Application of Cuckoo Search Optimization to Speed Control PMSM for Electric Vehicle

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***Abstract* - The procedure illustrated in this paper indicates a novel method for optimal multi-parameters fractional order PID base in nature inspired optimum algorithms' application for speed control for three phases of Permanent-Magnet-Synchronous Motors (PMSM) for application on Electric Vehicles. The stabilization method for speed control of PMSM uses the Cuckoo hybrid optimal fractional order *PID* controller. The Cuckoo optimization method used multi-subject target optimal parameters such as *Kp; Ki; Kd* and fraction order alpha and beta. Hybrid Cuckoo Optimization fraction order *PID* and Adaptivity Particle Swarm Optimization *PID* and fraction order *PID* controllers speed control for PMSM for Electric Vehicles. The simulation results of the paper are comparable, and the conclusions.**

Keywords – Electric Vehicle, Cuckoo Optimization Algorithm, HCOPI$^{\alpha}$D$^{\beta}$, Hybrid Cuckoo Optimization fractional order PI$^{\alpha}$D$^{\beta}$ controller, Speed control of Electric Vehicle.

I. INTRODUCTION

Currently, the study is being on the Permanent-Magnet-Synchronous motors are capable of providing high torque-to-current ratio, high efficiency, power density, high power-to-weight ratio, and high durability [1,2,3]. Due to these advantages, especially in Electric Vehicle applications, PMSM is often used in the latest variable-speed motor drives. Therefore, electric vehicles solve the pollution of city traffic because they do not emit harmful gases and have low noise levels. However, PMSM damages strong coupling, time-varying, and non-linear objects, and multivariable, and increases difficulty with speed and torque control. During the past decades with the growth of control methods, including feedback linearization, Feedback control, neural networks control, and sliding mode control, and anti-step control, and Fuzzy logic sontrol, and adaptive control strategies had suggested [4]. Therefore, the *PID* controller has a simple structure, high reliability, and better stability. Nowadays, exceeding 90% of total controllers are *PID* traditional controllers use to in the real process industry [5]. The *PIDs* are the most the *PIDs* are the maximum controller in electric motors control in the majority, and they give the control system feedback for proportionality, integral, and derivative actions. However, the quantity of parameters to regulate in the *PIDs* are very slight, and there are a lot of regulator rules. The *PIDs* show that 65% of loops working in automation modes are below-tuned due to inappropriate parameters, and and they were a veritable experiment that exceeding 30% of controllers were non-automatic mode-operated [6]. Actually is often used when most the control of the current closed-loop speed in the PMSM uses a *PID* controller [5]. However, the *PID* controller performs poorly in PMSM servo system controls speed due to inconsistent parameters.

These are important for solving different engineering problems by optimization methods. The objective function is the maximum or minimum value of the problem being solved to determine the goal of the optimization process. These issues include, but are not limited to, system design, power generation, and network operations, and include energy loss during long-distance transmission of power... The optimization algorithms require an assessment of convergence rate, and computational time to the accuracy to determine the maximum or minimum values [7]. Some researchers have innovated optimization algorithms based on nature observations, these algorithms are acknowledged

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as nature-inspired algorithms. Such as the Particle swarm optimization (*PSO*) was innovated after observing good behavior finding food of fishs, bees, ants, lions and birds [8]. The differential evolution (*DE*) algorithm is based on population evolution using Storm and Prince's mutation, crossover, and selection operations. Additionally, simulated annealing (SA) is based on the properties of metal annealing.

Furthermore, the Cuckoo Search Optimization Algorithm (*COA*) is based on the breeding strategy of cuckoos to increase their population and also nature-inspired algorithms [10]. However, the *COA* algorithm performs more efficiently than other nature-inspired algorithms such as *SA*, *DE*, and adaptive *PSO*. Therefore, it is not surprising that COA performs better than them [10].

The Podlubny and Igor extended the habitual *PID* controller to a fractional order *PID* controller (*FOPID*) by introducing two additional degrees of freedom, α and β of the integral and differential degrees [9]. The fractional order differentiator and integrator, fractional order controllers have been investigated for greater flexibility and better tuning capabilities. [9,10]. Simultaneously, *FOPID* has been researched and widely applied in the fields of solar energy systems and wind energy, new energy control, hydropower turbine and nuclear reactor.

