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A New Approach of BLDC Motor Using Fuzzy Fractional Order PID

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ABSTRACT- In order to manage the speed of brushless DC (BLDC) motors, this research presents a novel hybrid control method that simultaneously regulates the DC bus voltage of the inverter and the BLDC motor reference current. A fractional-order PID (FOPID) controller manages the BLDC motor reference current, and a fuzzy logic controller manages the inverter DC bus voltage. A modified harmony search (HS) metaheuristic technique is developed for adjusting the FOPID controller parameters. Three separate working scenarios—no load, varying load, and varying speed—are used to test the motor's capabilities. Run the proposed controller at a high speed to verify its efficacy. The suggested hybrid control method has also been put to the test. weighed against FOPID and fuzzy-based speed control techniques The outcomes demonstrate the effectiveness of the suggested control. approach enables more accurate speed control over a wide region.

I. INTRODUCTION

Brushless dc (BLDC) motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact size, reliability, and little maintenance requirements. However, over the past few decades, ongoing technological advancements in the production of permanent-magnet brushless electric motors, microprocessors, adjustable speed driver control schemes, and power semiconductors have combined to offer a dependable, economical solution for a variety of adjustable speed applications. One of the markets for electronic motor drivers' end products expected to develop at the greatest rate over the next five years is home appliances. There are also large pieces of equipment like clothes washers, room air conditioners, refrigerators, vacuum cleaners, and freezers. Traditional household appliances, such as split phase, capacitor-start, capacitor-run types, and universal motors, have relied on single phase AC induction. These conventional motors are frequently operated at constant speed while using main AC power, regardless of efficiency. Consumers are placing a higher priority on lower energy costs, better performance, less acoustic noise, and more convenience features. Traditional technologies are unable to offer fixes. Almost all market segments employ BLDC motors. Just a few examples such as Constant load BLDC motor, Differential loads, and Applications for positioning include appliances, industrial control, automation, and aircraft. These are the kinds of applications where keeping the accuracy of a given speed is less important than having a variable speed. In some applications, the load is directly connected to the motor shaft. These kinds of devices include blowers, pumps, and fans. These applications demand low-cost, essentially open-loop controllers. These are the uses where the load on the motor fluctuates throughout a speed range. These applications might require accurate and responsive high-speed control. Home appliances include things like washers, dryers, and compressors. In the automobile sector, examples of this include fuel pump control, electronic steering control, engine control, and electric vehicle control. The aerospace industry uses a wide range of technologies, including centrifuges, pumps, robotic arm controls, gyroscope controls, and others. These programmes may use speed feedback tools and can run in either a partially closed loop or a closed loop at all times. These applications employ intricate control strategies, making it more challenging to operate the controller. Additionally, this increases the system's overall cost.

Compared to DC motors, BLDC motors provide a number of benefits.

- Strong dynamic reaction.
- Effectiveness
- Long lifespan in use
- Little is being done.
- Wider speed range

The primary drawback of BLDC is its increased cost, which is caused by two drawbacks. To begin with, the operation of BLDC motors requires sophisticated electronic speed controllers. Brushed DC motors can be controlled by a fairly simple variable resistor (potentiometer or rheostat), which is inefficient but suited for applications where cost is a concern.

II. BLDC MOTOR DRIVE SYSTEM

A permanent magnet stimulated synchronous motor is fed by a variable frequency inverter under the control of a shaft position sensor in BLDC motor driving systems. Commercial simulation tools for the creation of controllers for these BLDC motor drives seem to be lacking. One of the main reasons is that their typical low cost fractional/integral kW application areas, like NC machine tools and robot drives, do not justify the high software development costs incurred, even though doing so might imply the possibility of demagnetizing the rotor magnets during commissioning or tuning stages. Recursive prototyping of the motor and inverter, however, may be used in unique drive topologies for cutting-edge and specialised applications, leading to a high drive system development cost. The market for BLDC motors is being driven into application regions with tens of kW where commissioning errors become prohibitively expensive by improved magnet materials with high (B.H) product. Modelling is therefore crucial and may provide cost-saving opportunities.

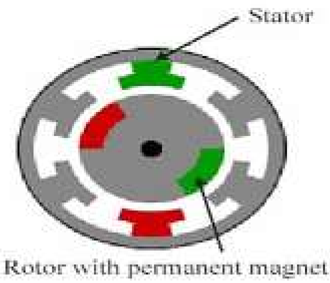

Figure 1: Cross-section view of a brushless dc motor

A. *Principle operation of Brushless DC (BLDC) Motor*

A brushless dc motor is a permanent synchronous device with rotor position feedback. To regulate brushless motors, a three-phase power semiconductor bridge is frequently employed. The motor needs a rotor position sensor to start and give the proper commutation sequence to turn on the power devices in the inverter bridge. Based on the rotor position, the power devices commutate every 60 degrees. It is an electronic motor because electronic commutation is used to switch the armature current instead of brushes. This makes a BLDC motor more lasting than a dc motor by eliminating issues related to the brush and commutator arrangement, such as sparking and the commutator brush arrangement wearing out.

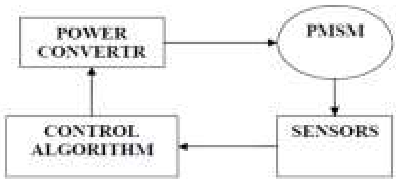

Figure 2: Basic block diagram of BLDC motor

The basic block diagram of a brushless dc motor is displayed in Figure 2.1. A power converter, permanent magnet-synchronous machine (PMSM) sensors, and a control algorithm are the four main parts of the brushless dc motor. The power converter converts power from the source to the PMSM, transforming electrical energy into mechanical energy. One of the brushless dc motor's most significant features is the rotor position sensors. Based on the rotor position and command signals—which might be torque, voltage, speed, and other commands—the control algorithms choose the gate signals for each semiconductor in the power electronic converter. Both voltage and current source based drives can be used with permanent magnet synchronous machines that have back emf waveforms that are sinusoidal or non-sinusoidal. A machine having a sinusoidal back emf (Fig. 2.3) can have its torque controlled to be almost constant. However, a machine with a non-sinusoidal back emf (Fig. 2.4) offers smaller inverter sizes and lower losses for the same power output.

