Arduino based stepper motor speed regulation for robotics applications

Khammampati R. Sreejyothi[1], Kalagotla Chenchireddy[2], Abbagoni Srujana[1], Dharavath Nagaraju[1], Golluri Ramcharan[1], Dhunnapothula Raghu[1]

[1]Department of Electrical and Electronics Engineering, Teegala Krishna Reddy Engineering College, Hyderabad, India
[2]Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology, Hyderabad, India

Article Info

ABSTRACT

This paper presents a stepper motor drive using the hybrid two-phase model. The stepper motor changes the pulse signals into angular displacement with some angles. Stepper motors are used to control the speed and are also more reliable for smooth operations. The stepper motor provides constant holding torque with controlled speed ranges from 0 to 6000 range. The closed-loop control technique with park transformation is used to control the speed torque variables in a design range. The simulation and hardware results were discussed in MATLAB\Simulink software. The verified simulation results are motor source voltage, motor source current, motor speed, and torque. The hardware results are also implemented in this paper, the implemented circuit by using Arduino microcontroller.
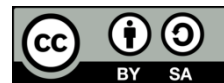
Corresponding Author:

Khammampati R. Sreejyothi
Department of Electrical and Electronics Engineering, Teegala Krishna Reddy Engineering College
Medbowli, Saroornagar, Meerpet, India
Email: krs.jyothi@gmail.com

1. INTRODUCTION

The best methods and their microprocessor implementation for closed-loop control of hybrid stepper motor drives were presented by the authors. The torque characteristics and ideal control angle of reluctant stepper motor drives and hybrid stepper motor drives with additional series resistance have already been covered in earlier research [1]. The primary contribution of the research is the analysis of the torque characteristics and ideal control angle of hybrid stepper motor drives that are fitted with a current controller and chopper amplifier [2]–[4]. The authors concentrated on the challenge of creating nonlinear controllers synthetically to guarantee stable tracking of servo systems driven by stepper motors with permanent magnets. To address the robust design, the authors make use of the admissibility idea, the Lyapunov-based design framework, and electric machinery reasoning. Using nonquadratic Lyapunov candidates and investigating the idea of nonlinear mapping, they present a novel nonlinear control technique [5]–[7]. The study also considers the case where stepper motor parameters vary, necessitating thorough research to ensure the validity and accuracy of the analytical, numerical, and experimental results [8]–[10]. The authors were presented on the modeling, simulation, and control of a two-phase hybrid stepper motor (HSM). The authors develop a simulation model using MATLAB to analyze the motor's transient performance under different excitation schemes. The simulation results are validated for two specific HSM models: ST601 and ST1701, with step angles of 1.8 degrees and torque ratings of 2 Kg.cm and 125 Kg.cm, respectively. To implement open-loop control, the authors use National Instruments LABVIEW along with a DAQ card PCI 6221. They experimentally observe and explain the resonance phenomenon in the motor system [11]–[12]. To maintain

speed under various loads, closed-loop current control is employed. Non-uniform motion in machines can be achieved using linkage mechanisms or cams, which transform the uniform motion from a motor into the desired non-uniform motion, alternatively, a servo motor can directly generate non-uniform motion under computer control. Linkage mechanisms and cams can enable higher speeds in the machine's operation [13]–[14]. They also allow for dynamic balancing to be incorporated without the need for additional parts, and they generally exhibit a high degree of energy conservation during motion [15]–[16]. The paper addresses the limitations of widely used full-step open-loop stepping motor drive algorithms, which suffer from a low torque/power ratio, large torque ripple, and resonance issues [17]–[18]. To improve the performance of stepping motors for more demanding applications, closed-loop control is proposed [19]. The paper introduces a load angle estimation algorithm, which utilizes only voltage and current measurements to provide the necessary feedback without requiring a mechanical position sensor [20]–[23]. Building upon this estimation, a novel closed-loop load angle controller is presented. The controller optimizes the current level based on the estimated load angle. Developing this controller is challenging due to the highly nonlinear current and load-angle dynamics [24]–[26]. This paper presents stepper motor control drive by using Arduino controller. The simulations are verified by using MATLAB/Simulink software.

