Performance Evaluation of DC Shunt Wound Motor and DC Series Wound Motor

Muhammad Rafay Umer Qureshi[a], Ali Asghar Memon[a], Shoaib Shaikh[a]

[a] *Mehran University of Engineering & Technology Jamshoro, Sindh, Pakistan*

Abstract

The industrial loads are mainly due to the motor used. DC motors are widely used in the industry for variable speed and starting torque applications. DC Series and DC Shunt wound motors respond efficiently when connected to different loads. A desirable range of speed at different load torques is therefore required for optimal performance of these motors. The existing controller for speed control have no significant output and therefore need of an efficient and reliable controller is needed. In this proposed work, FLC controller has been opted and implemented in the simulation model in MATLAB environment and the results are compared with existing PID controller. The obtained results are found satisfactory for both motors under FLC controller. The simulations are carried out for a range of operating parameters of the motor's operation.

Keywords: *DC Shunt Wound motor; DC Series Wound motor; Rule Based Knowledge; Proportional Integral Derivative (PID); Fuzzy Logic Controller (FLC).*

1. Introduction

In overall day a series of mechanical operations are executed by the DC (Direct current) Shunt Wound motor and DC Series Wound motor with higher efficiency and the ability to maintain constant speed and high torques at random loads by performing the conversion of energy from electrical form to the mechanical form through their proper and state of the art controlling means by Artificial Intelligence will update the industrial sector to a next level (Fig1. Almatheel, Y. A., & Abdelrahman, A. (2017, January). Speed control of DC motor using Fuzzy Logic Controller. In 2017 International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE) (pp. 1-8). IEEE. For researchers FLC (Fuzzy Logic Controller) remained a wise choice to keep the system stable and robust under the disturbance conditions when there is a much probability of the ambiguity and non-deterministic nature of system through the using of the FLC. For different load scenarios the stability and further enhancement of system can be achieved by the implementation of the FLC [1]. According to the comparative studies in which the stuned PI (proportional integral) controller and FLC is examined for response of the system in with and without load disturbance conditions and in both cases the FLC is proved to be a better controller from the either controller [2]. Research shows that the system response of the BLDC (Brushless Direct Current) motor drive with FLC and with PI controller in comparison of both of the controllers the system response for FLC shows fast speed response, reduced rise time then PI controller, the developed form of the FLC has the features of instantaneous learning and immediate adapt of control parameters for disturbances and reduced overshoot, risetime and with minimum steady-state error [3]. In comparison with each other DC Series wound motor and DC Shunt wound motor (as the equivalent circuits of DC shunt wound and DC series wound motors are shown in Figure 2a and 2b), each of them owns different operating and working phenomena which can be used in different appliances therefore their flexible operational and precise working control in commercial, agricultural and industrial sector with but due to the reason of non-linearity and other constraints as well, the Field Oriented Control (F.O.C) is deployed but it have some limitations of sensational reaction for varying constraints [4] To attain the desirable goal of the research is to achieve the speed control of the DC motor, DC motor system can be depicted in its equivalent circuit and then the control systems can be applied to it by using MATLAB program [23].

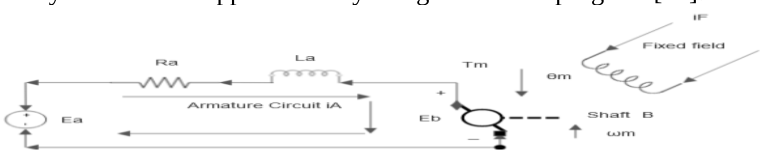
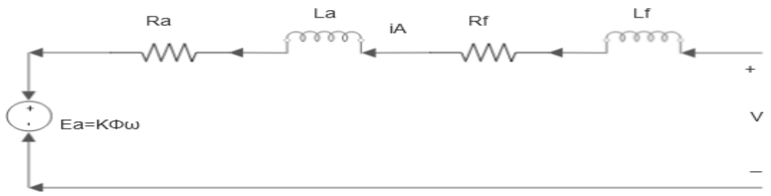
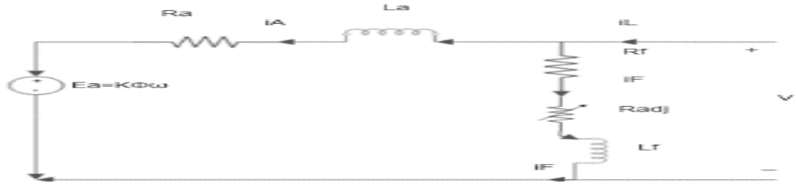