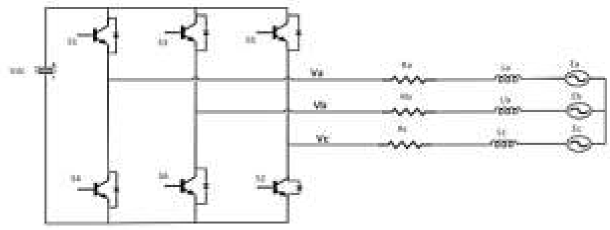

Figure 3: BLDC motor drive system equivalent circuit

B. *Drive Operation Principle*

In the BLDC motor drive depicted in Figure 1, the motor is driven periodically by energizing two phases of the motor based on the rotor position information obtained from the rotor position information obtained from the rotor position information obtained from the rotor position information obtained from three 120 volts different from hall-effect sensors It emits a 1 or 0 signal when it is close to the north and south poles. rotors of respective motors As a result of sensors, MOSFET gate signals are produced based on the hall effect. Switches S1–S6 can be either ON or OFF. Table 2 displays.

III. SPEED CONTROLLER DESIGN

A. *Fuzzy Controller*

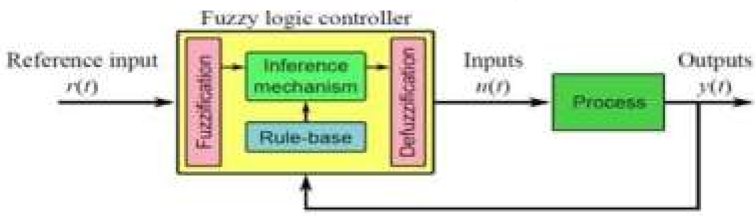

Figure 4: Fuzzy logic control system structure

Figure 3 shows the typical architecture of a fuzzy control system, which consists of four fundamental components:

1. The input values are transformed into a fuzzy set of values using fuzzyification. language's expression
2. The IF-THEN rules that make up the rule base.
3. A fuzzy control action is inferred from linguistic variables and control knowledge rules using an inference technique.
4. Defuzzification, which controls the procedure by converting the inference mechanism's output into a numerical value [16].

To control the amplitude of the inverter DC bus voltage, the proposed fuzzy controller was developed. The controller has the last say. Inputs are the variations between the desired and real motor. the speed and rate of change of the error, while the reference value for the DC bus voltage serves as a representation of the controller output.

B. Fractional-Order PID (FOPID) Controller

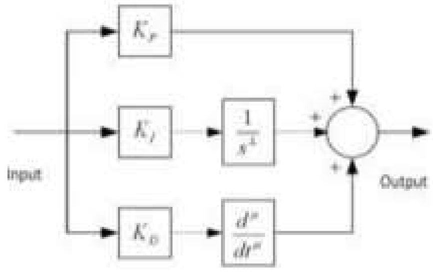

Figure 5: Block diagram for a FOPID controller

To regulate the speed of BLDC motors, the FOPID controller modifies the three-phase reference currents' magnitude in the hysteresis current controller. Then the motor is driven. utilising pulses from inverter gates. This paper discusses the harmony search optimisation technique. utilised to determine the optimal values for the parameters of the FOPID controller.

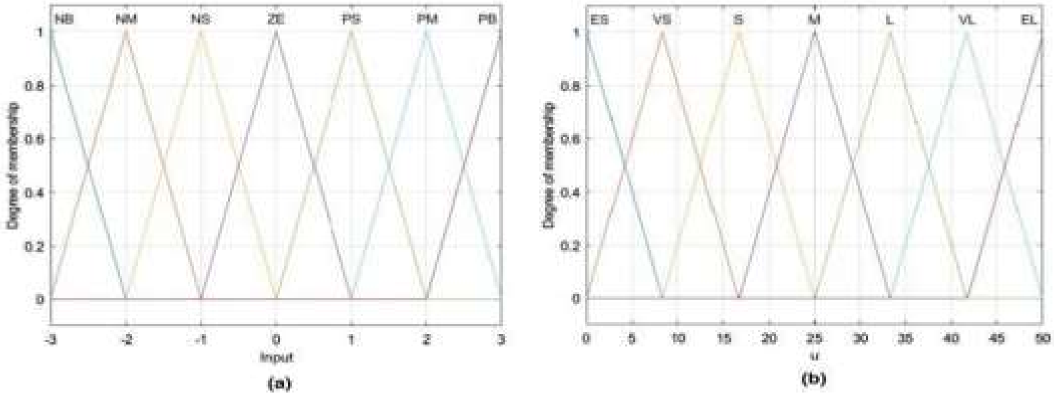

Figure 6: Input membership function is entered, then b membership function output

FOPID represent by the differential equation of FOPID as follows:

$$u(t) = K_p e(t) + K_i D_t^{-\lambda} e(t) + K_d D_t^{\mu} e(t)$$

$$G(s) = K_p + K_i s^{-\lambda} + K_d S^{\mu}$$

$$x_{new} = x_{old} + FW.r$$

The transfer function representation of FOPID using the Laplace transform is as follows:

K_p : is proportional constant	K_i : is integral constant
K_d : is derivative constant	λ : is the integration order
μ : is the differentiation order	

IV. HARMONY SEARCH ALGORITHM

The Harmony Search Algorithm (HSA), a population-based meta-heuristic algorithm with musical inspiration, was proposed by Gem [25]. HSA simulates the behaviour of musical improvisation by representing the process of fnding the best harmony by experimenting with various pitch combinations. This has been carried out. When the values of new variables are taken into account during the HSA selection process, Harmony Memory (HM) can be used to choose a harmony.

