Taken
1	Kp	1.5–1.7	1.588
2	KI	23–25	23.89
3	KD	0.015–0.05	0.027

3. Fuzzy Controller

FLC is a very effective controller and is currently used in many applications. FCL can be designed for small as well as big motor speed control [27]. First, we must know the input and range of the motor speed operation, accordingly selecting the fuzzy membership function limits. The initial error should be taken before any controlling action, and then, after changing in error (an error which comes after controlling action), prepare the fuzzy rules as per the selected fuzzy members. The fuzzy controller has three types of shapes of fuzzy membership and is represented with a triangular shape in [10].

Configuration of FLC

Various components are considered for the design of the FCL configuration listed in Figure 3.

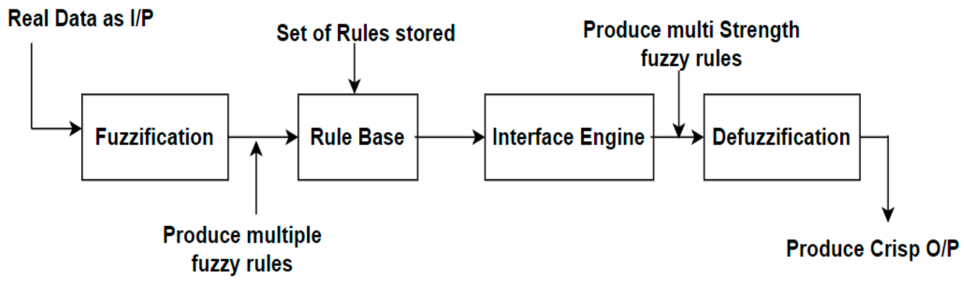

Figure 3. Components of a fuzzy controller.

Preprocessing: This is the process of normalization or scaling onto a particular range.
Fuzzification: This process is used to produce multiple fuzzy inputs.
Rule Base: This consists of all rules prepared by using the membership function.
Interface Engine: This is the mapping of input data to outputs using fuzzy rules. In the mapping used to input and output membership functions, consider suitable FL operators and implement logic.
De-fuzzification: This is the process of converting fuzzy rules to output electrical signals.

4. Novel PSO

In classical PSO, the velocity and position of the particles are updated after the completion of each iteration. However, the problem is that if the particle's velocity is zero at any particular time, then the particle's position cannot be updated, and particles rapidly rush toward a local optimum solution. At this condition, it is very difficult to achieve the global solution to the problem, within the prescribed number of iterations, of resolving such a condition using novel PSO where the particle moves in the search of space at the end of iterations, and hence, it updates its position and achieves a global solution to the problem.

In classical PSO, the value of cognitive factors (acceleration coefficients) c_1 and c_2 are considered constant. The proposed PSO values of c_1 and c_2 are variables, and hence, they support the particles to move in the search area up to the end of the iteration in a process called time-varying acceleration PSO [28]. So, first of all, particles are selected using maximum and minimum limits of the membership function considered in the fuzzy controller as given in Equation (10):

$$P_{position} = P_i^{Min} + rand*\left(P_i^{Max} - P_i^{Min}\right) \quad (11)$$

where $P_{position}$ is the initial position of the particles, rand is a numerical value generated between 0 and 1, and P_i^{Max} and P_i^{Min} are the maximum and minimum limits of the membership functions.

The velocity and position of each particle are updated after every iteration is given according to Equations (11) and (12):

$$V_i^{(N+1)} = w\, V_i^N + c_1 R_1 \times \left(P_i^{Best} - S_i^K\right) + c_2 * R_2 \times \left(P_i^{Gest} - S_i^K\right) \tag{12}$$

$$S_i^{(N+1)} = S_i^N + V_i^{N+1} \tag{13}$$

The acceleration coefficients are defined with iterations according to Equations (13) and (14):

$$c_1 = (c_{1f} - c_{1i}) * \frac{iter}{iter_{max}} + c_{1i} \tag{14}$$

$$c_2 = (c_{2f} - c_{2i}) * \frac{iter}{iter_{max}} + c_{2i} \tag{15}$$

where c_1 and c_2 are acceleration parameters, N is the number of particles, V_i^N is the initial velocity of the particles, $V_i^{(N+1)}$ is the new velocity after updating, S_i^K is the initial position of the particles, $S_i^{(N+1)}$ is the new particle position after updating, R_1 and R_2 are random initiated values in MATLAB, and P_i^{Best} and P_i^{Gest} are the best and global value of the particles, respectively. Different parameters' values taken during the optimization of PSO are shown in Table 3. Table 4 shows the maximum and minimum limits taken during optimization and the final optimized value given by PSO after the completion of the optimization process.