This article proposes the device of a PMSM speed stabilization controller for modern electric vehicle applications, to develop and assess the performance of multi-objective optimized PID regulator PMSM speed using the Hybrid Cuckoo Search Optimization Algorithm ($HCOAFO-PI^{\alpha}D^{\beta}$). The Cuckoo search algorithms have increasingly more transition parameters between global and local random jumps as the number of iteration increases. And, the $HCOAFO-PI^{\alpha}D^{\beta}$ optimization of five parameters: K_p, K_i, K_d, and faction order exponentiation alpha, beta is proposed and have higher accuracy and stability. The simulation results signify the comparison have the *PID* traditional and Adaptive Practical Swarm Optimization - *PID* controllers (*APSO-PID*).

The remainder of this article is organized as follows: The previous related work is mathematical model PMSM motor reviewed in Section 2. In Section 3, we described a fraction order *PID* ($PI^{\alpha}D^{\beta}$) controller. Next, the Hybrid Cuckoo Optimal Algorithm-Fraction Oder $PI^{\alpha}D^{\beta}$ ($HCOAFO-PI^{\alpha}D^{\beta}$) speed controller and *APSO-PID* speed controller in Sections 4. In Section 5, the obtained results simulation and discussion are presented. Finally, the conclusions were described in Section 6.

II. THE PMSM MOTOR WITH MATHEMATICS MODEL.

The PMSM motor with mathematics model [1,11], the rotor reference frame of PMSMs has been grown, the PMSM used the equations given:

$$\begin{aligned} u_d &= Ri_d + \frac{d\lambda_d}{dt} - \omega_e\lambda_q \\ u_q &= Ri_q + \frac{d\lambda_q}{dt} + \omega_e\lambda_d \\ T_E &= \frac{3}{2}p(\lambda_d i_q - \lambda_q i_d) \\ J\frac{d\omega_m}{dt} &= T_E - T_L - B\omega_m \end{aligned} \tag{1}$$

Where: Sequentially, the $\lambda_d = L_d i_d + \psi_d$ and $\lambda_q = L_q i_q + \psi_q$ are the sum of flux links follow d, q axes; ψ_d and ψ_q are the permanent magnet flux linkage follow the d, q axes; correspondingly, and the ω_e is the electrical angular speed. Furthermore, the u_d and the u_q are the voltages of stator follow the d, q axes; the i_d and the i_q are the currents of stator the d, q axes; correspondingly, L_d and L_q are the inductances of stator follow the d, q axes; correspondingly; the R is the resistance of stator. Where J is inertia coefficient; the T_L is the torque of load; T_E is the torque of electromagnetic, the B is friction coefficient, and *p* is the sum of pole pairs, and the ω_m is the angular speed of mechanical. It is further supposed that PMSM non-salient of poles surface-mounted have L_d equals L_q.

III. FRACTIONAL ORDER $PI^{\alpha}D^{\beta}$ CONTROLLER

The $PI^{\alpha}D^{\beta}$ controller is presented and considered here, which has a parallel structure (2) the same the conventional PID controller[16].

$$G_{FOPID}(t) = K_p + K_i\frac{1}{S^{\alpha}} + K_d S^{\beta} \tag{2}$$

Obviously, The $PI^{\alpha}D^{\beta}$ controller (2) is a general traditional *PID* controller with two additional knobs to adjust the integral and differential orders $\{\alpha,\beta\}$. By setting the value $\{\alpha,\beta\}$ = 1, we can get the traditional *PID* controller. When $\{\alpha,\beta\}$ = (0;1) we can get the fractional order $PI^{\alpha}D^{\beta}$ controller.

- Adding, now the $PI^{\alpha}D^{\beta}$ controller is tuned to use the constraint Cuckoo optimization algorithm at that time minimizing the control objective (J) determined in (3). To minimize the weighted sum of the error-index and the control signal is to optimize the constrained objective, which is given by:

$$J(t) = \int_0^{\infty}(\eta_1.t.|e(t)| + \eta_2 * u^2(t)) \tag{3}$$

Where, the Integral of Time-Absolute-Error (*ITAE*) is the first term that minimizes setting-up time, and overshoot, while the integral of squared controller produce is the second term.