HAS keeps the set of solutions at this place. They can also be chosen at random from the allowed range of values or from HM with slight adjustments [26,27]. Two crucial parameters serve as guidelines for this process: The pitch adjusts at a rate known as Pitch Adjusting Rate (PAR), which ranges from 0 to 1. HM-derived rate of a small change in the solution:

The fret width is denoted by FW, while r is a uniformly distributed random number in the [-1,1] range. After the adjustment process, the new pitch is xnew and the old pitch in the HM is xold.

The HS technique is the foundation upon which the implemented algorithm is built. It was suggested to develop multiple harmonies rather than just one at each improvisation to speed up convergence. The concept is introduced with this change [29]. A dynamic FW was also applied. [30] according to the subsequent equation.

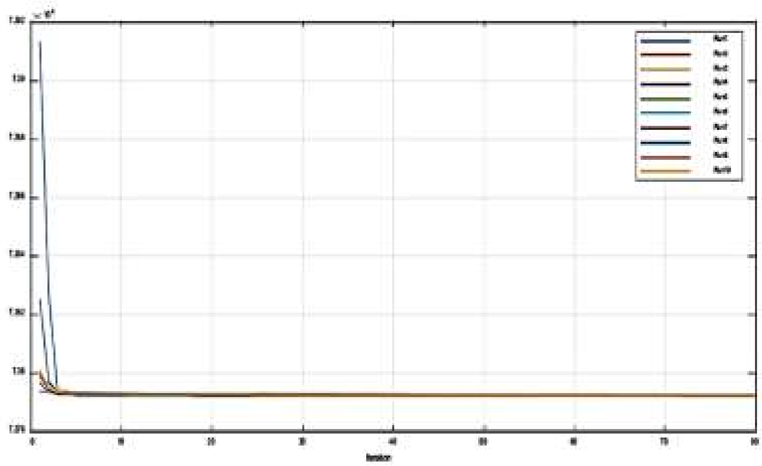

Figure 7: Illustration of convergence

By minimising the cost function described by Integral of Square Error (ISE), which is given by the following equation, HSA was used to adjust the FOPID parameters Kp, Ki, and Kd.

$$ISE = \frac{1}{10000} \int e^2 dt$$

Where t represents the time and E denotes the sped error. The inequality constraints are specified as follows

$$0.1 \leq K_p \leq 50$$

$$0.1 \leq K_i \leq 50$$

$$0.1 \leq K_d \leq 4$$

$$0.1 \leq \lambda \leq 2$$

$$0.1 \leq \mu \leq 2$$

The optimization has repeated ten epochs to ensure the solution's robustness, as shown in Fig. 6, with each run consisting of 80 iterations. The overall data was shown in the below Table 4.

Table 4 Statistics for 10 runs

	Minimum	Maximum	Average
HSA Objective function	73792.19	73792.35	73792.23

Table 5 FOPID controller tuned parameters

Parameter	K_p	K_i	K_d	λ	μ
value	21.88	27.4575	0.8709	1.2189	0.1186

Table 5 lists the optimised values, while Table 6 lists the unoptimized parameters. The stability and convergence of the suggested optimisation technique to the same objective function value are demonstrated. The solution convergence of the enhanced harmony search method and particle swarm optimisation (PSO) was also contrasted in Fig. 7. It is obvious that the HSA solution beats the PSO in terms of the minimum objective function value. Additionally, HSA executes more quickly than the system discussed in this article, finishing an evaluation of an objective function in 1.557 seconds as opposed to 2.142 seconds for PSO.

V. SIMULATION RESULTS

Figure 8 shows has projected hybrid-Fuzzy-FOPID controlled systems, which manage both the bus voltage of DC and the inverter gate circuit's reference current at the same time.