Table 3. Parameters used in convergence of novel PSO.

S. No.	Parameters	Values
1	Number of iterations	100
2	Population size (number of particles)	50
3	C_{1i}	2.5
4	C_{1f}	0.2
5	C_{2i}	0.2
6	C_{2f}	2.5
7	Inertia constant (w)	Wmax = 3.5 and Wmin = 0.5
8	Random values generated in MATLAB	R_1 = 0.64 and R_2 = 0.57

Table 4. Convergence results of fuzzy members' limits obtained by PSO.

Membership Name	Limits Taken for Optimization	Convergence Limits Obtained
LN (Large negative)	−0.180 to 0.25	0 to 0.1666
MN (Medium Negative)	0.00 to 0.40	0.0 to 0.332
SN (Small negative)	0.10 to 0.5	0.166 to 0.496
Z (zero)	0.2 to 0.7	0.332 to 0.665
SP (small positive)	0.4 to 0.9	0.498 to 0.832
MP (medium positive)	0.5 to 1	0.666 to 1
LP (large positive)	0.70 to 1	0.832 to 1

Algorithm for New PSO

1. Select the number of particles.
2. Define the minimum and maximum limits of the membership function considered in the fuzzy controller.
3. Create the group of swarms using such a limited, as explained above.
4. Define the velocity of the particles.
5. Define the initial value of local best, called P_{best}.
6. Define the initial value of global best, called $G_{best.}$

7. Set the objective.
8. Select the number of iterations.
9. Select the value of acceleration parameters.
10. Randomly start the swarm movement as given in Equation (10).
11. Update the velocity of the particles using Equation (11).
12. Update the position of the particles with the new velocity using Equation (12).
13. Check whether the particles are in defined space limits or not.
14. If particles are in limits, select the global best value as a final solution.
15. If it crosses the search space limit, start the program again.
16. When the iteration is completed automatically, stop the operation.

5. MATLAB Simulink of Proposed Control Scheme

The controlling approach used in this work is shown in Figure 4 and uses a double feedback system, which makes the system more reliable and provides smooth control. This work considered a PSO fuzzy controller for speed control of separately excited DC motors.

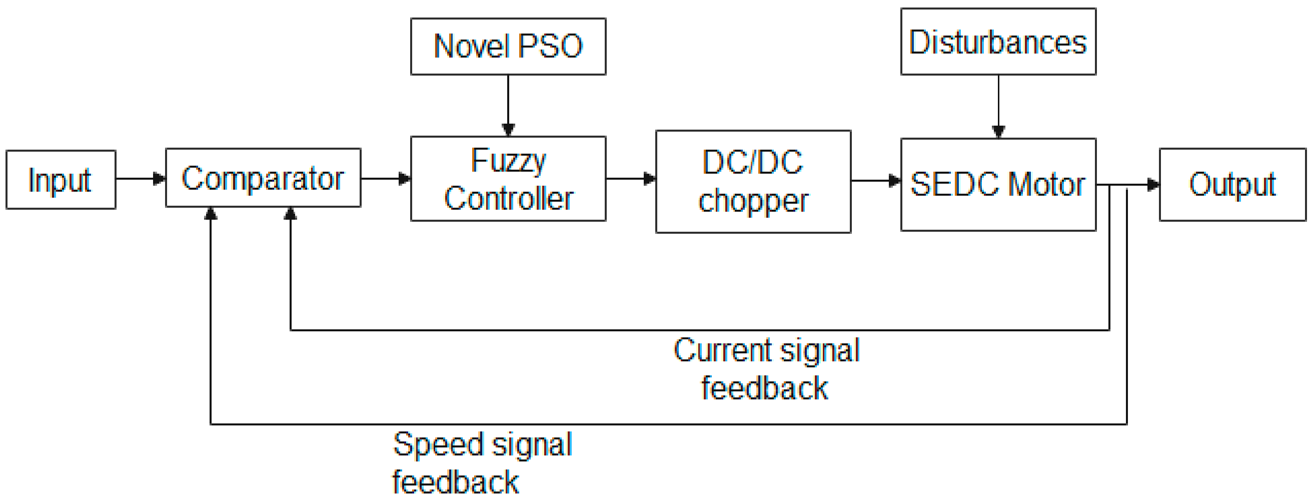

Figure 4. Block diagram of the proposed controlling scheme for SEDC motors.