2. STEPPER MOTOR

The Figure 1 shows the basic principle of a stepper motor's operation involves a cycle of electromagnets arranged around a rotor. These electromagnets are activated one after another in a specific sequence using pulses of electrical energy. When an electromagnet is energized, it generates a magnetic force that interacts with the rotor (typically made of iron). This interaction causes the rotor to move in incremental steps. The direction of rotation (clockwise or counterclockwise) depends on the sequence in which the electromagnets are activated. This controlled movement is widely used in applications requiring precise positioning and controlled rotation.

$$\frac{di_a}{dt} = [v_a - Ri_a + K_m\omega \sin(N_r\theta)]/L \tag{1}$$

$$\frac{di_b}{dt} = [v_b - Ri_b + K_m\omega \sin(N_r\theta)]/L \tag{2}$$

The (1) and (2) are the a and b phase differential equations.

$$\frac{d\omega}{dt} = [-K_m i_a \sin(N_r\theta) + K_m i_b \cos(N_r\theta) - B\omega - T_L + K_d \sin(4N_r\theta)]/J \tag{3}$$

$$\frac{d\theta}{dt} = \omega \tag{4}$$

$$M = \begin{pmatrix} \cos(N_r\theta) & \sin(N_r\theta) \\ -\sin(N_r\theta) & \cos(N_r\theta) \end{pmatrix} \tag{5}$$

$$\frac{di_d}{dt} = [v_d - Ri_a + N_r\omega Li_q)]/L \tag{6}$$

$$\frac{di_q}{dt} = [v_q - Ri_q + K_m\omega - N_r\omega i_d)]/L \tag{7}$$

The (6) and (7) are the d-axis and q-axis first-order differential equation currents.

$$\frac{d\omega}{dt} = [K_m i_q - B\omega] \tag{8}$$

$$\frac{d\theta}{dt} = \omega \tag{9}$$

$$\frac{di_{a\_fb}}{dt} = -\frac{R}{L_o}i_{a\_fb} + \frac{K_m}{L_o}\omega_{fb}\sin(N_r\theta_{fb}) + \frac{v_{A+} - v_{A-}}{L_o} \tag{10}$$

$$\frac{di_{b\_fb}}{dt} = -\frac{R}{L_o}i_{b\_fb} - \frac{K_m}{L_o}\omega_{fb}\cos(N_r\theta_{fb}) + \frac{v_{B+} - v_{B-}}{L_o} \tag{11}$$

$$T = K_m[-i_{a\_fb}\sin(N_r\theta_{fb}) + i_{b\_fb}\cos(N_r\theta_{fb})] - K_{d4}\sin(4N_r\theta_{fb}) \tag{12}$$

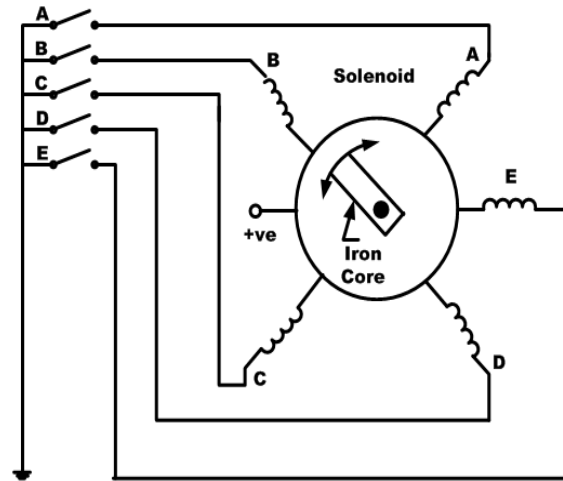The (12) represents the torque equation of stepper motor.