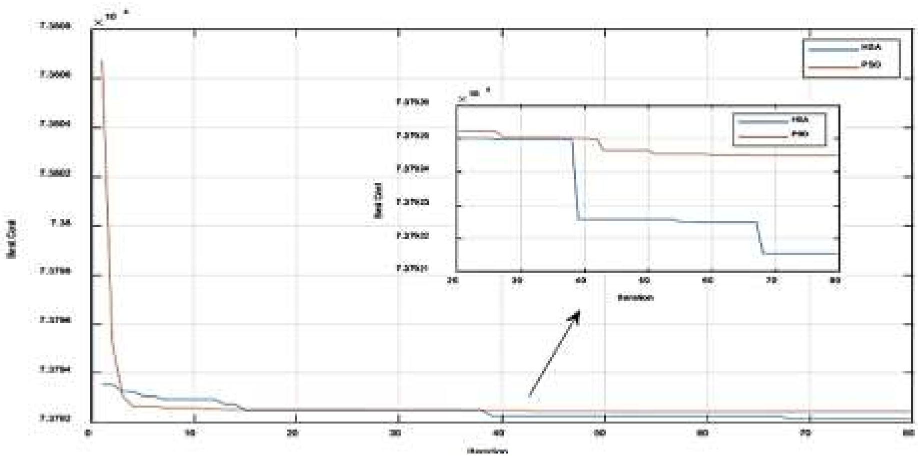

Figure 8: Convergence profile of HSA and PSO

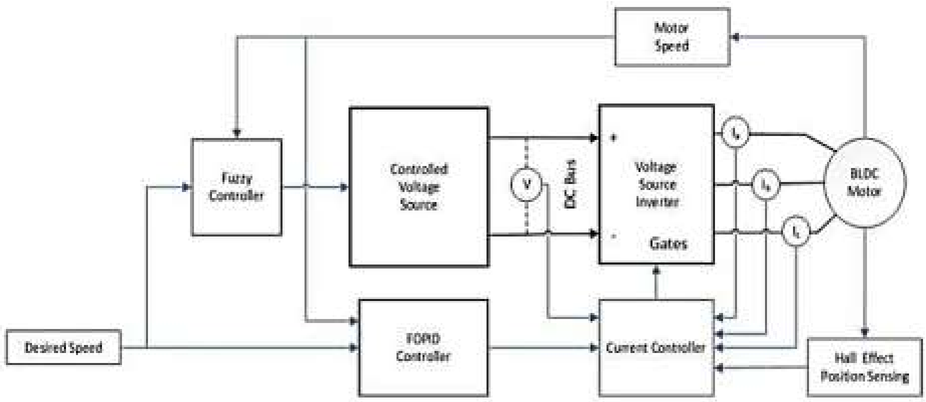

Figure 9: Control diagram of projected HFFOPID controller

In order to confirm the effectiveness of the suggested control technique, three situations were looked into. The BLDC motor is loaded with a constant load while the speed is adjusted after the system is first simulated at a constant speed with no load. Finally, a consistent speed is maintained for the motor. The voltage was kept constant while the motor load was changed in a specified manner. MATLAB 2019b was used to simulate. the structure The results have also been contrasted. for any Situation, with FOPID-based fuzzy speed control approaches. A fuzzy controller operates the BLDC. While the inverter gate signals are generated based on the to accomplish rotor position acquired from hall-effect sensors, you can control the motor speed by adjusting the DC bus voltage. The employment of electronic gadgets to transport people is known as "electronic commutation." As part of its control system, the FOPID The speed is managed and the DC bus voltage is kept at a constant value. This is accomplished by managing the BLDC motor reference.