The fuzzy controller works on the selection of membership functions and then, using these membership functions, creates a number of fuzzy rules. These rules make fuzzy controllers similar to automatic controllers because they are applied when any error arises in the operation of the motor. However, here, one problem arises in the selection of the correct value of the membership function. In fuzzy controllers, membership values are selected using the trail and hidden methods, which means the operator changes the values of the membership until he does not obtain the desired output. Such kinds of problems can be minimized by using the PSO.

PSO can give the optimum value of the membership and then create the rules. Such rule-maximum cases give the desired output. In this case, seven members are selected for input as error, and seven members are selected for change in error for the controller. Using these two inputs created 49 rules. The input of the DC voltage is considered a reference value, and the output is the actual mechanical work (speed) conducted by the motor. The flowchart of the design of the proposed system is shown in Figure 5.

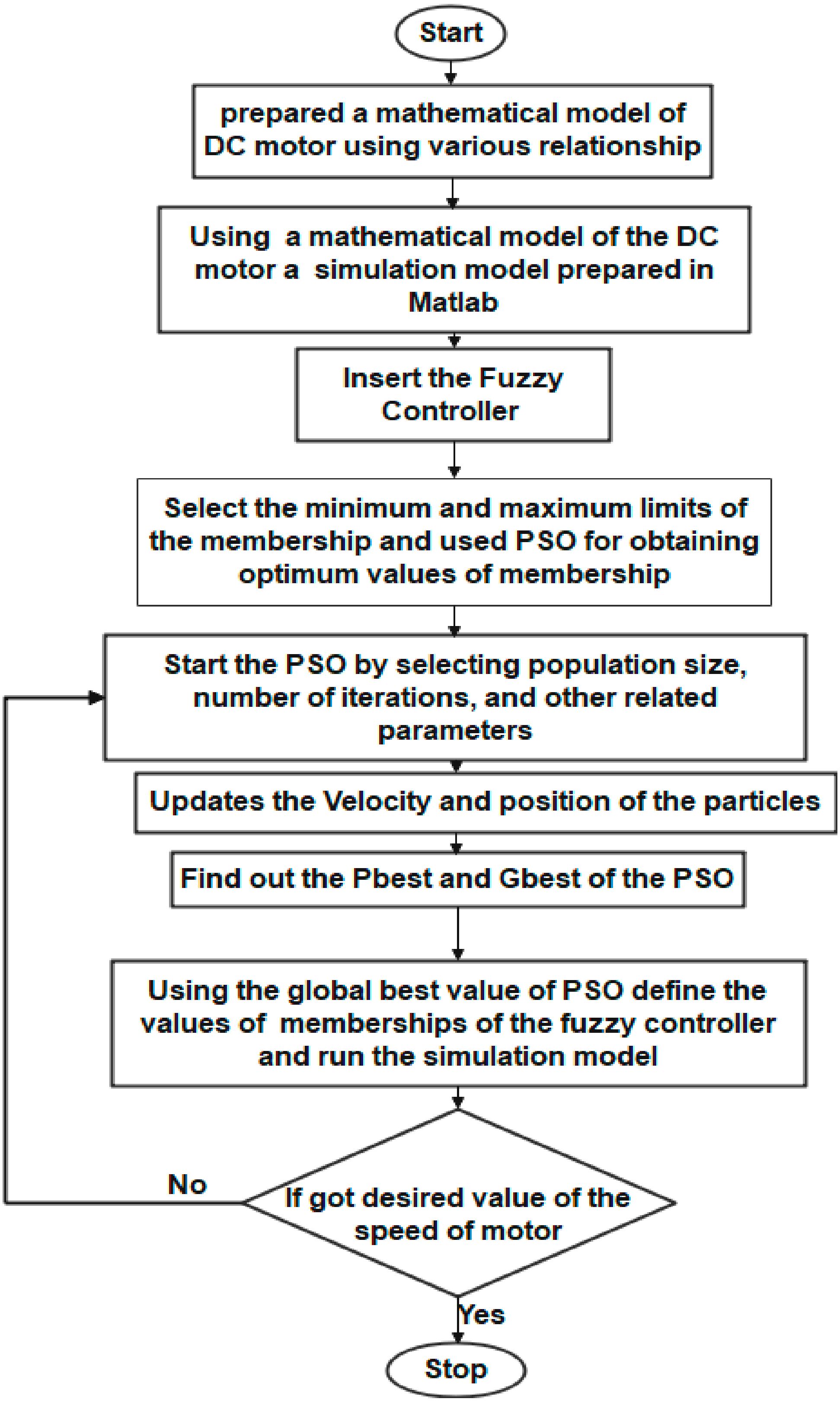

Figure 5. Flowchart of the proposed system.