Figure 1. Stepper motor drive circuit diagram

3. CONTROL SCHEME

Figure 2 shows the closed loop control of stepper motor. The servo system model consists of a motor with position feedback obtained from an optical encoder. Current control is achieved through a digital PI current loop with proportional gain (Kp) and integration gain (Ki). An external torque is applied to the motor shaft for testing. The identified constants, after tuning, include Kd4, Kd2, and Kd1 for torque ripple reduction, along with phase angles φ2 and φ1, and Fs values for clockwise and anticlockwise motion. Surprisingly, the first- and second-harmonic torque ripples are more significant than the fourth-harmonic ripple, despite conventional expectations. Additionally, static friction contributes to damping motor vibrations.
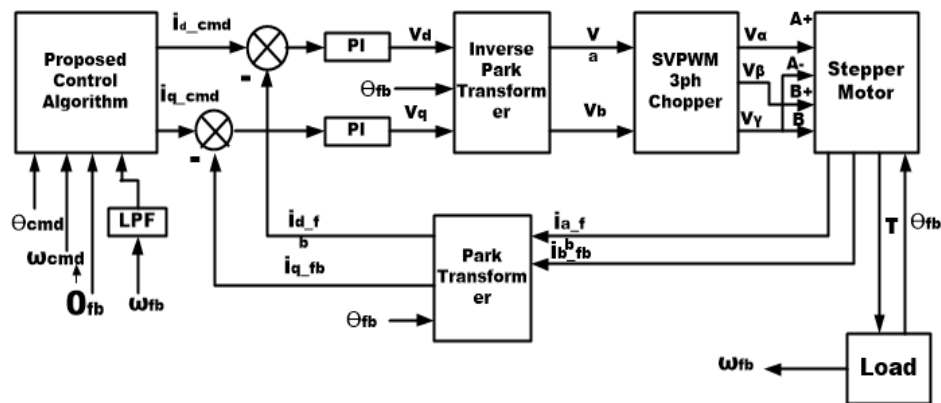

Figure 2. Closed loop stepper motor control scheme

4. RESULTS AND DISCUSSION

Figure 3 shows the stepper motor simulation diagram. The stepper motor moves in steps, unlike other machines where the motor rotates. They are not the one that where gives out power but they give torque. Here we have a torque a force a displacement which gives torque in pulses. It is not a continuous energy conversion device. An electromechanical device that transforms electrical pulses into distinct mechanical movements is called a stepper motor. When electrical command pulses are supplied to the stepper motor in the correct order, the shaft rotates in discrete step increments. Incredibly dependable because the motor lacks contact brushes. As a result, the motor's life is solely dependent upon the bearing's longevity. Open-loop control was made possible by the motor's reaction to digital input pulses, which made controlling it easier and less expensive. The stepper motor simulation parameters are displayed in Table.1.
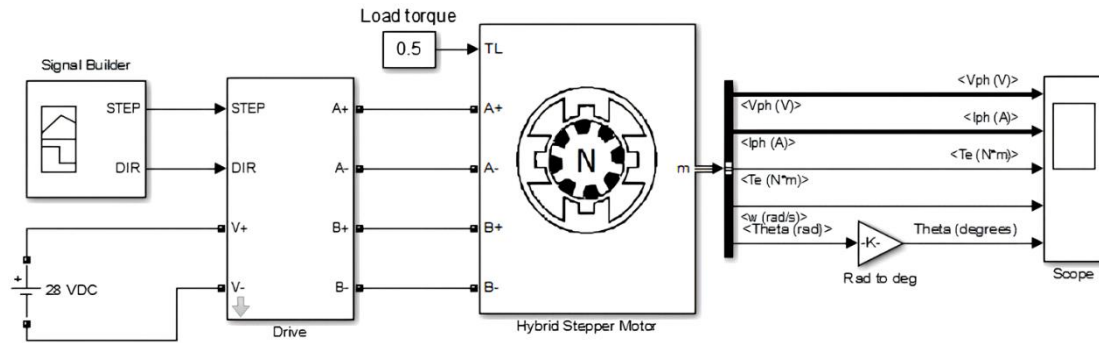
Figure 3. Stepper motor MATLAB/Simulink diagram

Table 1. Motor parameters

S.L.	Criteria	Achievement
1	DC supply	28 V
2	Motor input current	2 A
3	Winding inductance	1.4 mH
4	Winding resistance	0.7 Ohm
5	Step angle	1.8