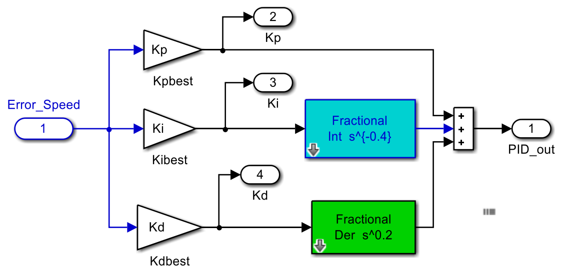

Fig. 1. The $PI^{\alpha}D^{\beta}$ controller simulation in Matlab/Simulink

Two balanced $\{\eta_1, \eta_2\}$ weights show the impact of control loop errors on oscillations and slowness or both. The control signal with larger actuator size and the possibility of built-in failure was selected as the present simulation study.

IV. Hybrid Cuckoo Optimal Algorithm - Fraction Oder $PI^{\alpha}D^{\beta}$ ($COAFO-PI^{\alpha}D^{\beta}$) Speed Controller

A. *Multi-Objective Cuckoo Optimal Algorithm*

Yang and Deb developed a meta-heuristic algorithm, specifically Cuckoo Search Algorithm, in 2009 [13]. The population-based optimization algorithm is inspired by the reproductive parasitism behaviour of some cuckoo species in the wild, based on the optimization method. The cuckoo algorithm uses the Lévy flight function to update the position state of parasitic nests. The calculation of the Lévy flight function is essentially based on Markov chain methods for calculation. In the Cuckoo Search Algorithm, they update state mode after each cycle, Lévy flights are used to generate a new solution. The process of finding new solutions consists of two distinct phases (exploration and exploitation). New solutions are evaluated and ranked by appropriate functionality for the excellent solution after each stage.

The current parasitic nest position and transition probability are determined by the destination of the parasitic nest position update. So the way of updating the position is blind and inaccurate because the eggs are the same. The value probability $P_a(t)$ of parasitic nest is determined, leading to a slow convergence speed and an insufficient local search in the late evolution. The $P_a(t)$ is calculate as follows:

With Cuckoo Search Algorithm, the current parasitic nest location and transition probability are determined by the destination of updating the new parasitic nest location. Therefore, the position updated method is blind and inaccurate because the eggs are considered the same. Calculating the probability of the $P_a(t)$ cost of the parasite nest is determined, which leads to a slow convergence speed of the goal function and insufficient local search in the late evolution process. The probability function $P_a(t)$ is calculated according to the following formula:

$$P_a(t) = (P_{a\_Max} - P_{a\_Min})\frac{t_{\max} - t}{t_{\max}} + P_{a\_Min} \qquad (4)$$

Where: The P_{a_Max} and the P_{a_Min} are the maximum and the minimum of probability; the $P_a(t)$ the probability of finding the t_th iteration, and the $t_{\max}$ is the maximal number of iterations, and the t is is the current number of iterations.number.

The cuckoo birds are very clever to choose the bird nest of other species to lay eggs, those eggs have the same colour, such as Cuckoo's eggs. Since cuckoos are parasites, they do not build their nests. The female Cuckoo always finds and lays her eggs in another host bird's nests in her zone living. This overall plan allows the Cuckoo's eggs to fool the host birds, as they can not recognize any strange eggs in their nest. Reality proves why more than 120 other bird species can be fooled and continuous incubated Cuckoo's eggs up to the time they hatched.

The number of Cuckoo’s eggs that would be identified as strange eggs and throw them out of the nest, or that the host bird will abandon their host nest, is about 20% of them. One season, the female Cuckoo will lay from 12 to 25 eggs [12] and lays each one to two eggs in each nest host bird. First, Cuckoos carefully observe the habits and behaviours of other species to choose species that have a longer hatching time than them. Second, it lays eggs in the host bird's nests.

The Cuckoo's chicks are truly ferocious towards their the chick host; Thus, the first instinctive actions that the Cuckoos push the host's egg out of their nest quickly instinctively to survive because minimizing the nestlings will increase the amount of food that can be consumed. The parents provide for the chicks after they hatch. So the Cuckoo optimization algorithm [13]**,** inspire by the survival instinct behaviour of real-life Cuckoo Birds that have undergone refinement and sustainable survival in the wild for many years, includes three ideal rules listed briefly belows:

Rule 1: Every Cuckoo can lay eggs, and then place each egg correctly into another bird's nest.

Rule 2: Cuckoo eggs of the best quality will be passed down to future generations to maintain the breed, and placed in the best nests of the host bird that it can find in the living area.

