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MFO-ANN based FOPID Controller for Torque and Speed Control of SRM Drive System

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***Abstract:** This paper proposed an optimal control algorithm based Fractional Order PID (FOPID) controller for the torque ripple minimization of Switched Reluctance Motor (SRM) drive system. That convalesce both control loop task, the Moth Flame Optimization (MFO)- Artificial Neural Network (ANN) algorithm is insinuated. The routine of intelligent technique is principally as the objective function of system error minimization. At this time the quality inspired algorithm of MFO is firstly reconnoitered to optimize the speed and torque error from the SRM system. Instead the output of MFO algorithm is optimized and to finding the premium value, the ANN method is recuperated. Nonetheless, the output of MFO-ANN is imperiled to the input of FOPID controller. For tweaking the exact FOPID gains, the multi objective functions are grew. Created on the operation of propositioned algorithm by normalize the system speed and minimalize the torque ripples of SRM system. The qualities of the suggested procedure are force falconer and in addition to augmented level of the reliability and flexibility in answering the system error. Also the enactment of proposed MFO-ANN process is executed in the MATLAB/Simulink running platform.*

***Keywords:** SRM drive system, MFO, ANN, PSO, FOPID, torque ripple, speed and current*

I. INTRODUCTION

The low lies electrical machine of SRM is a charming substitute to commonly utilized enlistment and synchronous machines on account of its straightforward assembling movement, high blame fairness and ease development, strength, high unwavering quality and execution at high speeds [1]. The SRM has straightforward structure and free of shoot-through blunders. Because of advantages comparative this, the SRM application zones are escalating to cross breed vehicles, electric power directing, electromechanical brakes, family products, mechanical apparatuses. SRM is an electrical machine which has important shafts on both the rotor and the stator. All stage grasps two or four loops wound on inverse stator posts and coupled in arrangement or parallel. It boss to the age of the attractive motion.

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The torque is yielded by inclination of its transportable part (rotor) to move in to an area where the inductance of the energized winding is improved . A satisfactory exhibition would imply that, on rate of blame, SRM drive, perseveres to work with a minutest dimension of working as notorieties (a) speed motions, (b) torque throbs, (c) vibration, (d) clamor (e) temperature rise and (f) control yield.Conversely, a SRM laments from its own disadvantages inferable from its twofold striking example on stator and rotor with high-torque swell coordinating to acoustic commotion [2]. The immense torque swell is a result of amazingly nonlinear electromechanical conduct activated by non-direct attractive physiognomies because of immersion.

Typically, the modification of torque swell has been disturbed and indistinguishable from the learning of the vibration and acoustic commotion . The acoustic clamor families in exchanged hesitance engines can be ghettoized into three primary classes. (I) Air weight variations achieve by the significant posts in the rotor at sharp rotational speed, (ii) stator outline vibration activated by electromagnetic power variety and (iii) others. The primary testing can be safely a barrel shaped rotor external shape by iron extensions or disguised on-attractive material in between polar areas [3].Additionally, the usage examination of exchanged hesitance engine is prepared utilizing hysteresis controller. SRM drive with four-organize bending by split converter was set up. The multiport converter with packed capacitance for SRM was fulfilled [4]. In conventional uneven kilter converter the enormous estimation of capacitance is required in spite of the way that in multiport converter with decreased capacitor triggers high dc swell voltage [5]. An inherent less of SRM is the torque swell. The reasons of torque swell are counting the geometric structure with doubly prominent motor, excitation windings exhaustive any place the stator shafts and the working systems which are conviction of appealing drenching that support the torque per mass extent and beat alluring field picked up by suckling continually the posts a segment stator windings. The stage current substitution is the focal wellspring of the torque swell [6].

Minimization of torque wave can be triumphed by soaring the attractive technique of the engine and by tasteful electronic control methodology. The control techniques can be acquainted by which ever moment direct torque control (DTC) or roundabout torque control strategies. In DTC, just one-circle torque control is pragmatic which is accommodating than roundabout torque control as far as the course of action. By the by, complicated exchanging rules, uncontrolled exchanging recurrence and no over-current assurance are restrictions of DTC. For aberrant torque control, which ever current control circle or motion linkage control circle is compulsory [7].

The execution of inward circle will straightforwardly affect torque waves of SRM drive . Capacity of exchanged hesitance engine, for example, high force servo framework propels small portion torque swell. The PWM based control stratagems are shocked and the electronic control framework depend on control parameters taking after the inventory voltage, turn ON, turn OFF point and reference flow.To mode rate magnetic flux tracks to create the spin-offs of self and mutual inductance waveforms more sinusoidal and the acoustic noise aside from the torque ripple be mineralized. Furthermore, various conventional approaches as optimizing the motor structure, optimizing the control plans and emerging SRM structure can be scrutinized. Henceforward, examination on torque ripple minimization of SRM drive as a valuable object and accomplishment can be reconnoitered [8]. The organization of these documents designated as follows. Foregoing to that the contemporary inquiry workings exist in section 2. In section 3 stipulates the recommended proto type for torque ripple minimization of SRM. The investigational results and discussion are measured in Section 4. Lastly, the deductions are delivered in section 5.