With the help of mathematical equations, a Simulink model of SEDC motors using MATLAB is shown in Figure 6.

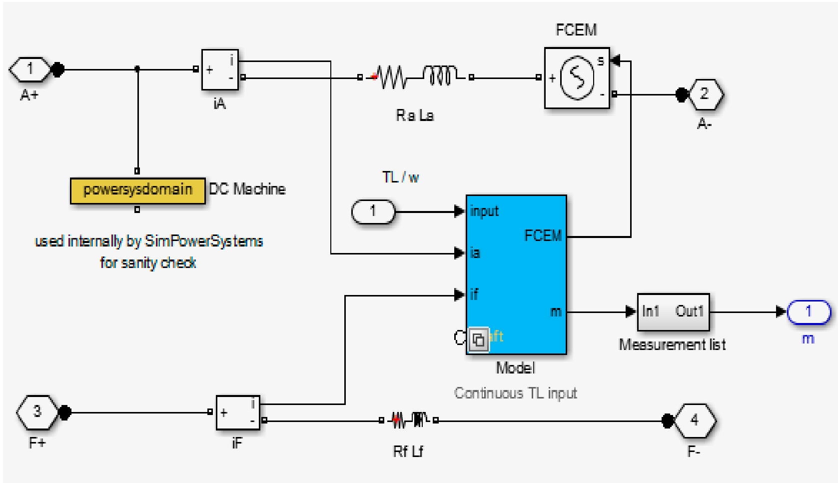

Figure 6. Simulink model of SEDC motors.

A fuzzy controller used for speed control of SEDC motors with seven membership functions is shown in Figure 7.

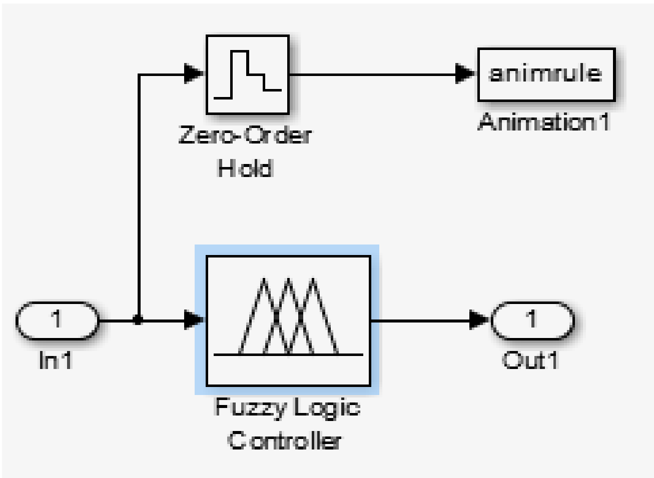

Figure 7. Fuzzy controller Simulink model.

DC-to-DC choppers are designed for providing variable DC supply to the motor for adjustment of speed, as shown in Figure 8.

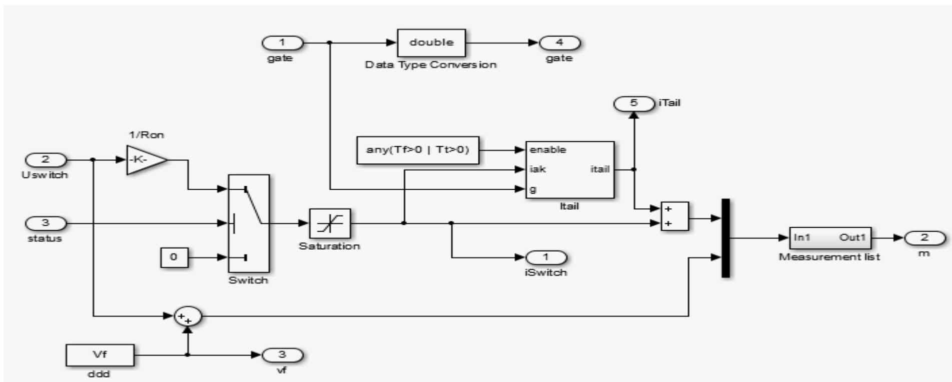

Figure 8. Simulink model of DC-to-DC chopper.

PID controllers are used as primary controllers, and their simulation design is shown in Figure 9. A comparator was used at the input side of the system for comparing the output results and applied reference input. It helps to find out the error between the desired value and the actual value, as shown in Figure 10.