Figure 4 shows the stepper motor input voltage the magnitude of the voltage is 25 volts. This voltage determines the strength of the magnetic field generated within the coils, which in turn controls the movement of the motor's rotor. The input wave is a square wave. A square wave is a type of two distinct voltage levels, typically a high voltage level and a low voltage level. The red color shows the A phase and the blue color shows the B phase. Figure 5 shows the stepper motor input current wave from the magnitude of the current is 2.5 Amps. The amount of electric current flowing through the coils of the stepper motor. In this waveform, the A phase and B phase operate in a complementary manner. One phase is energized with current, and the other phase is de-energized. When one phase is energized, the current rises to the specified magnitude, and when the phase is de-energized, the current drops back down.
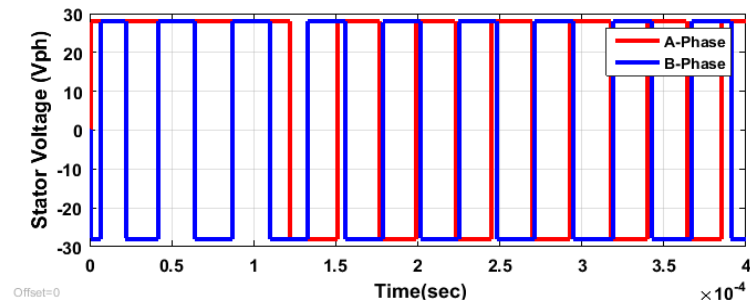
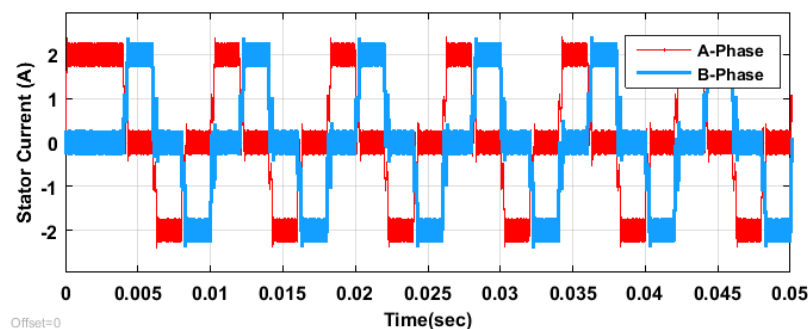