Rule 3: The host-bird able to detected as a foreign egg with a small portion of the original Cuckoo eggs. The range of $P_a(t) \in [0;1]$ is the probability of the discovery of the host bird.

The probability $P_a \in [0;1]$ will be set accessibility of host nests with some valuable and the foreign egg is searched in the host bird's nests. The circumvent computational burden and this probability index is valuable, chosen as: $P_a = 0.3 \div 0.7$.

Since a Cuckoo x_i^t of i^{th} at times t, the new Cuckoo x_i^{t+1} at $t+1$ generated using the Lévy flight as below:

$$x_i^{t+1} = x_i^t + \delta \oplus Levy(\lambda) \qquad (5)$$

Where the parameter $\delta > 0$ are step dimension, that depends on the influence type of interest problems. Most of time, the move step dimension $\delta = 1$ selected, and the product $\oplus$ meant entry-wise multiplication.

Thus, the function Lévy flight is a random move step, and the random move step length is evaluated from Lévy distributed to large move steps as below:

$$Le'vy \cong u = t^{-\lambda} (1 < \lambda \leq 3) \qquad (6)$$

The equation (6) has an infinite variance with an infinite mean. Thus, the Cuckoo's move steps mainly constitute a random walk processing following a power-law mover step of length distribution.

B. Hybrid Cuckoo Optimal Algorithm Fraction Order $PI^{\alpha}D^{\beta}$ controller ($COAFO-PI^{\alpha}D^{\beta}$) method

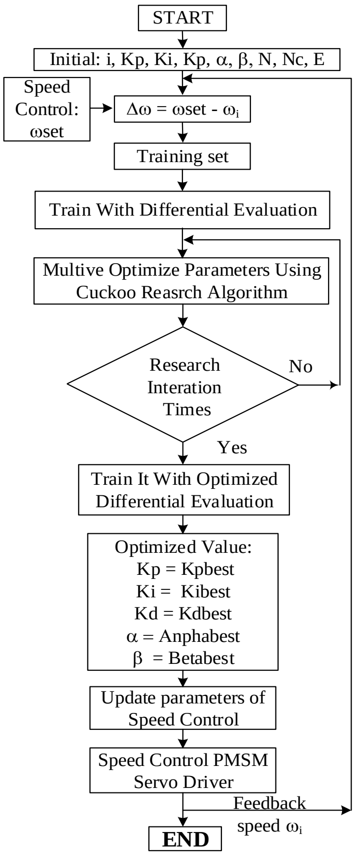

Fig. 2. The flowchart of the $COAFO-PI^{\alpha}D^{\beta}$.

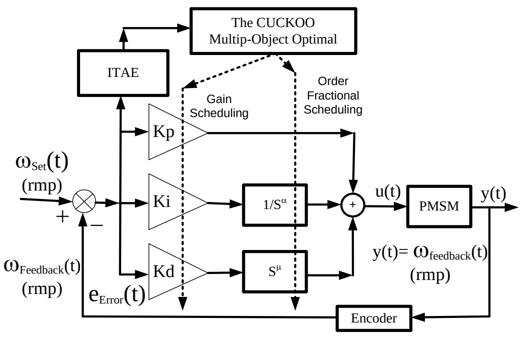

Fig. 3. Structure of $COAFO-PI^{\alpha}D^{\beta}$ controller

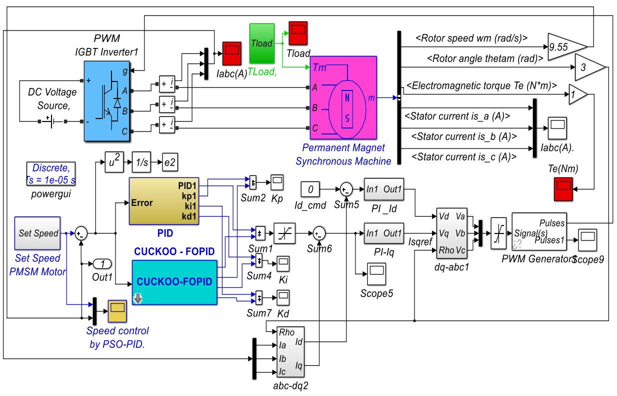

Fig. 4. Simulation PMSM use $COAFO-PI^{\alpha}D^{\beta}$ controller

V. RESULTS OF SIMULATION

The algorithm methods *APSOFO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ were used to adjust the PID parameter set of the PMSM speed controller for electric vehicles. The setting of the controller's initial parameters *Ki* = 4.9, *Kp* = 79, *Kd* = 0.003 for the traditional *PID* controller is selected using optimization methods from the integral absolute error (IAE). Leave the general control scheme running, *APSOFO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ data needs to be corrected will be corrected according to the follow rules:

- **The data of the** APSOFO-PID**:**

For the $APSOFO-PID$ optimistic *Kp*, and *Ki*, and *Kd*, and *alpha*, and *beta*. Dimension of the herd N = 100 individual; and weight of inertia γ descent in the iteration: $\gamma_{\min}$ = 0.022 and $\gamma_{\max}$ = 1.28; coefficients of accelerations C_1 =1.52; C_2 = 0.152; $K_{globle\_best\_position}$ = 6; Maximum of velocity $v_{max}=(x_{max}-x_{min})/2$.

For the optimistic *Kp, Ki, Kd, alpha,* and *beta* of $APSOFO-PID$ methods. Herd size N = 100 individuals; the inertial weight decreases linearly across iterations: $\gamma_{\min}$ = 0.022, and $\gamma_{\max}$ =1.28; the factor of accelerations: C_1 =1.52; C_2 = 0.152; $K_{globle\_best\_position}$ = 6, maximum speed $v_{maxi} = (x_{maix} - x_{mini})/2$.

- **The data of the** $COAFO-PI^{\alpha}D^{\beta}$ **:**

The initial population has the following numbers: NumCuckoos = 15; The eggs for individual Cuckoo with the minimum quantities: MinNumberofEggs = 2; the maximum quantity of eggs for individual Cuckoo: MaxNumberofEggs = 25; the maximal iteration of the Cuckoo Algorithms: MaxIter = 100; the total of cluttered which we desire to create: KnnClusterNum = 3; Lambda variables in the COA survey: MotionCoeff = 3; the maximum quantity of Cuckoos living for the time being in the habitat of the area: MaxNumOfCuckoos = 12; the egg laying control parameters: RadiusCoeff = 5; the population variance that cuts the optimization: CuckooPopVariance=1e^{-13}, $K_{P\_best}=10.021$, $K_{I\_best}=0.0022$ $K_{D\_best}=3.771$; and, $\beta_{best}=0.21$, and $\alpha_{best}=0.4$.

TABLE I. THE PMSM STUDY PARAMETERS [14]

The PMSM study parameters		
Components	**Symbols**	**Value**
Line Voltage	U_{AB}	220 V
Line Current	I	220 A
Rated Power	P_M	75 KW
Rated Torque	T_N	200 N.m
Rated Speed	W	3600 rpm
The number of poles of the magnet	P	12
The phase resistance	R	0.62 mΩ
d-axis Inductance	L_d	0.0034 mH
q-axis Inductance	L_q	0.0034 mH
The flux linkage	ψ_f	0.055 Wb

By choosing, the initial $PI^{\alpha}D^{\beta}$ parameters set of the $[K_p;K_i;K_d;\alpha;\beta]$ is chosen randomly. The target function is designed to minimize impact using the $COAFO-PI^{\alpha}D^{\beta}$ algorithm called minimum cost. This section includes the following necessary information: overshoot and error speed direct, the overshoot is presented in (2). The effectiveness of the $COAFO-PI^{\alpha}D^{\beta}$ algorithm in finding the best parameters of the PID regulator is equivalent to the lowest quantity cost function (2) as indicated in Figure 5.

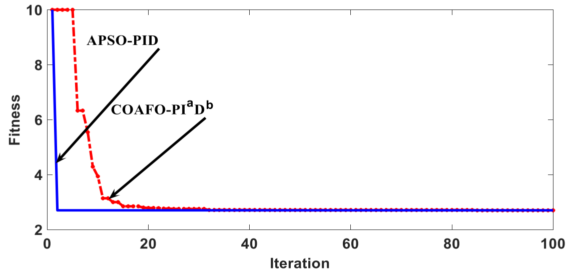

Fig. 5. Convergence characteristics of various optimization techniques $APSO-PID$ and $COAFO-PI^{\alpha}D^{\beta}$

By comparing the speed error of the *PID*, and the *APSO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ controllers into the "Figure 6" to the "Figure 15" it is illustrated that the $COAFO-PI^{\alpha}D^{\beta}$ controller is lesser than *APSOFO-PID* and traditional *PID* controller. The "Figure16" visible the PMSM operator loading and unloading the torque on the rotor PMSM system controller between 0 and 30(N.m) to test the speed rotor system controller electric vehicle.