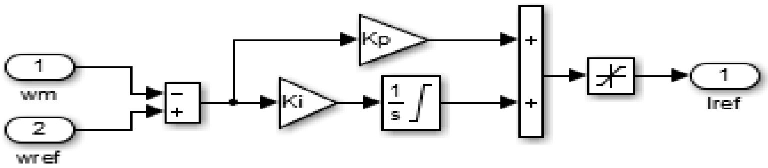

Figure 9. Simulink model of PID controller.

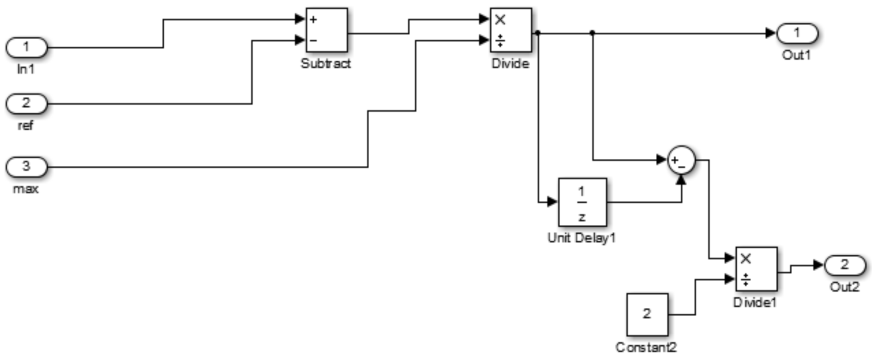

Figure 10. Simulink model of comparator.

This work considered seven membership functions in FLC, as shown in Figure 11.

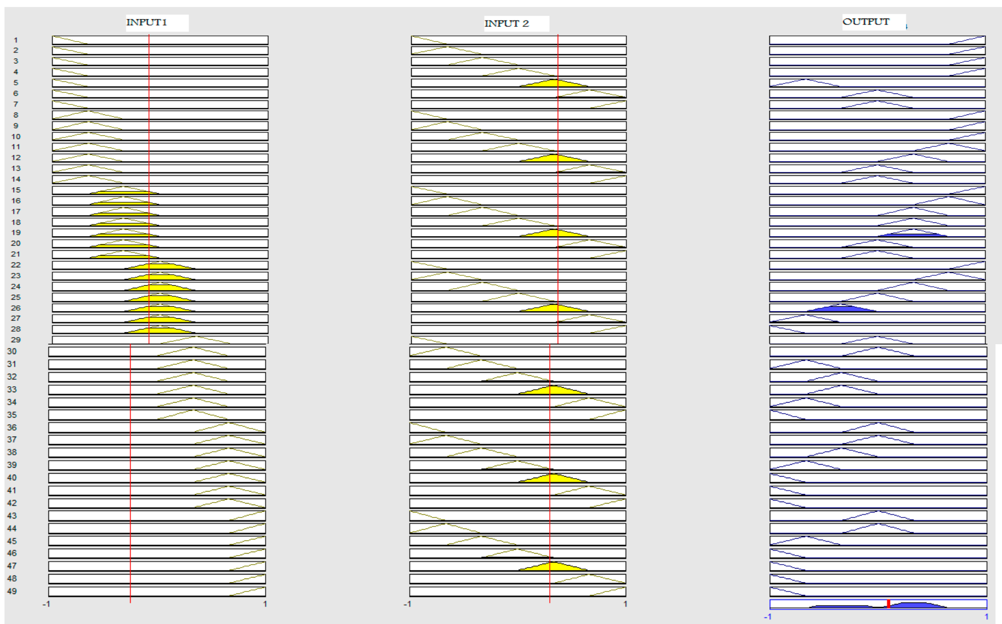

Figure 11. Fuzzy rules using the 7membership functions for fuzzy controller.

The surface viewer for the seven membership function rules on MATLAB is shown in Figure 12.

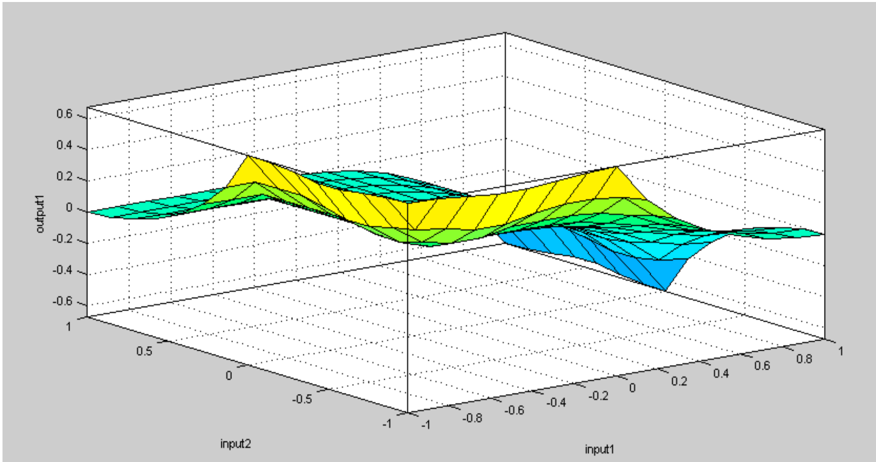

Figure 12. Surface viewers for fuzzy rule for the seven membership functions.