A. No Load Operation

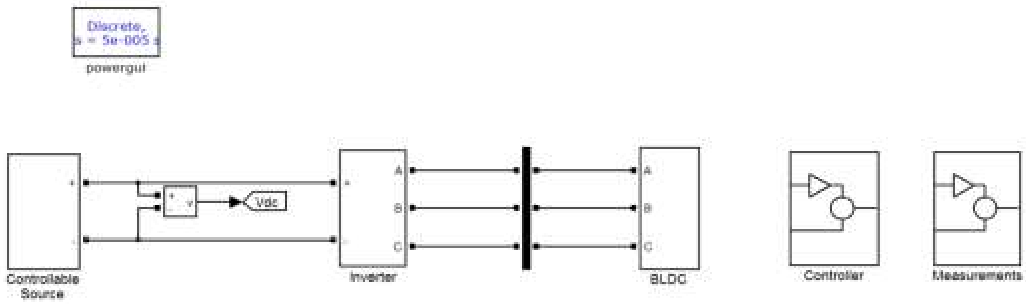

Figure 10: No-load response by Fuzzy controller

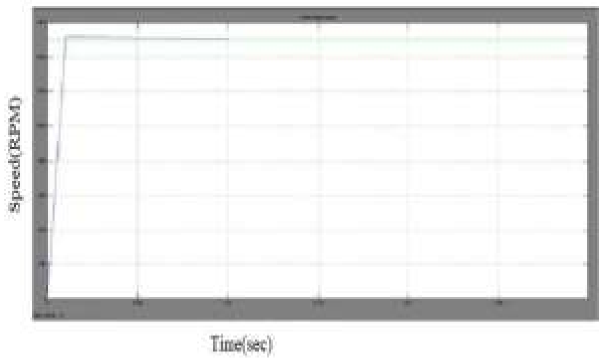

Figure 11: No-load speed by fuzzy controller

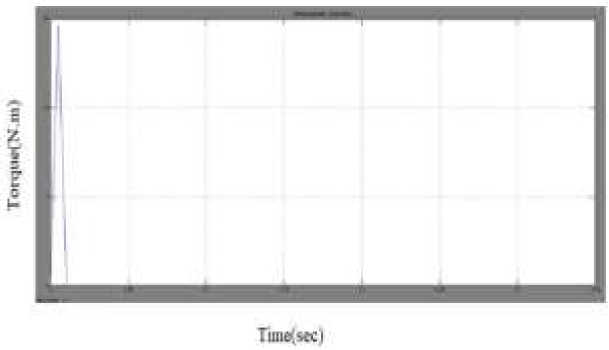

Figure 12: No-load torque by Fuzzy controller

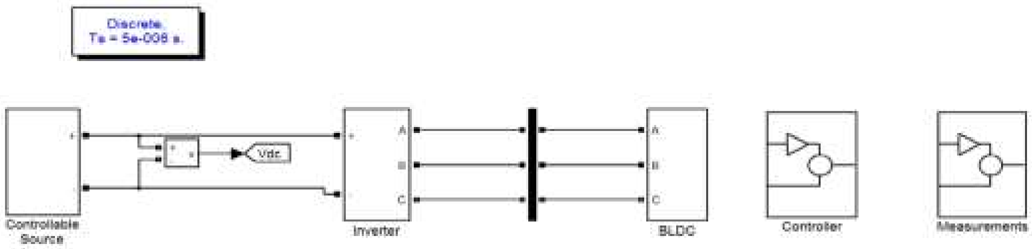

Figure 13: Variable load responses by the fuzzy controller

Figure 14: Speed response by the fuzzy controller under variable load

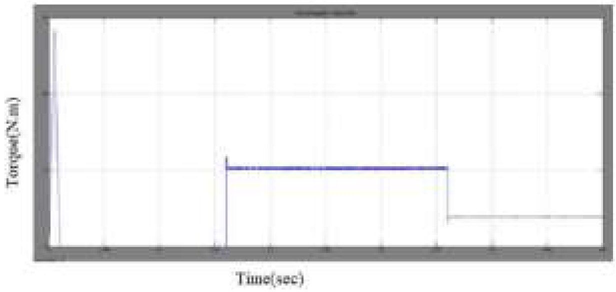

Figure 15: torque response of a fuzzy controller with a varied load

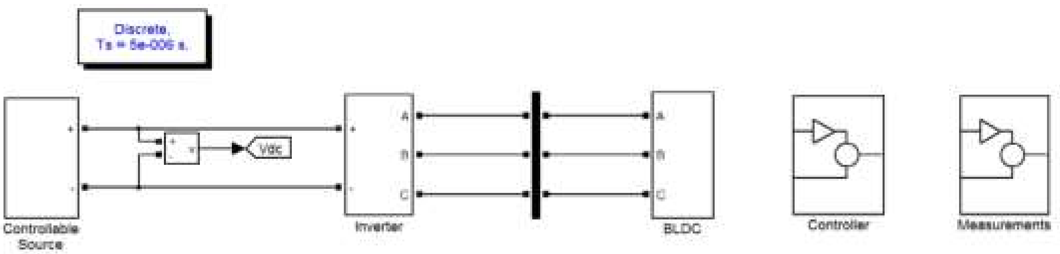

Figure 16: Under variable speed responses fuzzy controller

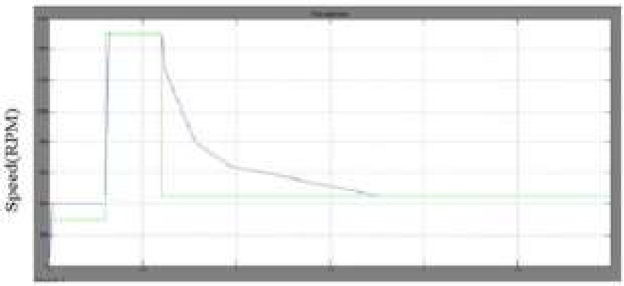

Figure 17: Under variable speed, fuzzy controller speed response

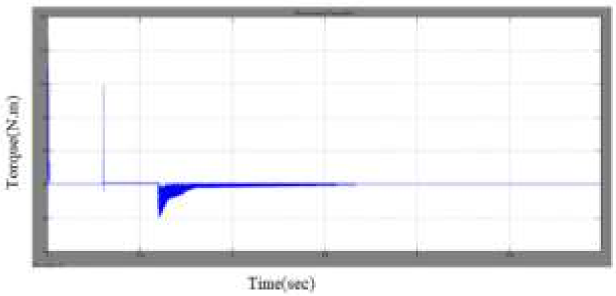

Figure 18: Under variable speed, fuzzy controller torque response

B. Varying Load Operation

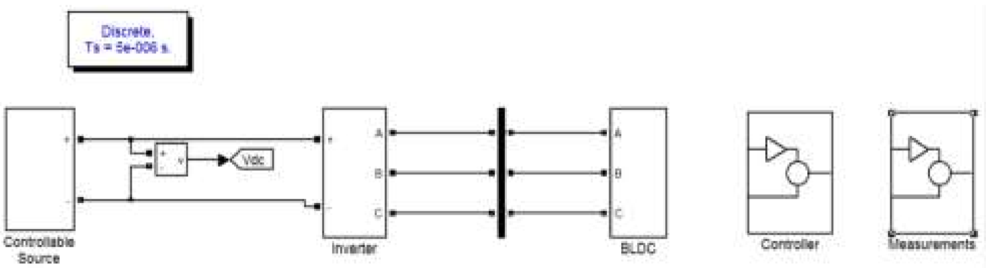

Figure 19: No-load output from the FOPID controller

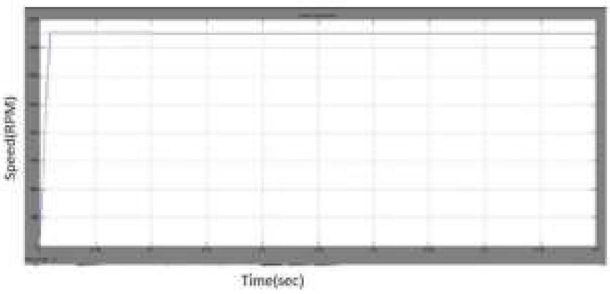