II. RECENT RESEARCH WORKS: A BRIEF REVIEW

In creative writing, there has been cluster of investigation proceeded for torque ripple minimization of SRM drive system. A few mechanisms were revised at this point.

NutanSaha *et al.* [9] have accessible a control mechanism for speed control of SRM accompanied by torque ripple minimization devoting any optimizing liasion (MOL) procedure.

Xin Cao et al. [10] have assessed the hysteresis current control in existing control plans for double winding Bearing Less Switched Reluctance Motors (BSRMs), the byzantine deduction of winding-current articulation was necessitous and certain choking influences were too facilitated that enhanced the tangle child planning the present control calculation.

NutanSaha et al. [11] have racked a control game plan for incidental control of the speed of SRM and diminishing the torque swell holding Hybrid Many Optimizing Liaison Gravitational Search Algorithm (Hybrid MOLGSA) methodology.

Jin Ye et al. [12] have propositioned an all-encompassing velocity low-swell torque control of SRM drives devouring torque sharing capacity (TSF). PhuocHoa Truong et al. [13] have recommended a system fixated on counterfeit neural systems for contracting the torque swell in a non-sinusoidal synchronous hesitance engine.

The Lagrange advancement process was utilized to determine the puzzle of scheming ideal flows in the d–q outline. A neural control structure was later exhorted as a versatile answer for start the ideal stator flows abundant steady electromagnetic torque and reducing the holmic misfortunes.

Researcher has been endeavoring to limit the torque swell in SRM for a considerable length of time through either elective machine structures or control strategies. In any case, the swell prerequisites for low torque-swell wide-speed applications, for example, accuracy tooling, apply autonomy and actuators were static lesser than what have been acknowledged so far off with SRMs. SRM drives have primary minuses involving high torque swell, acoustic commotion, and vibration issues and higher control intricacy. The present profiling calculation connected to reduce the torque swell captivating the leads of FEA and dynamic profiling modernizes. Recently advance the assessment calculations, for example, Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Artificial Neural Networks (ANN), GSA, Fuzzy Logic Control (FLC) method and so on have been ordinarily utilized in SRM drive model to determine a shifted scope of framework catches essentially in torque swells of the engine. The above improvements techniques are actualized to moderate the swells however the deficiency exercises are pronounced. In writing, extremely uncommon instruments are offered to answer this dangerous and the shortcomings have mixed to do this examination exertion. Consequently, areal keen procedure is imperative for following the SRM drive torque swells was inspected. In this exposition, an improved FOPID controller for torque swell minimization is made arrangements for the BLDC engine drive framework. The proposed swell minimization technique for the SRM is verified and portrayed in the segment 3.

a. Mathematical modeling and analysis of SRM Drive

SRM is an electrical contraption that has double remarkable shafts in the stator and the rotor. It transfigures the hesitance torque into the mechanical force. In the twofold remarkable design, there are no windings or the steady magnet on the rotor. All things considered, the torque can be pondered to be activated by the unrelated module of the electromagnetic power between the stator and the rotor centers. The SRM achieves high torque levels at low pinnacle flows by little air holes. The stage twisting of SRM is fomented through the positive developing locale of the stage inductance region which is executed over a converter. The pervasively utilized converter is Asymmetrical converter, as it has issue tolerant ability, autonomous excitation all things considered and alternative of delicate and hard exchanging. At lesser velocities, the engine back-EMF are inconsequential connected to the inventory voltage and the present coursing through the stator winding can be delimited by PWM Control. Figure 1 epitomizes the circuit chart of the SRM drive.

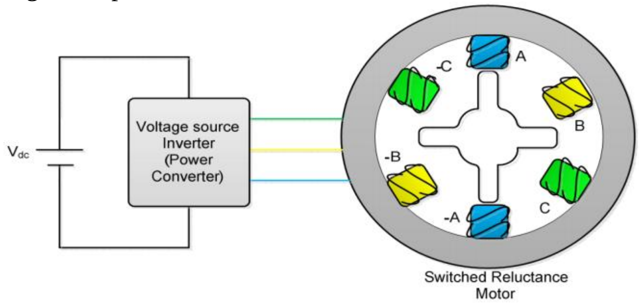


Figure 1: Basic structure of SRM drive system

The SRM drive framework contains power source in DC structure. This DC power is switched according to the commitment of the SRM drive. The condition is served as far as PWM signs to the Voltage Source Inverter (VSI) circuit. These PWM signals are noteworthy from the speed and torque control circle arrangement of the SRM drive. The numerical inductions of three stage input voltage of the SRM drive framework are determined underneath condition,

$$V_a = R_a . I_a + L_a \{\theta, I_a\}. \frac{dI_a}{dt} + e_a \quad (1)$$

$$V_b = R_b . I_b + L_b \{\theta, I_b\}. \frac{dI_b}{dt} + e_b \quad (2)$$

$$V_c = R_c . I_c + L_c \{\theta, I_c\}. \frac{dI_c}{dt} + e_c \quad (3)$$

Above equation (1), (2) and (3) of apiece phase voltage is ponders as single form $(z = a, b, c)$, that can be stated as below,

$$V_z = R_z . I_z + L_z \{\theta, I_z\}. \frac{dI_z}{dt} + e_z \quad (4)$$

Where,

$$e_z = \frac{dL_z \{\theta, I_z\}}{dt} \times \omega \cdot I_z \quad (5)$$

R_z, L_z *and* I_z denotes the winding resistance, inductance and current for each phase