Fig. 1: DC motor Equivalent Circuit

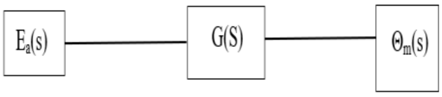
*Corresponding author. Tel.: +92 3342207835; fax: NA
E-mail address: ayazbabar94@gmail.com



(a)



(b)



(c)

Fig 2: Different circuuits, (a) Equivalent Circuit DC Series wound motor; (b) Equivalent Circuit DC Shunt wound motor; (c) Block diagram of Transfer Function G(s) which relates input applied armature voltage $E_a(s)$ with angular displacement $\Theta_m(s)$

2. Mathematical Modelling of DC motor in the Laplace Domain

Back emf generated by rotor motion in static magnetic field

$$Eb(t) = Kb\frac{d\Theta m(t)}{dt} \tag{1}$$

$$Eb(s) = kb\ s\ \Theta m(s) \tag{2}$$

Where Eb is the Back e.m.f (V), Θm is the angular displacement (in rads) and kb is back e.mf constant Relationship between armature current iA(t), applied armature voltage Ea(t) and Eb(t) can be found by Kirchhoff's Voltage Law

$$Ea(t) = iA(t)Ra + LA\ \frac{diA(t)}{dt} + Eb(t) \tag{3}$$

$$Ea(s) = (Ra + SL_A)\ i_A(s) + E_b(s) \tag{4}$$

Where Ea is the applied armature voltage (V),
Eb is the Back e.m.f (V), iA is the armature current (A), Ra is the armature resistance (Ω),
LA is the armature inductance (H)
Torque is proportional to the armature current

$$T_m(s) = K_t\, i_A\,(s) \tag{5}$$

$$i_A\,(s) = \frac{1}{Kt}\ Tm(s) \tag{6}$$

Where iA is the armature current (A), Tm is the motor Torque (Nm) and Kt torque constant. Substituting Eq. (2), (6) into Equation (4)

$$Ea(s) = (Ra + SL_A)\ \frac{1}{Kt}\ Tm(s) + k_b\Theta m(s) \tag{7}$$

$$T_m(s) = (Jms^2 + D_m\, s)\ \Theta m(s) \tag{8}$$

Where Tm is the motor Torque, Jm is the rotor inertia (kg.m^2), Dm is the Damping Constant and Θm is the angular displacement Substitute Eq. (8) into Eq. (7)

$$Ea(s) = [\frac{1}{Kt}\ (Ra + SLA)\ (Jms2 + Dm\ s) + kb\ s]\ \Theta m(s) \tag{9}$$

Assume that L_A small compared to R

$$Ea(s) = [\frac{Ra}{Kt}\ (Jm\ s + Dm) + kb]\ s\Theta m(s) \tag{10}$$

$$\frac{\Theta m(s)}{Ea(s)} = \frac{Kt}{[Ra\ (Jm\ s + Dm) + kb\ kt]\ s} \tag{11}$$

Simplify by putting out J_m, R_a

$$\frac{\Theta m(s)}{Ea(s)} = \frac{\frac{Kt}{Ra\,Jm}}{s\left(s+\frac{1}{Jm}\left(Dm+\frac{kb\,kt}{Ra}\right)\right)} \quad 12)$$

$$G(s) = \frac{k}{s(s+a)} \quad (13)$$

Where K (capital) is some constant.