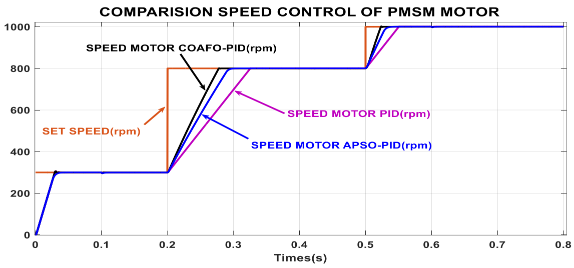

Fig. 6. PMSM speed control comparison for an electric vehicle using *PID*, *APSOFO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ controllers.

From the simulation results comparing the adaptive controller between *PID* and *APSOFO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ speed rotor controller, it is exhibited that it is continually in the process working of the PMSM electric motor for electric cars. The "*Fig.6*" to "*Fig.12*", with the table II noticeable *PID* comparison, *APSOFO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ speed controllers. The control quality of PMSM controlling speed system is start-up, gradually increasing the speed, step acceleration, discharge load and motor reverse, intake load. In "*Fig.12*", when the PMSM motor carries a load increasing from 20(N.m) to 30(N.m), the motor speed decreases then quickly stabilizes, the $COAFO-PI^{\alpha}D^{\beta}$ controller gives best quality control.

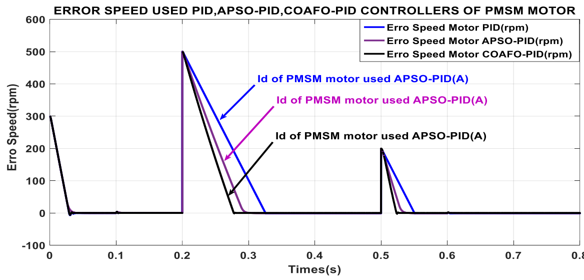

Fig. 7. Speed error control The PMSM for electric vehicle uses a tradional PID, *APSOFO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ controllers.

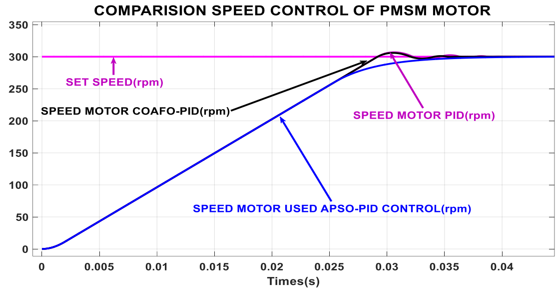

Fig. 8. Perform speed control PMSM comparison among *PID* and *APSO-PID*, and $COAFO-PI^{\alpha}D^{\beta}$ controllers inscreate speed 0-300(rpm).

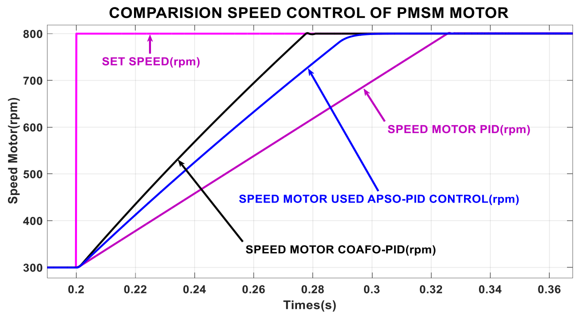

Fig. 9. Perform speed control PMSM comparison among *PID* and *APSO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ controllers inscreate speed 300-800(rpm).

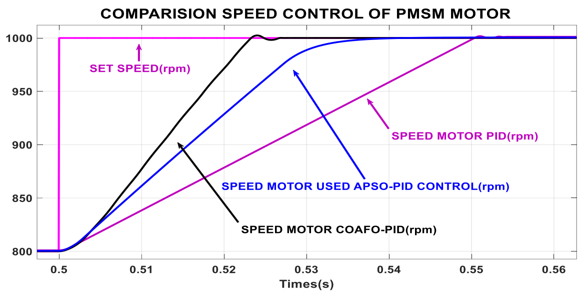

Fig. 10. PMSM speed control comparison among *PID* and *APSO-PID*, and $COAFO-PI^{\alpha}D^{\beta}$ controllers descent speed 800-1000(rpm).