Figure 4. Stepper motor stator voltage waveforms

Figure 5. Stepper motor stator current waveforms

Figure 6 shows the stepper motor input torque waveform the torque waveform looks like a chattering. "Chattering" describes irregular torque behavior in a stepper motor due to resonance, low torque, missed steps, noise, and incorrect current or mechanical issues. Figure 7 shows that we compared all the input motor voltage, current, torque, and speed. Speed and torque look like an inverse proportion in this waveform. Figure 7(a) shows the input voltage and the magnitude of voltage is 25 volts. The input waveform is a square wave.in Figure 7(b) current is 0 to 1 sec. The current is steady state after 1 sec the current is dynamic state. The waveform takes time 2 cycles for stability. The Figure 7(c) shows the torque wave form. In Figure 7(d) the speed waveform increases from 0 to 6000. Time taken for the increase is 0.005 sec.
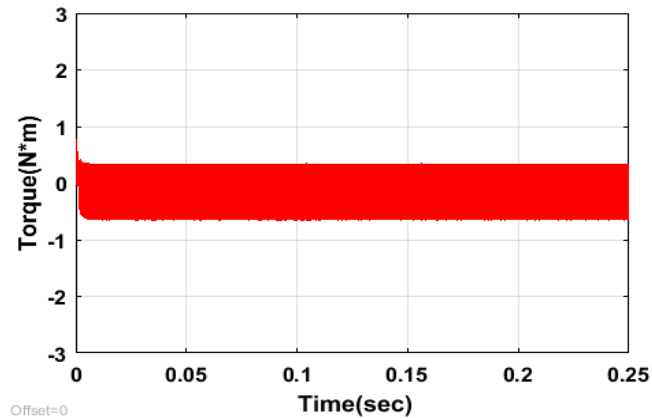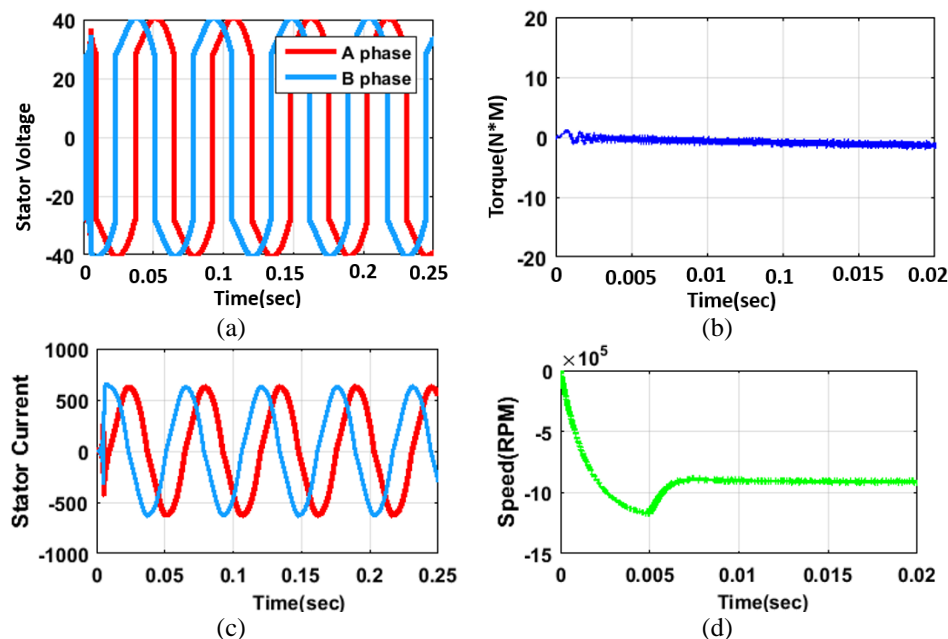

Figure 6. Stepper motor torque waveform

Figure 7. Stepper motor waveforms (a) source voltage, (b) source current, (c) torque, and (d) speed

Figure 8 shows the stepper motor design in tinker cad. The major components in this diagram are the motor, battery, and IC ULN2004A. The Arduino is used for generating pulses for the stepper motor. The battery gives a supply to the motor. The resister controls the current. Figure 9 This hardware implementation of the stepper motor. In this hardware Arduino Uno board 5 k ohm stepper motor: the primary actuator that converts electrical pulses into rotational movement. It has coils or phases that need specific signals to move. Battery: provides the power supply to the motor. Ensure it's suitable for the motor's voltage and current requirements. IC ULN2004A: A motor driver IC that acts as a buffer between the Arduino and the motor coils. It amplifies the signals and handles the higher current requirements. The Arduino is to generated pulses that control the stepper motor's movement. It sends step and direction signals to the ULN2004A. The resister

might be used to control the current flowing through the motor coils. It helps prevent excessive current that could damage the motor. The widely used and adaptable Arduino platform is ideal for managing stepper motors. Numerous applications, such as robotics, CNC machines, 3D printers, and others frequently use stepper motors.
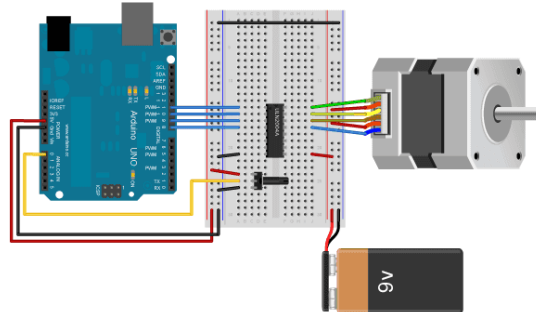
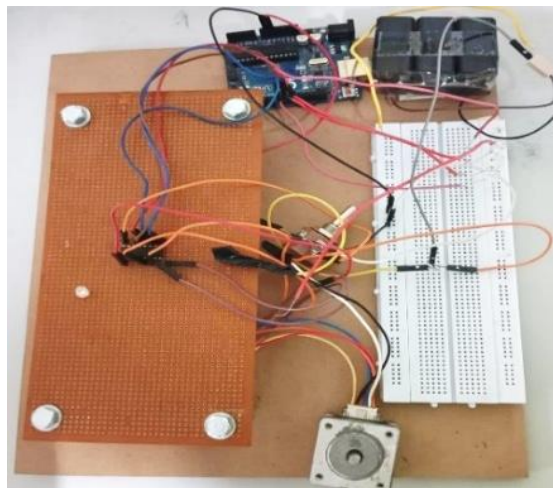