3. Fuzzy Logic Controller

"Fuzzy logic control is a set of rules composed of the linguistic control variables defined through proper rule-based knowledge and verified through its validation". The whole Fuzzy logic control is composed of the following mechanism The whole process of Fuzzification, Inference and Defuzzification can be depicted as show in the block diagram in Fig. 3.

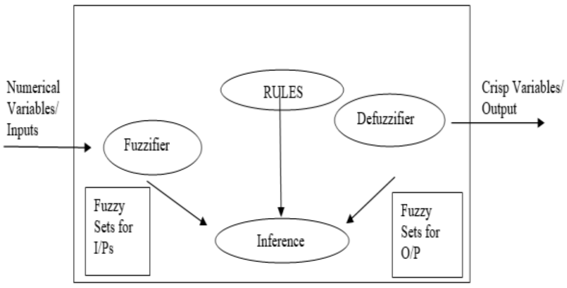


Fig. 3: Block Diagram Representation for the Fuzzy Logic Controller

3.1. Rule Base

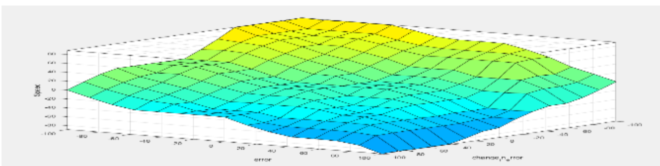
A logic on which decisions are based, simulate the decision process based on the human skills. The linguistic variables and control rules are the blueprint to execute the fuzzy control action. The rules are formed in the "IF THEN" format, the IF side is the conditions side while the THEN side is for conclusion. The MATLAB/SIMULINK program gets the direction from rule-based knowledge and takes an action in the form of control action signal "triggered by the difference obtained by the output speed and the reference" in the inputs 1 & 2 (error and change in error). A rule-based knowledge controller is a user-friendly environment programming, processing and easy to understand for a general user. The linguistic variables used to form the rules are LF (Large Negative), MF (Medium Negative), Small Negative (SF), Zero (ZE), Small Positive (ST), Medium Positive (MT) and Large Positive (LT).

Table 1: Rules Table for DC shunt wound motor and DC Series Wound motor in Fuzzy Logic Controller.

eΔ / e	LF	MF	SF	ZE	ST	MT	LT
LF	LT	LT	LT	ST	ST	ST	ZE
MF	LT	MT	MT	ST	ST	ZE	SF
SF	LT	MT	ST	ZE	ZE	SF	SF
ZE	MT	ST	ZE	ZE	ZE	SF	SF
ST	MT	ST	ZE	ZE	SF	SF	MF
MT	ST	ST	SF	SF	SF	SF	MF
LT	ZE	SF	SF	MF	LF	LF	LF

3.2. Surface viewer of the Fuzzy Logic Controller

In FLC, Surface viewer is the area covered by the function as shown in Fig. 4. Based on fuzzy rules, the Fuzzy Inference Engine (mentioned below) or more specifically Fuzzy Inference System (FIS) file loaded in the workspace produce output responses during the designed model simulation. Each one of the stated Fuzzy rules correspond to its concerned one input from the two inputs (in general) and either to "error" or "Change in error" (specifically) according to the syntax the Fuzzy Inference Engine generates outputs (waveforms) from where these (in general) and waveform (specifically) are converted into a certain crisp output by the execution of the process called as DEFUZZIFICATION and this phenomenon is displayed in Fig. 4.



ig. 4: Surface viewer of Fuzzy

3.3. Controller Design

Through simulation we can practice different models in a simple, safe, and protective way. By this the user can try different models in a limited time without realistic efforts and purchases. It is a way to construct a desirable prototype in a safe environment. MATLAB R2018a is used for simulation analysis in this study.

4. Block Description

The circuits shown in Fig. 5 (a), b) & (c) represents the Series-wound motor without controller, with PID and with FLC. Whereas, The circuits shown in Fig 6 (a), (b) & (c) represents the Shunt wound motor without controller, with PID and with FLC.