ω is symbolizes the angular speed

In equation (4) expresses that the source voltage of SRM drives system is equivalents the total of three phase voltages. The formed voltage is disbursed by the first voltage is the voltage drop in the resistance, the second voltage is the transformer electromotive force affected by the changed flux since the current was reformed and the third one is about electromechanical energy of SRM instigated by the changed flux for the position of the rotor was rehabilitated.

A. Because of profoundly nonlinear attractive attributes of the twofold striking posts, the torque brought forth in a SRM is an element of the rotor position (θ) with worship to the empowered stage. In like manner, the torque age is made on the wellspring of minimalizing the put away attractive vitality noticeable all around hole. The air hole is a segment of the attractive circle and is fenced by the high penetrability of the ferromagnetic iron center. This vitality is corresponding to the hesitance in the midst of the stator and the rotor. The stored energy in the magnetic field in the motor is attained from the subsequent equation:

$$W_e = \frac{1}{2} L_z(\theta) \times I_z^2 \quad (6)$$

To compute the electromagnetic force by discriminating total energy with deference to the location of the rotor for single phase excitation as follows ,

$$T_z(\theta) = \partial W_e / \partial_\theta \quad (7)$$

The torque of an SRM with phases (z) excited can be conveyed in below equation,

$$Te_z = \frac{1}{2} \times \frac{dL_z(\theta, I_z)}{d\theta} \times I_z^2 \quad (8)$$

Where,

$L_z(\theta)$ is signifies the inductance which is a function of the rotor position (θ) for a given current,

I_z is indicated as the phase current.

The n number of phase and the total electrical torque formed in the SRM motor can be considered as in equation (9),

$$Te = \sum_{z=1}^{n} Te_z \qquad \text{For } n = 1, 2, 3 \quad (9)$$

The equation (8) can be used to originate the mechanical system in the SRM drive system and it is explained below

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

$$\frac{d\omega}{dt} = \frac{T_e - T_l - B \cdot \omega}{J} \quad (10)$$

Where,

ω symbolizes the angular velocity, J and B signifies the moment of inertia and friction co-efficient correspondingly. With the change in the load torque, the change in the total load to the SRM drive can be consummate.

B. Right now, proposed savvy controller is examined for recoup the presentation of the SRM drive framework. The proposed controller is incredibly accomplished to support both a low torque swell and change the speed variety. This can be come to by vaccinating suitable symphonious segments in the proposed controller to create the ideal results. The square outline of future topology is appeared in figure 2.

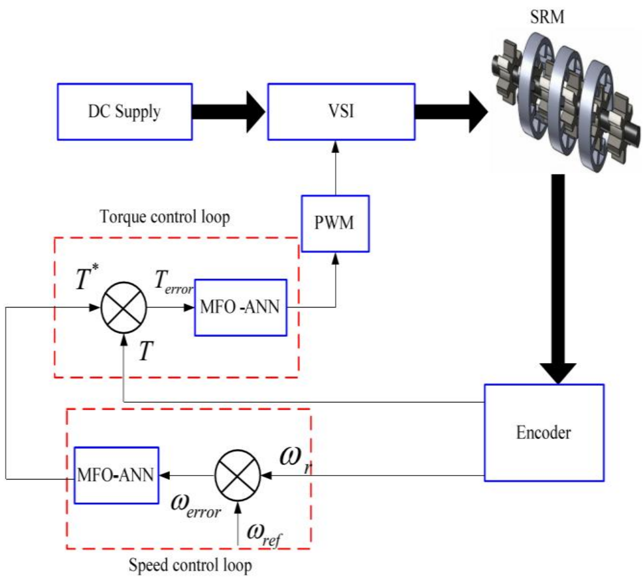


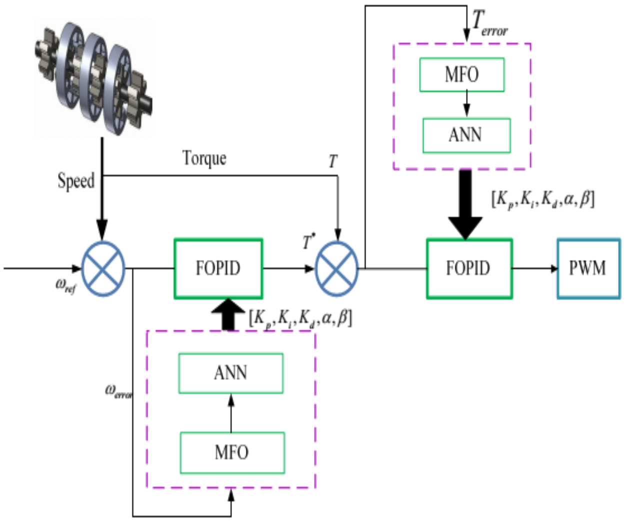
Figure 2: The structure of proposed control strategy based SRM system

The proposed diagram comprises a drive with its VSI and DC power supply. Different control tactics like voltage control, PI and PID control, and hysteresis control can be applied for the control of an SRM. Yet, these control procedures yield more vibrations, noise and too origin tough to control the speed and torque. Hereafter the control strategy of MFO-ANN procedure based FOPID controller is projected. In this article, a motor covers two loop operations, the first one is speed control loop and second one is torque control loop. The requirement of these two loop controller are developed by normalize the speed and minimalize the torque ripples of SRM drive.