Figure 8. Stepper motor interfacing diagram

Figure 9. Stepper motor hardware diagram

5. CONCLUSION

This paper presented speed control of stepper motor using Arduino. There are many special purpose motors are available in market, like brush less dc motor, switched reluctance motor and servo motor. Comparing to all this special purpose motors stepper motor has special features, this is highly reliable and there no contact brushes in motor. This paper stepper motor simulation results are verified in MATLAB/Simulink. The verified results are speed, torque, and current. The steady-state simulation results are shown in results section.

REFERENCES

[1] C. Zheng and Z. Zhang, "Implementation of 4-axis stepper motor control system based on TC5540," in *2011 International Conference on Electrical and Control Engineering*, IEEE, Sep. 2011, pp. 210–212, doi: 10.1109/ICECENG.2011.6057015.

[2] K. R. Sreejyothi, P. V. Kumar, and J. Jayakumar, "SRF theory-based PI controller applied to micro grid interfaced with hybrid sources for power quality improvement," in *2022 8th International Conference on Advanced Computing and Communication Systems (ICACCS)*, IEEE, Mar. 2022, pp. 01–06, doi: 10.1109/ICACCS54159.2022.9785173.

[3] M. Onsal, Y. Demir, M. Aydin, and M. . Guven, "Impact of airgap on the performance of 3-phase permanent magnet hybrid stepper motor," in *IECON 2021 – 47th Annual Conference of the IEEE Industrial Electronics Society*, IEEE, Oct. 2021, pp. 1–5, doi: 10.1109/IECON48115.2021.9589260.

[4] K. R. S. Jyothi, P. V. Kumar, and J. Jayakumar, "A review of different configurations and control techniques for DSTATCOM in the distribution system," *E3S Web of Conferences*, vol. 309, p. 01119, Oct. 2021, doi: 10.1051/e3sconf/202130901119.

[5]   P. Prodanov and D. Dankov, "Reliability of low-power stepper motor drivers," in *2022 XXXI International Scientific Conference Electronics (ET)*, IEEE, Sep. 2022, pp. 1–5, doi: 10.1109/ET55967.2022.9920214.

[6]   I. C. Stika, L. Kreindler, and A. Sarca, "A robust method for stepper motor stall detection," in *2013 8th International Symposium on Advanced Topics in Electrical Engineering (ATEE)*, IEEE, May 2013, pp. 1–5, doi: 10.1109/ATEE.2013.6563391.

[7]   C.-K. Lai, J.-S. Ciou, and C.-C. Tsai, "FPGA-based stepper motor vector control system design," in *2017 International Automatic Control Conference (CACS)*, IEEE, Nov. 2017, pp. 1–5, doi: 10.1109/CACS.2017.8284269.

[8]   B. Aranjo, P. K. Soori, and P. Talukder, "Stepper motor drives for robotic applications," in *2012 IEEE International Power Engineering and Optimization Conference*, IEEE, Jun. 2012, pp. 361–366, doi: 10.1109/PEOCO.2012.6230890.

[9]   N. F. B. Filho, "Numerical and experimental analysis on the planar force and the magnetic field in a DC Linear Stepper Motor," in *2013 Brazilian Power Electronics Conference*, IEEE, Oct. 2013, pp. 884–889, doi: 10.1109/COBEP.2013.6785219.