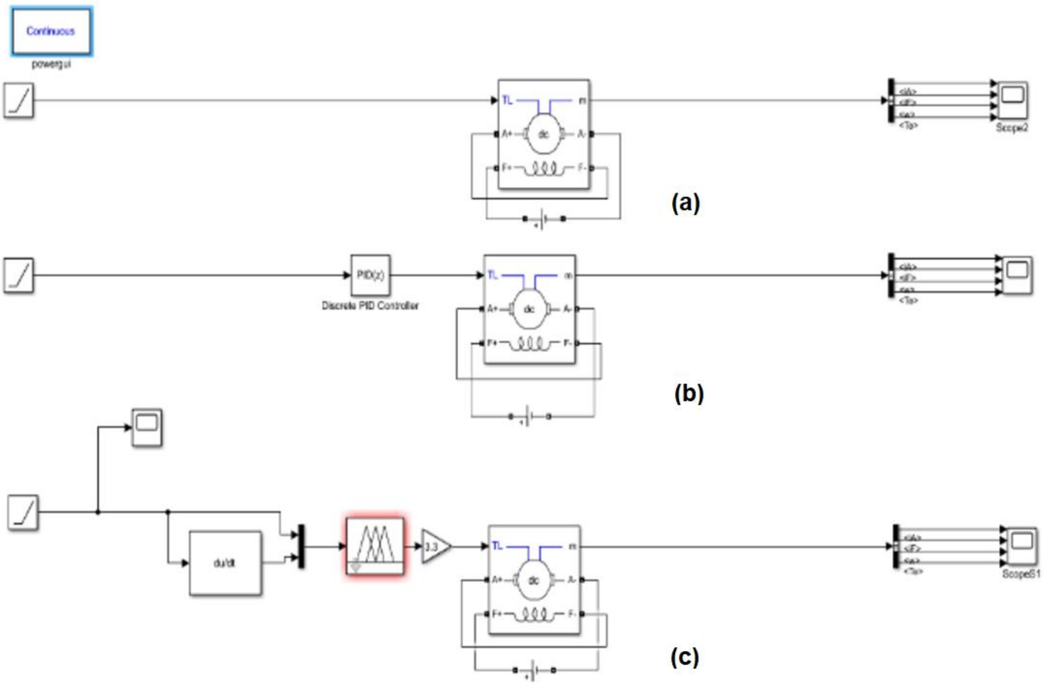


Fig. 5: The Simulink block diagrams (a) Series-wound motor without controller (b) with PID (c) with FLC