C. **Control strategy of torque ripple minimization**

The focal objective of the manuscripts depicted for minimize the torque ripples in SRM drive system with the aid of proposed controller. In the suggested system be made of two control loops that are speed control and torque control.

Each control loops have its own discrete parameters to act an identifiable duty. The construction of enhanced FOPID controller with anticipated model is demonstrated in figure 3.



Once the DC supply is agreed to the power converter as the SRM motor should be in seriatim state. In speed loop, the signals of motor output speed are associated with the reference speed and is suckled through MFO-ANN based FOPID speed controller to acquire reference torque (T^*). These torque references succeed the control deed to be achieved for minimizing the speed error specifically instigated. Formerly, these positions are related with the actual SRM drive torque and are nourished to the torque loop. In the torque control loop, over alternative proposed controller of enhanced FOPID with MFO-ANN is implemented for optimizing the torque error and decisive the control signal. To enrich the performance of FOPID controller in both control loops, the optimal gain parameter is strong-minded. Now five gain parameters viz., Proportional (k_p), Integral (k_i) and Derivative (k_d) constants the controller have additional integral order (α) and the derivative order (β) are used. From the optimal parameters of FOPID, the controller output is estimated. The enhanced performance of FOPID controller is evaluated. In this system, the multi-objective functions are resolute. The multi-objective functions to be optimized are the speed error and the current error that embraces the torque ripples. The mathematical forms of the objective functions are specified as follows,

$$\text{Speed} \Rightarrow Obj\ \omega_{error} = \omega_{ref} - \omega_r \tag{11}$$

$$\text{Torque} \Rightarrow Obj\ T_{error} = T^* - T_{actual} \tag{12}$$

Another one objective of torque ripple is expressed in percentage,

$$\%T_{ripple} = \frac{1}{T_{avg}}(T_{\max} - T_{\min})\times 100 \tag{13}$$

Where, T_{avg} be the average torque value, $T_{\min}$ be the minimum total torque and $T_{\max}$ be represented as the maximum total torque. In the future system, these objective functions are assessed from the comparator which is offered as the input of the MFO-ANN method. Originally, the performance of MFO algorithm is studied and the consistent outputs are heightened by using the ANN practice. With the consumption of proposed MFO-ANN performance, the routine of FOPID controller is heightened. Besides the recital of enhanced FOPID controller is considered underneath.

Control strategy of FOPID controller enhancement

The fractional order PID (FOPID) controller is the extension of the conventional PID controller depends on fractional calculus. For countless decades, proportional integral derivative (PID) controllers have been very prevalent in industries for process control applications. Their virtue resides in straightforwardness of design and good execution such as low percentage overshoot and small settling time (which is essential for slow industrial processes). Henceforward, devising an optimum FOPID controller compels fine tuning of parametric gains $\{k_P, k_I, k_D, \alpha, \beta\}$ which in revert calls for real parameter optimization in five-dimensional hyperspace. In the article, FOPID controller gain parameters are applied to handle the speed error and torque error and for concluding the reference current and the control signal. The both FOPID controller movements are characterizes in mathematical form as follows:

$$T^*(t) = \omega_{error}(t)\left[k_{p,speed} + \frac{k_{I,speed}}{S^{\alpha,speed}} + k_{D,speed}\cdot S^{\beta,speed}\right] \tag{14}$$

$$Q(t) = T_{error}(t)\left[k_{p,torque} + \frac{k_{I,torque}}{S^{\alpha,torque}} + k_{D,torque}\cdot S^{\beta,torque}\right] \tag{15}$$

Where,

$T^*(t)$ is denoted as the reference torque

$Q(t)$ is denoted as the control signal

$k_p, k_I, K_D, \alpha, \beta$ are represents the gain parameters of FOPID, that acts in both speed and torque control

The output of control signal $(Q(t))$ is served through the PWM block for minimalizing the speed error and the torque error. The Equations (11) and (12) statuses that the rewards of both the FOPID controllers are the control parameters to be tweaked for receiving an exact performance from the minimization of torque ripple in SRM drive system. So as to settle the optimal values of the both FOPID gain parameters, MFO-ANN system is active. The objective functions are pondered as input of the proposed MFO algorithm to preference on the optimal control gain parameters of the SRM drive system.