[10]   K. R. Sreejyothi, K. Chenchireddy, N. Lavanya, R. M. Reddy, K. Y. G. Prasad, and R. Revanth, "Level-shifted PWM techniques applied to flying capacitor multilevel inverter," in *2022 International Conference on Electronics and Renewable Systems (ICEARS)*, IEEE, Mar. 2022, pp. 41–46, doi: 10.1109/ICEARS53579.2022.9752074.

[11]   K. Thadkapally, F. T. Josh, J. J. Joseph, and J. Jayakumar, "The hybrid solar energized back-to-back high voltage direct current modular converter for distributed networks," *Bulletin of Electrical Engineering and Informatics*, vol. 13, no. 1, pp. 88–97, Feb. 2024, doi: 10.11591/eei.v13i1.5771.

[12]   S. Gong and B. He, "LabVIEW-base automatic rising and falling speed control of stepper motor," in *2009 International Conference on Electrical Machines and Systems*, IEEE, Nov. 2009, pp. 1–4, doi: 10.1109/ICEMS.2009.5382704.

[13]   W. Kim, C. Yang, and C. C. Chung, "Design and implementation of simple field-oriented control for permanent magnet stepper motors without DQ transformation," *IEEE Transactions on Magnetics*, vol. 47, no. 10, pp. 4231–4234, Oct. 2011, doi: 10.1109/TMAG.2011.2157956.

[14]   A. H. Ahmed, A. E. S. B. Kotb, and A. M. Ali, "Comparison between fuzzy logic and PI control for the speed of BLDC motor," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, no. 3, p. 1116, Sep. 2018, doi: 10.11591/ijpeds.v9.i3.pp1116-1123.

[15]   M. A. Ibrahim, A. K. Mahmood, and N. S. Sultan, "Optimal PID controller of a brushless dc motor using genetic algorithm," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 2, p. 822, Jun. 2019, doi: 10.11591/ijpeds.v10.i2.pp822-830.

[16]   S. J. Hammoodi, K. S. Flayyih, and A. R. Hamad, "Design and implementation speed control system of DC Motor based on PID control and matlab simulink," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, p. 127, Mar. 2020, doi: 10.11591/ijpeds.v11.i1.pp127-134.

[17]   M. S. Amiri, M. F. Ibrahim, and R. Ramli, "Optimal parameter estimation for a DC motor using genetic algorithm," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 2, p. 1047, Jun. 2020, doi: 10.11591/ijpeds.v11.i2.pp1047-1054.

[18]   F. A. Hasan and L. J. Rashad, "Fractional-order PID controller for permanent magnet DC motor based on PSO algorithm," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 4, p. 1724, Dec. 2019, doi: 10.11591/ijpeds.v10.i4.pp1724-1733.

[19]   B. Ramesh, K. Chenchireddy, B. N. Reddy, B. Siddharth, C. V. Kumar, and P. Manojkumar, "Closed-loop control of BLDC motor using hall effect sensors," *International Journal of Applied Power Engineering (IJAPE)*, vol. 12, no. 3, p. 247, Jul. 2023, doi: 10.11591/ijape.v12i3.pp247-254.

[20]   J. Yu, Y. Wang, H. Kang, and G. Lu, "A control system of three-axis stepper motor based on the FPGA," in *Proceedings 2013 International Conference on Mechatronic Sciences, Electric Engineering and Computer (MEC)*, IEEE, Dec. 2013, pp. 3334–3337, doi: 10.1109/MEC.2013.6885593.

[21]   M. A. Vernezi, D. V. Nazarenko, and E. H. Abderrazzak, "Vibration suppression of stepper motors by the electric method," in *2021 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, IEEE, May 2021, pp. 566–570, doi: 10.1109/ICIEAM51226.2021.9446366.

[22]   T. A. Khan, T. A. Taj, and I. Ijaz, "Hybrid stepper motor and its controlling techniques a survey," in *Proceedings of the 2014 IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference*, IEEE, Feb. 2014, pp. 79–83, doi: 10.1109/ElConRusNW.2014.6839207.

[23]   K. P. Soneji, H. K. Patel, and S. Karkari, "Vacuum linear feed through drive using stepper motor and lead screw," in *2013 Nirma University International Conference on Engineering (NUiCONE)*, IEEE, Nov. 2013, pp. 1–4, doi: 10.1109/NUiCONE.2013.6780185.