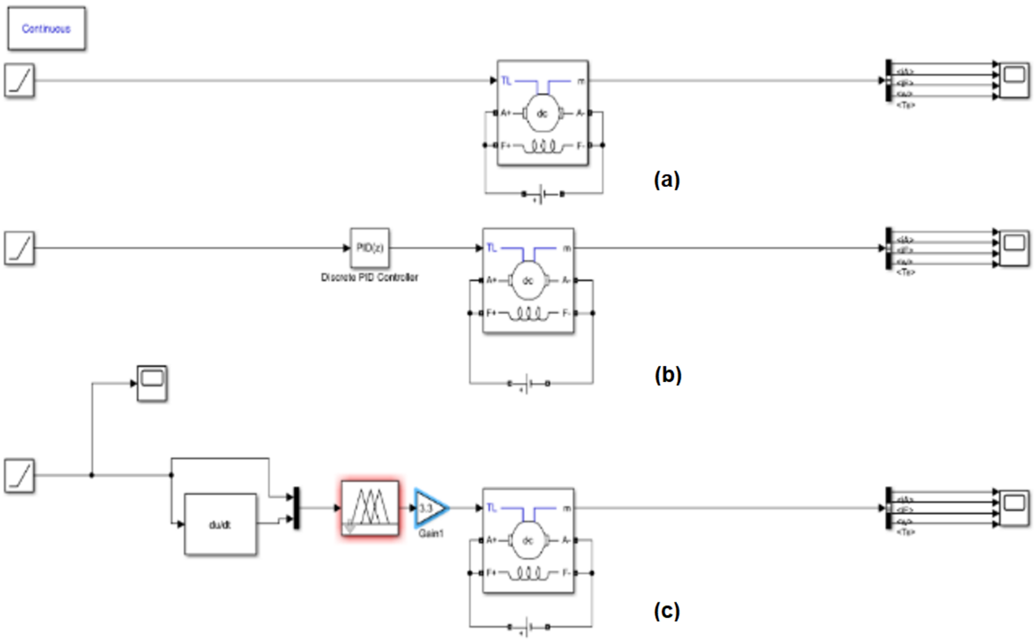


Fig. 6: The Simulink block diagrams (a) Shunt wound motor without controller (b) with PID (c) with FLC

Here Unit Step is given to the pre-set model (of 5HP 500V 1750RPM 300V) of the DC Shunt wound motor and DC Series wound motor. There parameter are as follows:
Armature resistance and inductance [Ra (ohms) La (H)], [11.2 0.1215]
Field resistance and inductance [Rf (ohms) Lf (H)], [281.3 156]
Field-armature mutual inductance Laf (H): 1.976
Total Inertia J (kg.m^2): 0.02215
Viscous friction coefficient Bm (N.m.s) 0.002953
Coulomb friction torque Tf (N.m) 0.5161
Initial speed (rad/s): 1
Initial field current (A): 1
In this proposed work, FLC is used as a speed controller due to its efficiency to control more flexibly, precisely and accurately and the results are presented in comparison without controller and with PID that the speed control of Fuzzy Logic Control is ultimately gives better system response.

5. Results and Discussions

The results shows that the study of speed control of DC Series wound motor and DC Shunt wound motor can be controlled with flexibility, accuracy, and precision through the execution of the designed model of both the motor's types respectively in the MATLAB as the figures shows the obtained system responses using PID, FLC and no Controller.

Fig. 7(a) shows the response of the system without controller for DC Series wound motor for output "Speed".
Armature Current (iA) possess a trasient frequency of 0.2Hz with an amplitude of 1.430 rad/sec.The waveform shows a falling time of 2.555 sec with overshoot of 1.3% and steadystate value of 0.55A and **Speed (w)** possess a transient frequency of 0.2Hz with an amplitude of 24.48 rad/sec. The waveform shows a overshoot of 0.9 % and steadystate value of 140A.

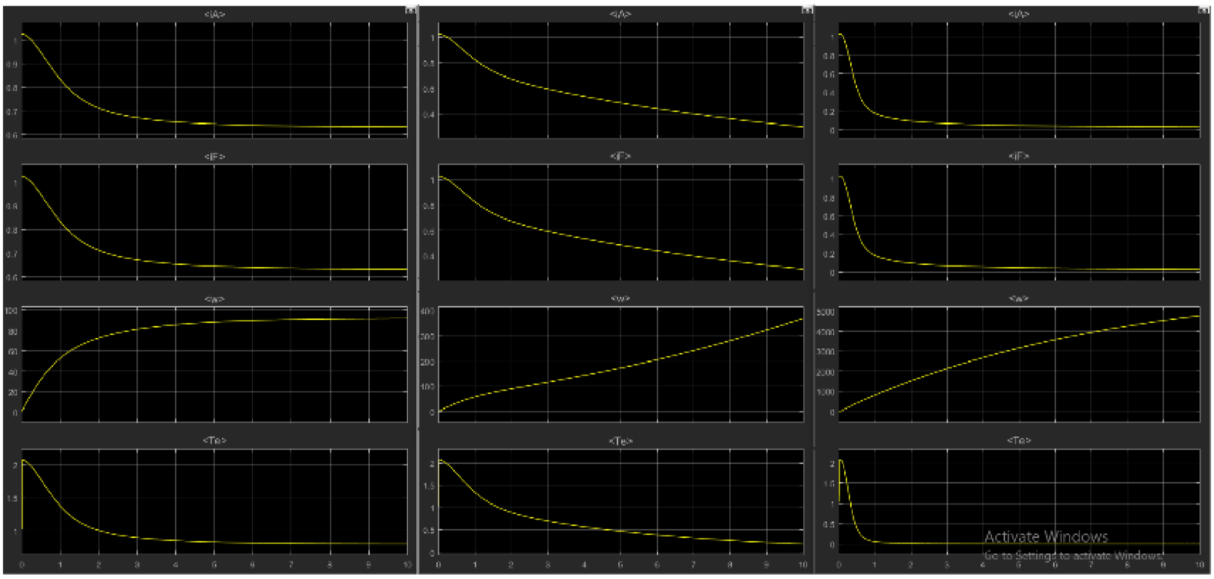
Fig. 7(b) shows the response of the system with PID controller for DC Series wound motor for output"Speed".
Armature Current (iA) possess a transient frequency of 0.2Hz, with an amplitude of 2.65 rad/sec. The waveform shows a falling time of 2.062 sec with overshoot of 1.2 % and steadystate value of 0.55A and **Speed (w)** possess a trasient frequency of 0.2Hzwith an amplitude of 27.00 rad/sec. The waveform shows a overshoot of 0.5 % and steadystate value of 140A.