6. Results and Discussion

Separately excited DC motor simulation models were prepared for the PID controller and fuzzy PSO controller, and in both cases, the simulation models were tested separately. The simulation model tested for constant load torque as well as variable load torque. The DC motor simulation model was first tested for the speed of 120 rad/s by the PID controller using the proportional, integral, and derivative gains shown in Table 2 for constant load torque. The results for constant load torque are shown in Figure 13. In the simulation results, the first quantity shows the DC voltage, the second quantity shows the armature current, and the third quantity shows the speed of the separately excited DC motor. Here, it is observed that during the starting time, the motor takes a larger current compared to the normal operating current.

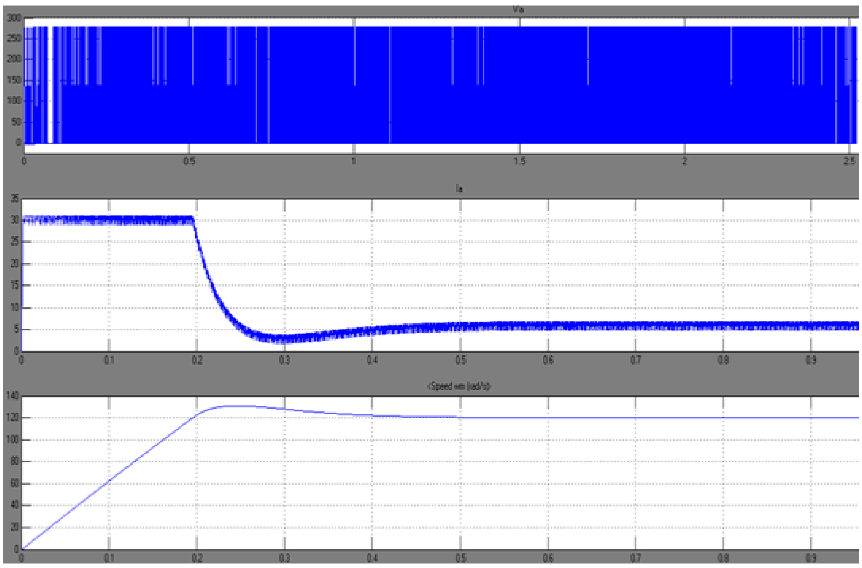

Figure 13. Simulation results of PID controller.

The speeds of the motor increase and reach the maximum overshoot value, but as soon as the PID controller takes action, its speed slows down and the motor starts operating at a constant speed. PID controller rise time, maximum overshoot, setting time, and time delay are shown in Table 5. In Figure 13, it can be observed that motor speed is initially not smooth, so it reached maximum overshoot because of the PID controller delay action. After a few seconds, it gains the required speed, and at that time, the current of the motor also decreases to the normal value.

Table 5. Comparative analysis of different controllers.

Types of Controllers	Measured Parameters			
	Rise Time (s)	Maximum Overshoot %	Settling Time (s)	Time Delay (s)
PID controller with constant torque	0.2	5.48%	0.04	0.04
Fuzzy PSO controller with constant torque	0.000264	0	0.00024	0.031
PID controller with variable torque	0.31	5.428	0.04	0.034
Fuzzy PSO controller with variable torque	0.00026	0	0.000214	0.016
PID fuzzy [30]	1.4	11.2	2.1	-
PID controller [29]	0.874	8.0298	0.3687	0.0528
PID-GA [29]	3.77×10^{-4}	0	6.9×10^{-4}	0.0502

The same DC motor simulation model was tested by using fuzzy PSO for the speed of 120 rad/s and constant load torque, and the obtained results are shown in Figure 14. The performance of the motor for different parameters is shown in Table 5. The starting current taken by the motor again increases, but the speed suddenly does not increase because the fuzzy controller takes immediate action and controls the speed of the motor from the start and maintains the desired motor operation. In this case, motor performance increases, and hence, it achieves the desired speed without any overshot, so its steady-state performance is good. The current also decreases as speed increases with time.