D. **Optimization of Gain Parameters Using MFO-ANN Algorithm**

I. Objective functions using MFO algorithm

Moth-Flame Optimization (MFO) is characteristic propelled streamlining calculation put together by Mirjalili. MFO obtains its motivation from transverse direction of moths in condition. The main motivation of this enhancer is the route method for moths in nature named transverse direction. It is a populace based developmental calculation search technique which caricaturists the conduct of moths in their particular route strategies at daily.

The sign of the MFO depends on a contraption called transverse direction for bearing finding in late evening fling the moon light. A hypothetical model of transverse direction is exemplified in figure 4.

By this hardware, moth flies with a fixed point with yielding to the moon. At the point when moths visit a human made counterfeit light, they cut to save a comparative edge with the light to float in straight line [14].

The moths are bona fide look for operators that movement around the inquiry are anyway flares are the best situation of moths that takes up until this point.

As pronounced over the motivation of this calculation is the transverse direction. By minimalizing the fitness function by get the optimal parameters of FOPID controllers. Also the proposed MFO algorithm stepwise method is accessible below.

Step 1: Process of parameters specification

Mainly, the FOPID controller parameters are started subjectively, for example, , and harmoniously.

The essential parameters of MFO enters, inconsistently produce starter populace for moths and blazes with measurements, the quantity of factors, the most extreme emphasis number. Stipulate the irregular age of upper bound and lower bound of all factor as follow,

Lower bound: $\lambda = \lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_{n-1}, \lambda_n$ (16)

Upper bound: $\eta = \eta_1, \eta_2, \eta_3, \ldots, \eta_{n-1}, \eta_n$ (17)

Step 2: Position initialization process

MFO calculation can be existing by position network assigned by M covering number of moths and F containing number of blazes.

Both moth and fire can fly in different measurements in space by setting number of factors for each moth and fire. Presently the situation of the moths and flares are signposted as conditions (15) and (16) correspondingly.

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & m_{1,k} \\ m_{2,1} & m_{2,2} & \cdots & m_{2,k} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ m_{i,1} & m_{i,2} & \cdots & m_{i,k} \end{bmatrix} \quad \text{and}$$

$$F = \begin{bmatrix} f_{1,1} & f_{1,2} & \cdots & f_{1,k} \\ f_{2,1} & f_{2,2} & \cdots & f_{2,k} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ f_{i,1} & f_{i,2} & \cdots & f_{i,k} \end{bmatrix} \qquad (18)$$

Where, M and F are representative the position matrix of moth and flame, i is the number of moths and k is the number of dimensions. Then the initialization of moth and flame can be computed by,

$$M_{c,d} \text{ or } F_{c,d} = rand(\eta_d - \lambda_d) + \lambda_d \qquad (19)$$

Where, $M_{c,d}$ and $F_{c,d}$ implied as the number of variables or dimensions, $rand$ is the random number produced with uniform distribution in the interval [0, 1], λ_d and η_d means the lower and upper bounder of d^{th} variables compatibly.

Step 3: Process of fitness function evaluation

Every moth and fire is choked by transient the steady position vector to the ideal target work which at that point apportions to a section vector and the best wellness estimation of each moth and fire.

$$M^O = \left[M_{11}^O,\ M_{21}^O, M_{31}^O \ldots\ldots\ldots, M_{i1}^O\right] \quad \text{and}$$

$$F^O = \left[F_{11}^O,\ F_{21}^O, F_{31}^O \ldots\ldots\ldots, F_{i1}^O\right] \quad (20)$$

Constructed on the above function, the best fitness function is appraised by the equation exposed as follow.

$$F_f = Min\ E(\phi) \qquad (21)$$

Where, the mean of fitness function (F_f) is diminish the error value of torque and speed $(E(\phi))$ in SRM drive system.

Step 4: Start iteration process

Right now moth goes around the arrangement space. With the point of scientifically model the conduct of combining close to the light or moon, a logarithmic winding is all around characterized for the MFO calculation to imagine the winding flying way of moths with adoration to a fire.

The introduced MFO calculation utilizing logarithmic winding capacity as follow,

$$S(M_c, F_d) = D_c * e^{qt} * \cos(2\pi t) + F_d \qquad (22)$$

Where,

$$D_c = |F_d - M_c|$$

M_c is symbolizes the c^{th} moth, F_d exemplifies the d^{th} flame. D_c is the distance between the c^{th} moth and d^{th} flame, q is a constant, t is a random number between -1 and 1. To become upgraded numerical outcomes, this interim is improved from r to 1, and r is directly diminished from - 1 to - 2 in the iterative procedure.

Moths perpetually reestablish their situations with regard the fire by following winding way. Investigation and misuse of the total inquiry space can be guaranteed as logarithmic winding capacity lets moth to move around the fire.

Step 5: The optimal result selection process

The spot of target fire would be modernized if a portion of the moths convert preferred quality over it.

As said by this standard, the position and the wellness of blazes would be rebuilt then re-decide the best outcome and reestablish its position if any moth creates fitter than the best fire selected from the first cycle.

While the emphasis basis is get the top goals would be continued as the best picked up estimation of the ideal.