Fig. 7(c) shows the response of the system with FL controller for DC Series wound motor for output "Speed".
Armature Current (iA) possess a transient frequency of 0.2Hz with an amplitude of 3.62287 rad/sec. The waveform shows a falling time of 1.132 sec with overshoot of 0% and steadystate value of 0.55A and **Speed (w)** possess a transient frequency of 0.2Hz with an amplitude of 94.9845 rad/sec. The waveform shows a overshoot of 0.0 % and steadystate value of 140 A.

Figure 8(a) shows the system reponse of without controller DC Shunt wound motor for output "Speed".
Armature Current (iA) possess a transient frequency of 0.2Hz with an amplitude of 5.82255 rad/sec. The waveform shows a falling time of 97 sec with overshoot of 27.5% and steadystate value of 0.5A and **Speed (w)** possess a transient frequency of 0.2Hz with an amplitude of 8.334855 rad/sec. The waveform shows a overshoot of 0.59 % and steadystate value of 140A.

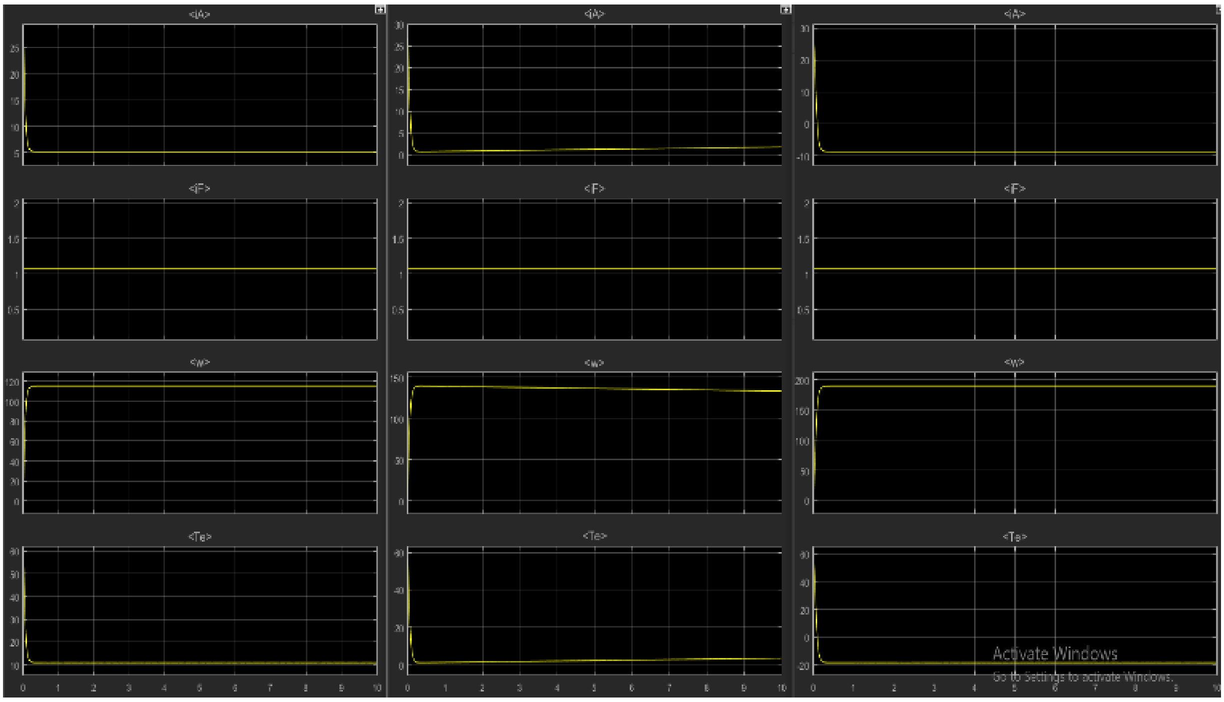
Figure 8(b) shows the response of the system with PID controller for DC Shunt wound motor for output "Speed".
Armature Current (iA) possess a transient frequency of 0.2Hz with an amplitude of 7.04578 rad/sec. The waveform shows a falling time of 96.5 with overshoot of 27.3% and steadystate value of 0.5A and **Speed (w)** possess a transient frequency of 0.2Hz with an amplitude of 10.108 rad/sec. The waveform shows a overshoot of 0.55 % and steadystate value of 140A.