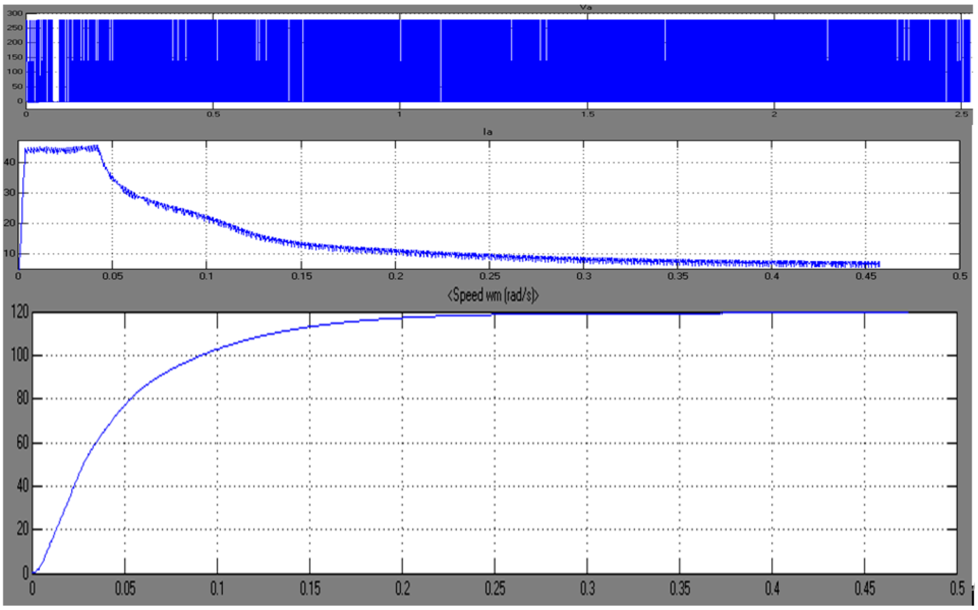

Figure 14. Simulation results of novel PSO fuzzy for SEDC motors.

In the third case of study, the DC motor simulation model was tested for variable load torque and two different desired speeds. The initial speed of the motor was set at 80 rad/s, and the final speed of the motor was set at 120 rad/s. The PID controller was first applied for the abovementioned configuration, and its performance results are shown in Figure 15. In this case study, motor speed again suddenly increased and achieved the maximum overshoot on both set points of speed positions. Motor achieved the desired speed after action taken by the PID controller, so steady-state transients arose in both case studies of the PID controller. DC motor performance at a steady-state condition was not good when using the PID controller. So, when using a PID controller, motor operation is not initially constant, this can affect the design or operation of the connected loads.

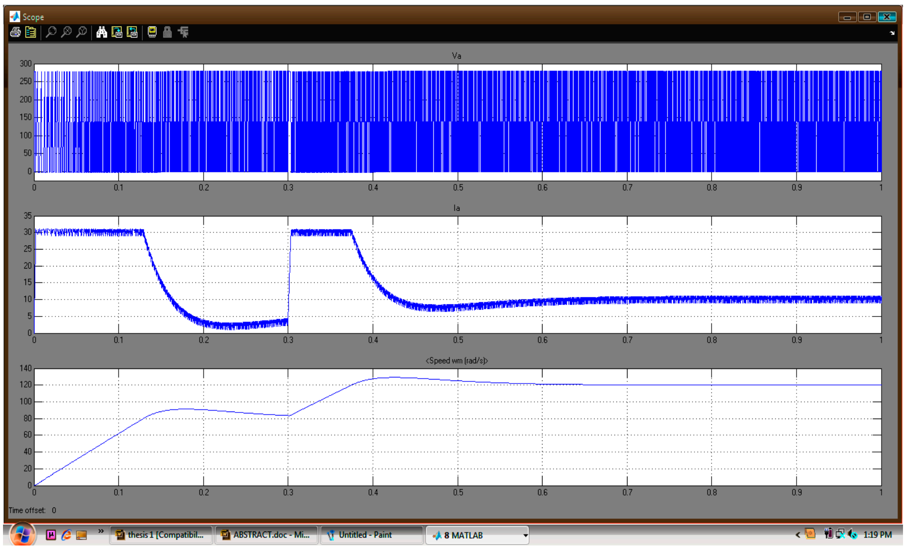

Figure 15. Simulation results of PID controller for the speed of 80 rad/s and final 120 rad/s.