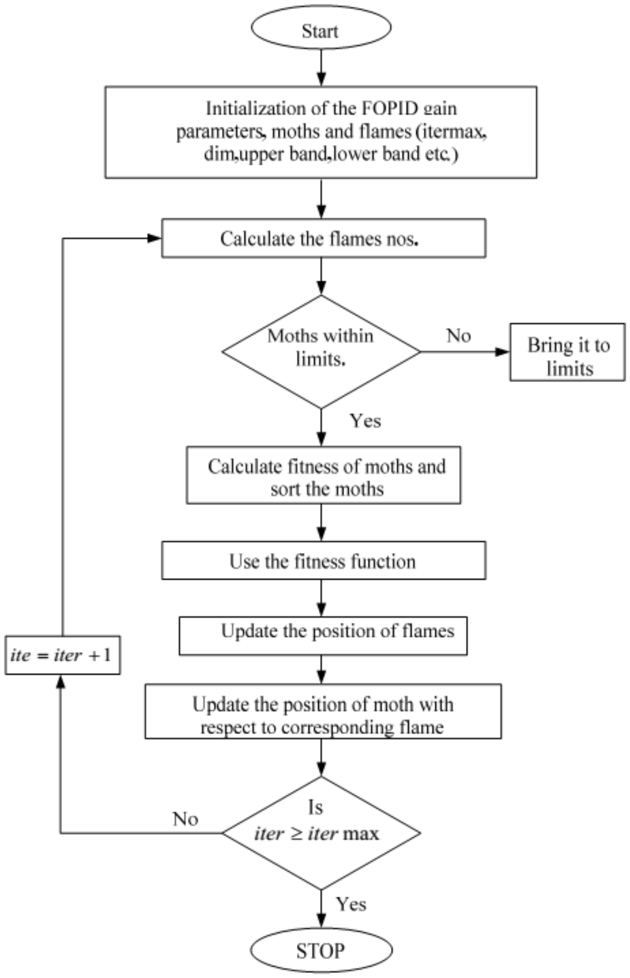


Figure 5: The flowchart of MFO algorithm

The general flowchart of MFO algorithm is elucidated in figure 5. Next the resultant value of MFO algorithm is optimized by proposed ANN method. Likewise, the performance of ANN performance is reconnoitered in under section II.

III. ANALYSIS OF ANN TECHNIQUE

The neural network is expended to procession the optimized values for the proposed hybrid system. The optimized gain parameter is pertained to the input of neural network. As seen in figure 6, the inputs of ANN controller are the error signals ($e(t)$) and modification in error signals ($\Delta e(t)$). The output of the ANN is fixed to the input of FOPID controller which is measured as Y. To understand the effective control of the framework, the neural system ought to be qualified in such a condition, that for the given contribution of the controller should develop a legitimate increase signals. The point by point depiction of the ANN is incorporated right now . For developing the scientific structures, ANNs are fine strategy with the capacity to contemplate. Regularly, Neural system contains two stages viz., preparing and testing stages. The ANN have Input layer, shrouded layer and yield layer. The preparation structure of ANN is appeared in Fig. 6. Back proliferation calculation is utilized to direct the neural systems

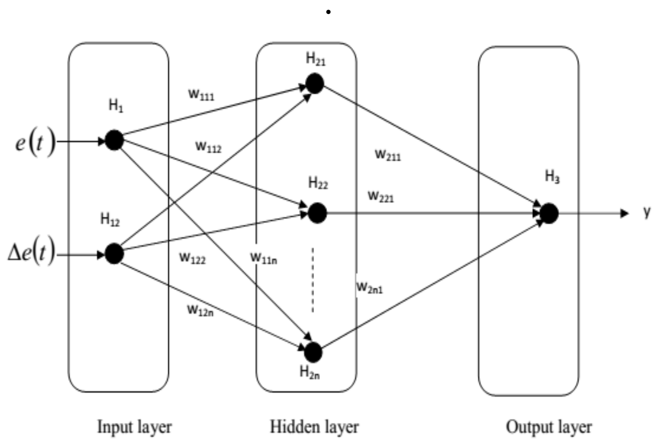


Figure 6: Training structure of ANN using proposed hybrid approach

Now, the weight of the network is allocated for input layer to hidden layer and hidden layer to output layer. From the input layer to hidden layer weights are represented as $(w_{11}, w_{12}, \ldots w_{1n})$, $(w_{21}, w_{22}, \ldots w_{2n})$ and $(w_{31}, w_{32}, \ldots w_{3n})$ correspondingly. The hidden layer to output layers' weights is epitomized as $(w_{211}, w_{221}, \ldots w_{2n1})$. The output of the node is required as (Y). Then the neural network is skilled by back propagation algorithm. The training algorithm steps are expressedas follows,

Steps for Training algorithm

Step 1: Now, the weight of each neuron is allotted casually for learning the network. The minimum and maximum weight (i.e., $W = (w_{\min}, w_{\max})$) of the interval range is indicated as $(0,1)$.

Step 2: Using the subsequent equation, the back propagation error of the network is considered.

$$BP_{error} = Y_{t\arg et} - Y_{out} \tag{23}$$

Where, $Y_{t\arg et}$ be the network target of the node and Y_{out} be the current output of the network.