Figure 20: Response time of the FOPID controller with no load

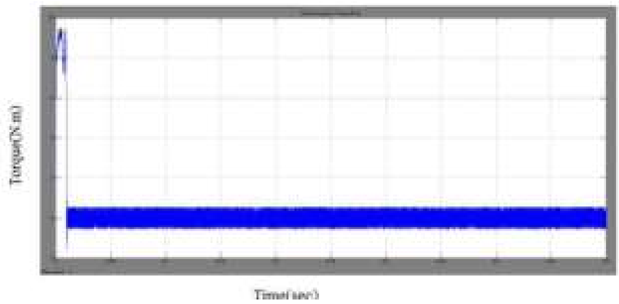

Figure 21: Reactions of the FOPID controller to no-load torque

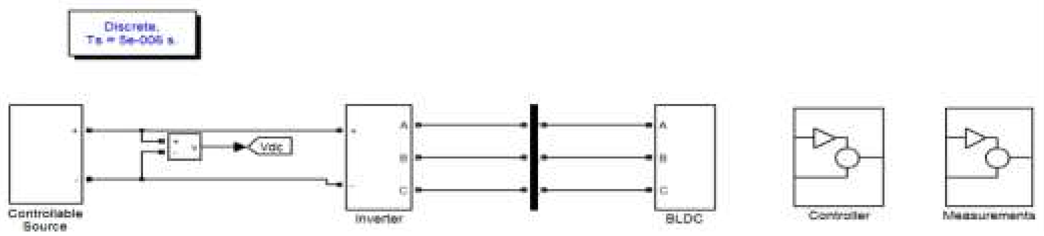

Figure 22: Under-variable load responses FOPID controller

Figure 23: Speed responsiveness of the FOPID controller with varying load

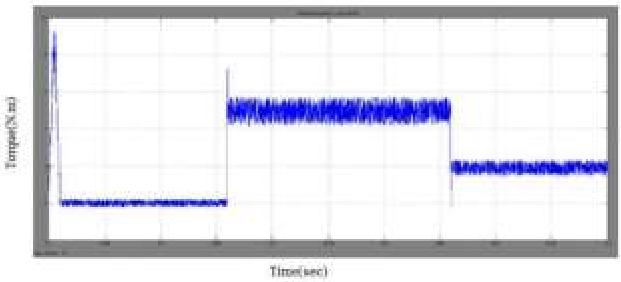

Figure 24: under varying load, FOPID controller torque response

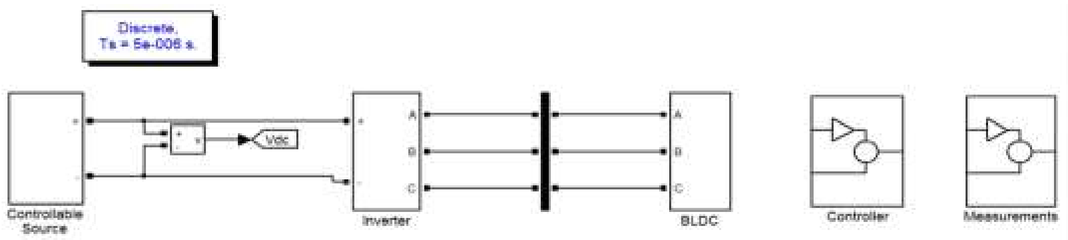

Figure 25: Under variable speed responses, a FOPID controller

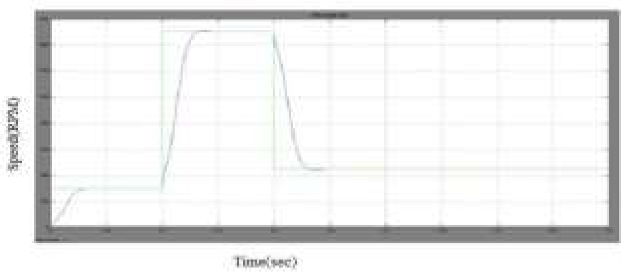

Figure 26: Under variable speed, FOPID controller speed response

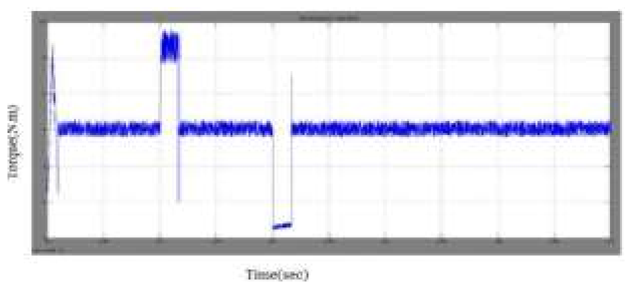

Figure 27: Torque response of the FOPID controller with varied speed

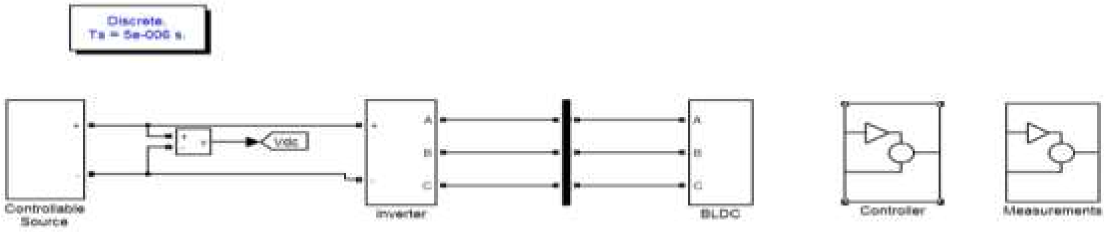

Figure 28: For no-load answers, fuzzy-FOPID controllers

C. Varying Speed Operation

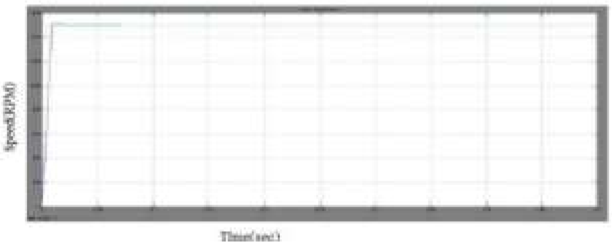

Figure 29: Fuzzy-FOPID controllers with no-load fast response are proposed.