Figure 8(c) shows the response of the system with FL controller for DC Shunt wound motor for output "Speed".
Armature Current (iA) possess a transient frequency of 0.2Hz with an amplitude 9.58466 rad/sec. The waveform shows a falling time of 96.0 sec with overshoot of 27.0% and steadystate value of 0.5A and **Speed (w)** possess a transient frequency of 0.2Hz with an amplitude of 27.1257 rad/sec. The waveform shows a overshoot of 0.50 % and steadystate value of 140A.



(a) (b) (c)

Fig. 7: System responses for DC Series wound motor in conditions of (a) without controller, (b) with PID and (c) with FLC



(a) (b) (c)

Fig. 7: System responses for DC Shunt wound motor in conditions of (a) without controller, (b) with PID and (c) with FLC

6. Conclusion

The performance of DC Shunt wound motor and DC Series wound motor models are simulated without any controller, with PID controller and then results are compared with FLC. The Trapezoidal Membership Functions model have been developed which is better than other models. The results show that FLC gives less Rise/Fall time and less overshoot than PID conventional controller and without controller system response The system shows better performance on both controllers as compared to without controller results and all the four parameters are monitored with all aspects (i.e., Rising/Falling time, amplitude, and overshoot). From the results it can be analyzed that FLC gives better, more accurate and precise control as compared to PID as it can be predicted from characteristics of the system that if FLC is implemented in large control system then this Artificial Intelligence based controller will give better results in more controllable manner than other conventional controllers with more preciseness, accuracy in the results.

References

[1] Yarlagadda, V., Radhika, G., Gnanendar, R., & Rajesh, K. (2021). cIn *Intelligent Computing in Control and Communication* (pp. 79-90).

[2] Yarlagadda, V., Babu, V. R., Veeresham, K., Rajesh, K., & Kumar, S. K. (2021). Transient Response Improvement of Separately Excited DC Motor Using Fuzzy Logic Controller. In *Proceedings of International Conference on Advances in Computer Engineering and Communication Systems*

[3] Pedapenki, K. K., & Kumar, J. (2021). Fuzzy Logic Controller-Based BLDC Motor Drive. In *Recent Advances in Power Electronics and Drives*

[4] Thattil, A., Vachhani, S., Raval, D., Patel, P., & Sharma, P. (2019). Comparative Study of using Different Electric Motors for EV. *International Research Journal of Engineering and Technology (IRJET)*, *6*(4), 4601-4604.

[5] Parhizkar, N., Shafiei, M., & Kouhshahi, M. B. (2011, August). Direct torque control of brushless DC motor drives with reduced starting current using fuzzy logic controller. In *2011 International Conference on Uncertainty Reasoning and Knowledge Engineering* (Vol. 1, pp. 129-132). IEEE.