Step 4: From the neural network, the current output is dogged by following them,

$$Y_{out} = \beta + \sum_{n=1}^{N} w_{2n} Y_i(n) \tag{24}$$

Now, w_{ij} be the weight of the $i - j$ link of the network. Later, y_i be the output of i^{th} hidden neuron. As well realize the change in weights depend on the obtained BP error.

Step 5: Regulate the bias (or) activation function of the network.

$$Y_i(n) = \frac{1}{1 + \exp(-w_{1n} * Y_i(n))} \tag{25}$$

Step 6: The new weights of each neurons of the network are reorganized by using the succeeding equation,

$$w_{new} = w_{prev} + \Delta w \tag{26}$$

Now, w_{new} be the new weight, w_{prev} be the previous weight and Δw be change of weight of each output.

Step 7: Using the subsequent equation, change of weight in the network is appraised.

$$\Delta w = \delta . Y_{out} . BP_{error} \tag{27}$$

In Eq. (24), δ is the learning rate. Reiterate the above steps till the BP_{error} becomes minimized $BP_{error} < 0.1$. When the neural network training process is finalized, the network is qualified well for minimalizing the error value of the input [31]. Thenceforth the neural network output is given to the input of the FOPID controller. Afterward, the gain parameter of FOPID controller is optimized. From the two phase analysis, the speed and torque is regulated optimally using the proposed technique. The detailed experimental results analysis was specified by the resulting section 3.

IV. RESULTS AND DISCUSSION

In this section, the efficiency of the proposed algorithm based FOPID controller is operated to decrease the torque ripples in SRM drive system. That validate the proposed SRM drive system is executed by MATLAB/Simulink platform. And the simulation result of proposed procedure is likened with the existing methods like MFO-FOPID and PSO-PID correspondingly. The optimization process is passed out by using the MFO-ANN algorithm based on the multi-objective function. The Simulink diagram of the proposed system is showed in the diagram 7 which is used to diminish the torque ripple of the SRM drive with the benefit of planned method. In the process, FOPID controller is working to shift the speed and torque of the SRM drive system. Now, the proposed system condenses the torque ripple and normalizes the speed of the SRM system. Firstly, the controlling parameters are assessed from the SRM such as current, rotor position, flux, torque and speed compatibly. The presentation of motor action in simulation model the time is taken as t= 0 to 1.5 sec. The FOPID controller is adjusted at rated conditions as well the proper variation of SRM system is deliberated. The value of proposed way is gagged in the below segment.

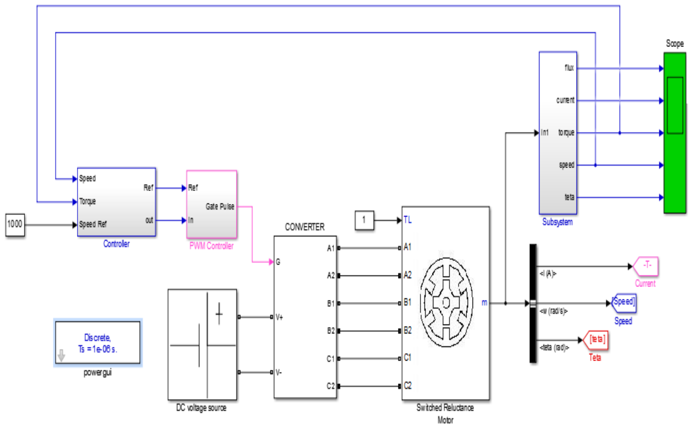


FIGURE 7: SIMULATION DIAGRAM OF SRM PROPOSED MODEL

A. Performance analysis:

The action of a proposed controller is to optimize the error function. The projected algorithm is consumed for optimize the gain parameters, to minimize the speed and torque errors. The minimized torque and the speed output are accompanied by optimal tuning of gain parameters. The SRM drive is tried under constant load and at dissimilar speed conditions. Concerning the speed condition, the recital of proposed controller action is verified under two cases.