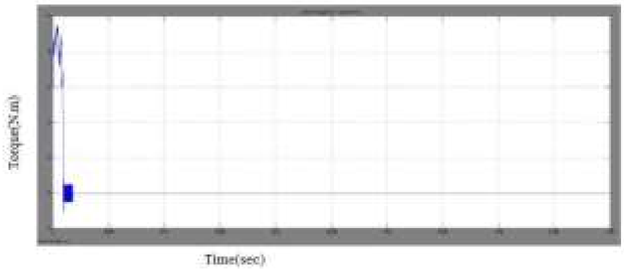

Figure 30: Fuzzy-FOPID controllers with no-load torque response are proposed

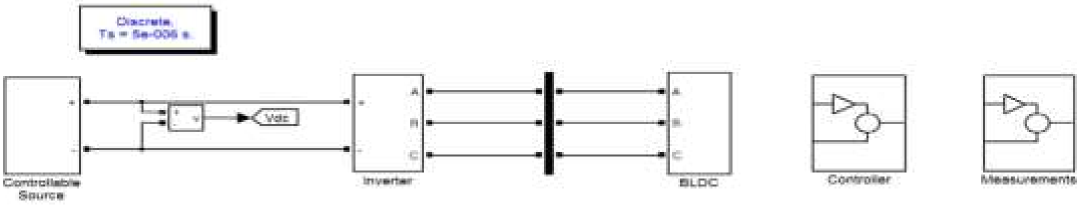

Figure 31: Under variable load responses, fuzzy-FOPID controller

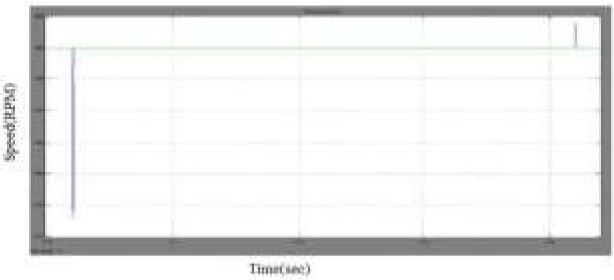

Figure 32: The suggested fuzzy-FOPID controller has variable load speed response.

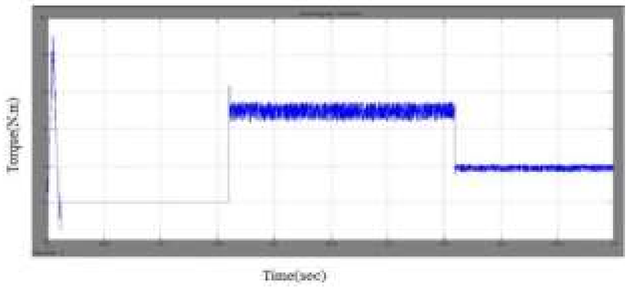

Figure 33: The torque response of the proposed fuzzy-FOPID controller under varied load

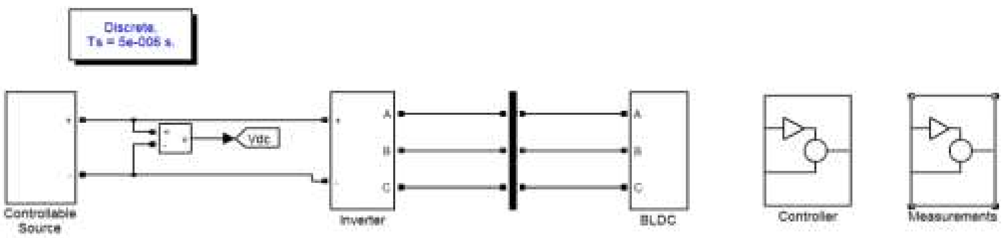

Figure 34: Fuzzy-FOPID controller for responses at low speeds

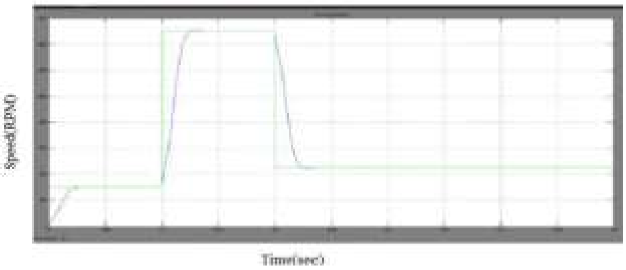

Figure 35: under variable speed, the proposed fuzzy-FOPID controller speed response

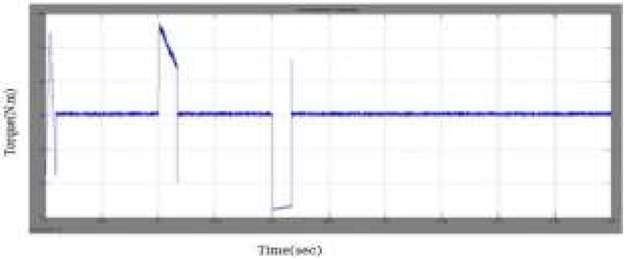

Figure 36: The torque response of the proposed fuzzy-FOPID controller at varied speed

VI. CONCLUSION

This article suggests a hybrid fuzzy FOPID controller for BLDC motors that can manage both the reference current of the hysteresis current regulator and the DC bus voltage of the inverter. The proposed hybrid fuzzy FOPID was refined by the updated HSA. A solo purging system, a FOPID-based system, and a hybrid control strategy were contrasted. The benefits of the fuzzy controller are combined with modest steady-state errors and adaptability to changing operating conditions in the proposed fuzzy FOPID hybrid controller. varying pace FIG 17 Variable speed proposed FOPID speed curve with fuzziness, b FOPID fuzzy Proposed FOPID-like rapid response and inrush current limit function for variable speed torque thirteen. The fuzzy FOPID hybrid controller, which was built in light of the simulation results, exhibits notable increases in engine speed and torque response with different operating situations.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interes*t.*

REFERENCES

[1] Yedamale, P.: "Brush less DC (BLDC) motor fundamentals," Microchip Technology Inc., 2003.