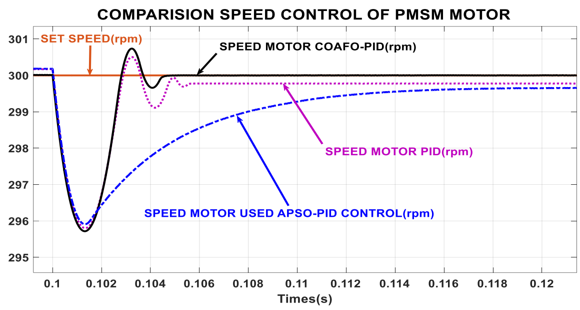

Fig. 11. Perform PMSM speed control comparison among *PID*, and *APSO-PID*, and $COAFO-PI^{\alpha}D^{\beta}$ controllers when change load.

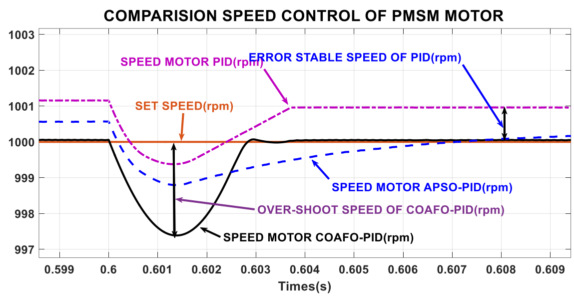

Fig. 12. Perform PMSM speed control comparison among *PID*, *APSOFO-PID*, and $COAFO-PI^{\alpha}D^{\beta}$ controller when dischange load

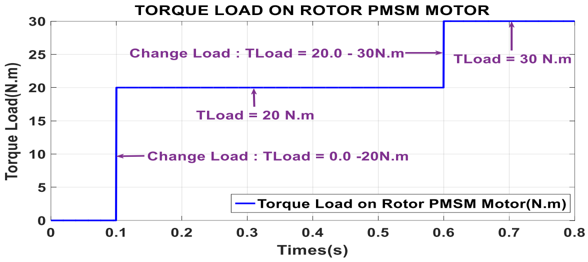

Fig. 13. The torque load on the PMSM motor's rotor changes and discharges

VI. CONCLUSION

In the present study, the *APSOFO-PID* and the $COAFO-PI^{\alpha}D^{\beta}$, and traditional PIDs are suggested to balance the pertain relations among optimum $K_p, K_i, K_d, \alpha, and\ \beta$ of the fractional order $PI^{\alpha}D^{\beta}$ specifications and response characteristically. Dynamic feedback of the control systems information have been fully utilized by $K_p, K_i, K_d, \alpha, and\ \beta$ for the ongoing search process, including monitoring system stability to create new solutions to replace existing solutions slow stabilization and lower quality. The design of new update rules on inertial weights such as: $K_p, K_i, K_d, \alpha, and\ \beta$ involves values; and integration of new time domain performance criteria has been proposed.

From the results of the suggested controller, it is almost possible to effectively rummage for the optimism fractional order *PID* controller parameters compared to the *PID* traditional controller and the proposed *APSOFO-PID*, and $COAFO-PI^{\alpha}D^{\beta}$ controllers. It is obvious from the good research results show the proposed method solve difficult problems $APSO-PID$ and $COAFO-PI^{\alpha}D^{\beta}$ searches. The $COAFO-PI^{\alpha}D^{\beta}$ controller automatically adjusts the $K_p, K_i, K_d, \alpha, \beta$ variables of the fractional order $PI^{\alpha}D^{\beta}$ controller parameters more lightly and precipitously, using the progressing *APSOFO-PID* and $COAFO-PI^{\alpha}D^{\beta}$ methods. The excellent quality results are the $COAFO-PI^{\alpha}D^{\beta}$ speed controller.

By stabilizing the proposed controllers' speed, the PMSM system applied to Electric Vehicles will significantly improve the speed stability of the main drive electric motor. The speed stabilization controller applies the $COAFO-PI^{\alpha}D^{\beta}$ algorithm for the best control quality among the controllers surveyed, this supports Electric Vehicles by significantly improving acceleration and deceleration control modes. The $COAFO-PI^{\alpha}D^{\beta}$ speed controller meets the increasingly strict requirements of modern Electric Vehicles.

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