[6] Shanmugasundram, R., Zakariah, K. M., & Yadaiah, N. (2009, November). Digital implementation of fuzzy logic controller for wide range speed control of brushless DC motor. In *2009 IEEE International Conference on Vehicular Electronics and Safety (ICVES)* (pp. 119-124). IEEE.

[7] Chitra, V., & Prabhakar, R. S. (2006). Induction motor speed control using fuzzy logic controller. *World Academy of Science, Engineering and Technology*, *23*(2006), 17-22.

[8] Guillemin, P. (1996). Fuzzy logic applied to motor control. *IEEE transactions on industry applications*, *32*(1), 51-56.

[9] Rajagiri, A. K., Rani, S., & Nawaz, S. S. (2019). Speed control of dc motor using fuzzy logic controller by pci 6221 with matlab. In *E3S Web of Conferences* (Vol. 87, p. 01004). EDP Sciences.

[10] Premkumar, K., & Manikandan, B. V. (2013, February). Adaptive fuzzy logic speed controller for brushless DC motor. In *2013 International Conference on Power, Energy and Control (ICPEC)* (pp. 290-295). IEEE.

[11] Ibrahim, B. S. K. K., Azubir, N. A. M., Ishak, N. H. M., Hassan, M. K., Toha, S. F., Abidin, M. A. Z., & Zamzuri, H. (2012, November). PI-fuzzy logic control for 3 phase bldc motor for electric vehicle application. In *2012 Sixth UKSim/AMSS European Symposium on Computer Modeling and Simulation* (pp. 84-88). IEEE.

[12] Aloui, H., Jridi, A. B., Chaker, N., & Neji, R. (2013, December). Fuzzy control for speed tracking of an electrical vehicle enclosing an axial-flux synchronous motor. In *14th International Conference on Sciences and Techniques of Automatic Control & Computer Engineering-STA'2013* (pp. 36-42). IEEE.

[13] Natick, Fuzzy Logic Toolbox User's Guide, 1995 – 1999.

[14] Mohan, N., Undeland, T. M., & Robbins, W. P. (2003). *Power electronics: converters, applications, and design*. John wiley & sons.

[15] Neema, D. D., Patel, R. N., & Thoke, A. S. (2011). Speed control of induction motor using fuzzy rule base. *International Journal of Computer Applications*, *33*(5), 21-29.

[16] Allan R. Hambly, Electrical Engineering Principles and Applications, chapter 16.

[17] Karl Johan Astrom, control system design,2002.

[18] Almatheel, Y. A., & Abdelrahman, A. (2017, January). Speed control of DC motor using Fuzzy Logic Controller. In *2017 International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE)* (pp. 1-8). IEEE.

[19] Azizah, D. F., Dedes, K., & Utama, A. B. P. (2021, October). DC Motor Speed Modeling and Simulation Using Fuzzy Logic Control Method. In *2021 7th International Conference on Electrical, Electronics and Information Engineering (ICEEIE)* (pp. 279-284). IEEE.

[20] Djafar, D. (2021). Speed control of induction motor with broken bars using sliding mode control (SMC)

[21] based to on type-2 fuzzy logic controller (T2FLC).

[22] Atar, K. D., Patil, C. B., & Mudholkar, R. R. (2021). Fuzzy algorithm implementation in microcontroller for DC motor control. *International Journal of Engineering, Science and Technology*, *13*(3), 1-9.

[23] Jayetileke, H. R., de Mel, W. R., & Ratnayake, H. U. W. (2021). Dynamic Optimization Self-adaptive AI Controller for a Four-wheel Independent Drive Electric Rover. *Advances in Technology*, 127-145.

[23] . Sriram and K. Sureshkumar (2014) “Speed Control of BLDC Motor Using Fuzzy Logic Controller Based on Sensorless Technique,” International Conference on Green Computing Communication and Electrical Engineering: 1–6.