[2] Xia, C.L.: Permanent Magnet Brush less DC Motor Drives and Controls. Wiley, New York (2012)

[3] Padula, F.; Visioli, A.: Tuning rules for optimal PID and fractional-order PID controllers. J. Process Control 21(1), 69–81 (2011)

[4] Cajo, R.; Mac, T.T.; Plaza, D.; Copot, C.; De Keyser, R.; Ionescu, C.: A Survey on Fractional Order Control Techniques for Unmanned Aerial and Ground Vehicles. IEEE Access 7, 66864– 66878 (2019)

[5] Chen, Y. Q.; Petráš, I.; Xue, D.: "Fractional order control - A tutorial," In: Proceedings of American Control Conference, pp. 1397–1411 (2009)

[6] Xuet, D.; Chen, Y.: A comparative introduction of four fractional order controllers. In: Proceedings of the 4th World Congress on Intelligent Control and Automation, pp. 3228–3235 (2002)

[7] Termous, H.; Moreau, X.; Francis, C.; Shraim, H.: From the standard PID to the CRONE frst generation controller: Application to an anti-roll system for Electric Vehicles. IFAC-PapersOnLine 51(4), 733–738 (2018)

[8] Podlubny, I.: Fractional-order systems and fractional-order controllers. Inst. Exp. Phys., Slovak Acad. Sci. 12(3), 1–18 (1994)

[9] Shah, P.; Agashe, S.: Review of fractional PID controller. Mechatronics 38, 29–41 (2016)

[10] Valério, D.; Sá Da Costa, J.: "A review of tuning methods for fractional PIDs," In: 4th IFAC Workshop on Fractional Diferentiation and its Applications, p. 13 (2010).

[11] Shaheen, A.M.; Spea, S.R.; Farrag, S.M.; Abido, M.A.: A review of meta-heuristic algorithms for reactive power planning problem. Ain Shams Eng. J. 9(2), 215–231 (2018)

[12] Chang, L.Y.; Chen, H.C.: Tuning of fractional PID controllers using adaptive genetic algorithm for active magnetic bearing system. WSEAS Trans. Syst. 8(1), 158–167 (2009)

[13] Aghababa, M.P.: Optimal design of fractional-order PID controller for fve bar linkage robot using a new particle swarm optimization algorithm. Soft. Comput. 20(10), 4055–4067 (2016)

[14] Haji Haji, V.; Monje, C.A.: Fractional-order PID control of a chopper-fed DC motor drive using a novel frefy algorithm with dynamic control mechanism. Soft. Comput. 22(18), 6135–6146 (2018)

[15] Li, C.; Zhang, N.; Lai, X.; Zhou, J.; Xu, Y.: Design of a fractionalorder PID controller for a pumped storage unit using a gravitational search algorithm based on the Cauchy and Gaussian mutation. Inf. Sci. (Ny) 396, 162– 181 (2017)

[16] K. M. Passino; S. Yurkovich, Fuzzy control. 2010.

[17] El-samahy, A.A.; Shamseldin, M.A.: Brushless DC motor tracking control using self-tuning fuzzy PID control and model reference adaptive control. Ain Shams Eng. J. 9(3), 341–352 (2018)

[18] Shamseldin, M.A.; Ghany, M.A.A.; Ghany, A.M.A.: Performance study of enhanced nonlinear PID control applied on brushless DC motor. Int. J. Power Electron. Drive Syst. 9(2), 536–545 (2018)

[19] Gobinath, S.; Madheswaran, M.: Deep perceptron neural network with fuzzy PID controller for speed control and stability analysis of BLDC motor. Soft. Comput. 24(13), 10161–10180 (2020)

[20] Maharajan, M.P.; Xavier, S.A.E.: Design of Speed Control and Reduction of Torque Ripple Factor in BLdc Motor Using Spider Based Controller. IEEE Trans. Power Electron. 34(8), 7826–7837 (2019)

[21] Baharudin, N.N.; Ayob, S.M.: "Brushless DC motor drive control using Single Input Fuzzy PI Controller (SIFPIC)," 2015 IEEE Conf. Energy Conversion, CENCON 2015, 13–18 (2015)

[22] Potnuru, D.; Tummala, A.S.L.V.: Grey wolf optimization-based improved closed-loop speed control for a BLDC motor drive. Smart Innov. Syst. Technol. 104, 145–152 (2019)

[23] Prabhu, P.; Urundady, V.: One-Cycle Controlled Bridgeless SEPIC with Coupled Inductors for PAM Control- Based BLDC Drive. Arab. J. Sci. Eng. 44(8), 6987–7001 (2019)

[24] Khorrami, F.; Krishnamurthy, P.; Melkote, H.: Modeling and Adaptive Nonlinear Control of Electric Motors, 3rd edn, p. 523. Springer Science & Business Media, Berlin (2003)

[25] Geem, Z.W.; Kim, J.H.; Loganathan, G.V.: A New Heuristic Optimization Algorithm: Harmony Search. Simulation 76(2), 60–68 (2001)

[26] Geem, Z. (ed.): Music-Inspired Harmony Search Algorithm. Springer, Heidelberg (2009)

[27] Zhang, T.; Geem, Z.W.: Review of harmony search with respect to algorithm structure. Swarm Evol. Comput. 48, 31–43 (2019)

[28] Lee, K.S.; Geem, Z.W.: A new meta-heuristic algorithm for continuous engineering optimization: Harmony search theory and practice. Comput. Methods Appl. Mech. Eng. 194(36–38), 3902–3933 (2005)

[29] Cheng, Y.M.; Li, L.; Lansivaara, T.; Chi, S.C.; Sun, Y.J.: An improved harmony search minimization algorithm using diferent slip surface generation methods for slope stability analysis. Eng. Optim. 40(2), 95–115 (2008)

[30] Mahdavi, M.; Fesanghary, M.; Damangir, E.: An improved harmony search algorithm for solving optimization problems. Appl. Math. Comput. 188(2), 1567–1579 (2007)

[31] A Mohammed Eltoum, M., Hussein, A. & Abido, M.A. Hybrid Fuzzy Fractional-Order PID-Based Speed Control for Brushless DC Motor. Arab J Sci Eng 46, 9423–9435 (2021). https://doi.org/10.1007/s13369-020-05262-3

[32] https://core.ac.uk/download/pdf/53188902.pdf

[33] A Mohammed Eltoum, M., Hussein, A. & Abido, M.A. Hybrid Fuzzy Fractional-Order PID-Based Speed Control for Brushless DC Motor. Arab J Sci Eng 46, 9423–9435 (2021). https://doi.org/10.1007/s13369-020-05262-3