In the last case of the study, the motor simulation model was tested for variable load torque and variable speed, and the PID controller was replaced by a fuzzy PSO controller. The results obtained by novel fuzzy PSO for the variable speed and variable load torque are shown in Figure 16. It can be observed in Figure 16 that the motor started smoothly and reached the set point of speed without any overshoot. Motor rise time was also very small, so when it is used for applications where very smooth and continuous action is required, the fuzzy PSO controller performance is very excellent. Its motor dynamic performance was better than that of the PID controller, and the motor achieved the desired set point of speed without any transient or overshoot. Performance parameters achieved in such control action are shown in Table 5. Motor operation was very smooth, and its rise time and delay time were also very small compared to the PID controller.

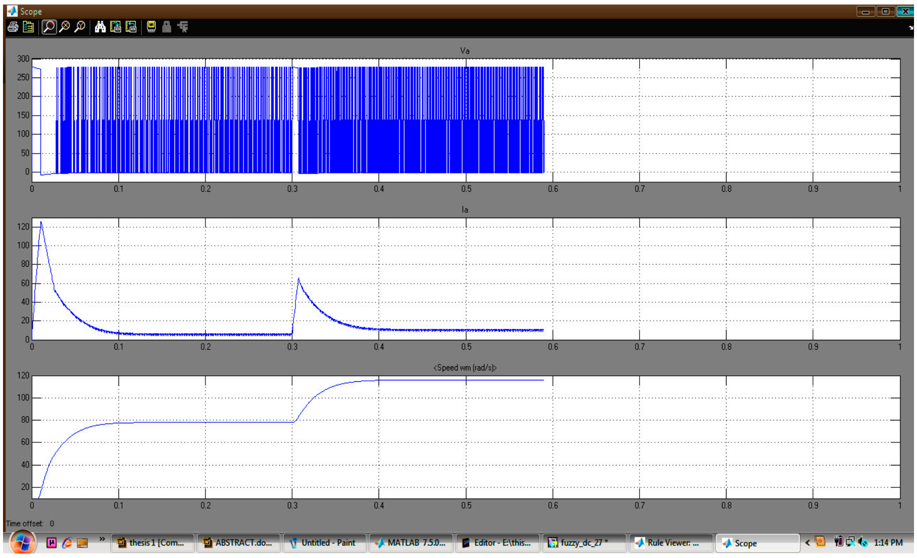

Figure 16. Simulation results of novel PSO fuzzy controller for the speed of 80 rad/s and final 120 rad/s.

The performance of the proposed PID controller as well as the fuzzyPSO controller compared with the literature is shown in Table 5. The proposed PID controller performance, in terms of rise time, maximum overshoot, and settling time, wasbetter than the PID controller used in article [29]. Similarly, the proposed fuzzyPSO performance is excellent if compared with the PID-GA [29] and PID-Fuzzy [30–32]. Overall, the proposed PSO fuzzy controller performs well and controls the speed of the motor as per the desired application. So, this controller can be used for many applications [31] where smooth, stable, and constant or variable speed is required.

7. Conclusions

The application of the SEDC motor can be increased if its speed can be controlled for various modes of operation. The SEDC motor is very suitable for controlling its speed from the rotor side or stator side. Many classical controllers were used for various applications, but the most common problem found in such controllers is not effective for the nonlinear operation of the motor. Nowadays, the design of very accurate and compact devices for the operation of motor control is very important in all operating modes to ensure that the motors can start smoothly and operate at a continuous speed, especially in steel and rolling mills.

The proposed novel fuzzy PSO is tested for different speeds, and we found that its operation is very smooth, and that overshoot does not arise as compared to the PID controller. The proposed fuzzy controller is tested for the seven membership functions using the optimum value given by PSO. PSO gives a global optimum solution for the set of membership functions very quickly. The proposed controller also provides automatic control if any disturbances arise in the motor during the operation. PSO selects the appropriate values of fuzzy membership so that if the load value is varied, the speed of the motor cannot deviate from the set point of operation. Hence, the novel PSO fuzzy controller provides an accurate signal and controls the speed of the motor as per the desired value.

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Abbreviations and Symbols

V_a	armature voltage (in volt)
E_b	back emf the motor (in volt)
I_a	armature current (in ampere)
R_a	armature resistance (in ohm)
L_a	armature inductance (in Henry)
T_m	mechanical torque developed (in Nm)
J_m	moment of inertia (in kg/m^2)
B	friction coefficient of the motor (in Nm/(Rad./s))
ω_m	angular velocity (in Rad./s)
T_L	load torque in Nm.
Φ	flux generated on motor
k_m and K_b	proportional constants
R_a	armature resistance
R_f	field resistance
I_a	armature current
I_f	field Current
L_a	armature inductance
L_f	field inductance
V_{avg}	average value of chopper output

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