[24]   D. Ceulemans, N. van Oosterwyck, J. Demetsenaere, J. de Viaene, J. Steckel, and S. Derammelaere, "Time-optimal stepper motor motion profile through a novel load-angle-based step-command optimization," in *2021 IEEE International Electric Machines & Drives Conference (IEMDC)*, IEEE, May 2021, pp. 1–7, doi: 10.1109/IEMDC47953.2021.9449522.

[25]   K. Chenchireddy, V. Kumar, and K. R. Sreejyothi, "Investigation of performance vector control single-phase induction motor," in *2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS)*, IEEE, Mar. 2021, pp. 887–891, doi: 10.1109/ICACCS51430.2021.9441773.

BIOGRAPHIES OF AUTHORS

Khammampati R. Sreejyothi 🆔 📇 sc 🔗 is an Assistant Professor of Electrical and Electronics Engineering at Teegala Krishna Reddy engineering College located at Hyderabad. She pursuing her Ph.D. at Karunya Institute of Technology and Sciences located at Coimbatore, Tamil Nadu. Completed her M.Tech. in Dr. Paul Raj Engineering College located at Bhadrachalam, Khammam dist in 2013. Completed her B.Tech. in SAI Spurthi Institute of Technology located at Sathupally, Khammam dist in 2009. Her research interest includes power systems, power electronics. She can be contacted at email: krs.jyothi@gmail.com.

Kalagotlam Chenchireddy ⬡ 🔳 🆂🅲 ⬡ is received the B.Tech. and M.Tech. from JNTU Hyderabad, Hyderabad, India, in 2011 and 2013 respectively and completed Ph.D. in Karunya Institute of Technology and Sciences, Karunyanagar, Coimbatore, Tamil Nadu, India. He is working presently as Assistant Professor in Geethanjali College of Engineering and Technology, Hyderabad, India, in 2024. He has presented technical papers in various National and International Conferences. His area of interest includes power electronics, power quality; multilevel inverters. He is a regular reviewer of ISA Transactions, Cybernetics and Systems SCIE journals, IJPEDS and IJAPE. He can be contacted at email: chenchireddy.kalagotla@gmail.com.

Abbagoni Srujana ⬡ 🔳 🆂🅲 ⬡ is presently UG Student in Electrical and Electronics Engineering, at Teegala Krishna Reddy Engineering College, Hyderabad, India. She has presented technical papers at various National and International Conferences. His area of interest includes power electronics, power quality; multilevel inverters. She developed a single-phase inverter in Teegala Krishna Reddy Engineering College, Hyderabad. She can be contacted by email: srujanaabbagoni@gmail.com.

Dharavath Nagaraju ⬡ 🔳 🆂🅲 ⬡ he is presently UG Student in Electrical and Electronics Engineering Department, Teegala Krishna Reddy Engineering College, Hyderabad, India. He has presented technical papers in various National and International Journals and Conferences. His area of interest includes power electronics, power quality, multilevel inverters. He got first Prize national level project expo 2023 in VJIT college Hyderabad. He can be contacted at email: dharavathnagaraju2001@gmail.com.

Golluri Ramcharan ⬡ 🔳 🆂🅲 ⬡ he is presently UG Student in Electrical and Electronics Engineering Department, Teegala Krishna Reddy Engineering College, Hyderabad, India. He has presented technical papers in various National and International Journals and Conferences. His area of interest includes power electronics, power quality, multilevel inverters. He got first Prize national level project expo 2022 in NNRG college Hyderabad. He can be contacted at email: charansagar098@gmail.com.

Dhunnapothula Raghu ⬡ 🔳 🆂🅲 ⬡ he is presently UG Student in Electrical and Electronics Engineering Department, Teegala Krishna Reddy Engineering College, Hyderabad, India. He has presented technical papers in various National and International Journals and Conferences. His area of interest includes power electronics, power quality, multilevel inverters. He got first Prize national level project expo 2023 in Gitanjali Engineering college Hyderabad. He can be contacted at email: raghudp1122@gmail.com.