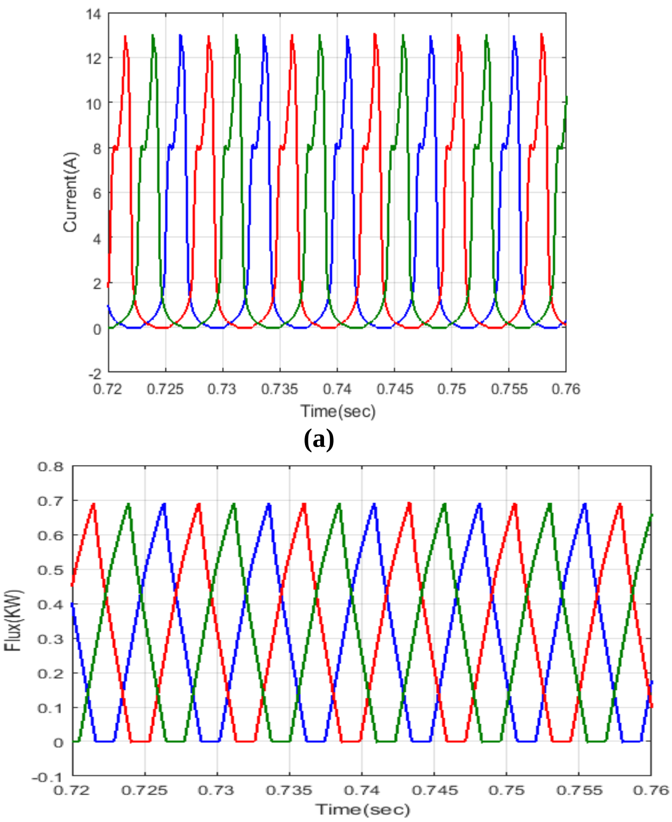
Case 1: Constant speed at 1000 rpm

Case 2: Constant speed at 1500 rpm

In the following, these two cases are designated and the performance of proposed scheme is depicted in below.

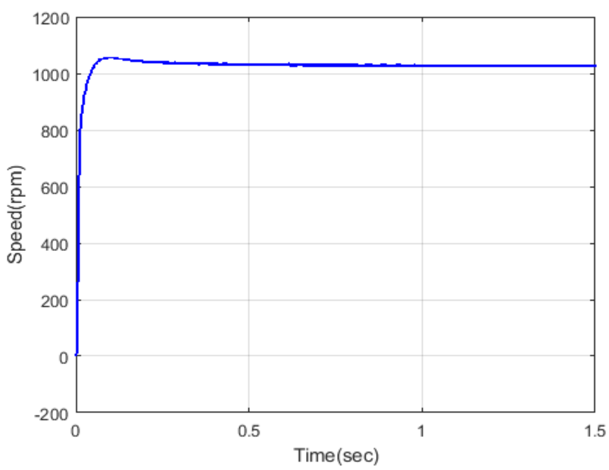
I.Case 1 Analysis

In the case 1 analysis, the motor is confirmed alongside its constant speed at 1000 rpm with a load torque of 1.5 Nm. To evaluate controller and thus to measure the effectiveness and control capability of the proposed arrangement, the performance of the SRM drive system created on the recommended control scheme is studied. The optimization ideas comprise the minimization of torque ripples.

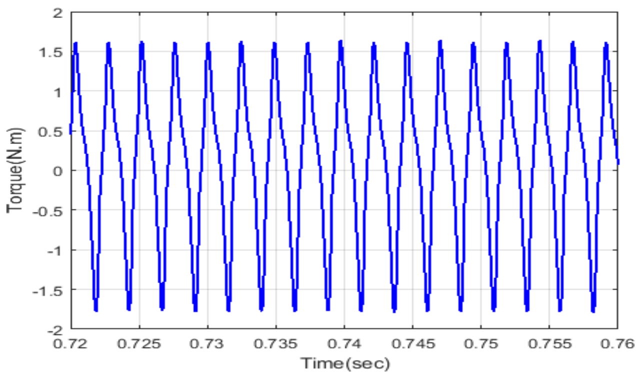


(b)

Figure 8: Analysis of (a) Current and (b) Flux using proposed method in case 1



(a)



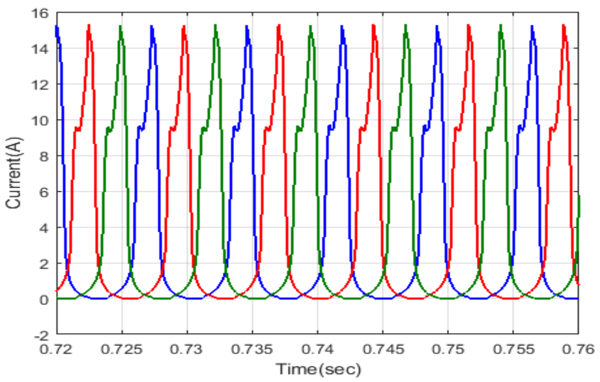
(b)

Figure 9: Analysis of (a) Speed and (b) Torque using the proposed method

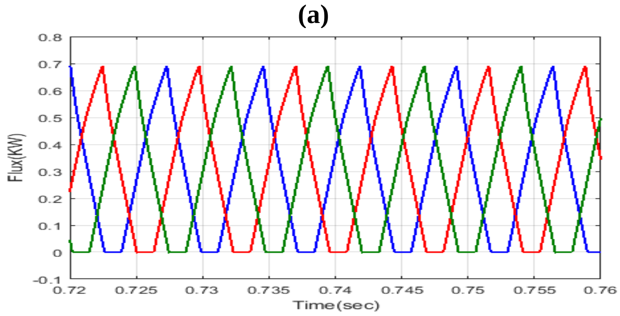
The dc supply voltage is known to the input of the SRM drive system. The measured phase current, phase flux linkage, rotor position, speed and torque of the future technique are evaluated in figure 8 and 9consistently, once the SRM drive functions at the speed of 1000 rpm. At the view, the proposed system estimates the minimization of error as the objective function implementation for the system parameters. The performance of the current and flux are shown in figure 8 (a) to (b) congruently. By the proposed mode the current turbulences are abridged at range zero to 13 A with the time t= 0.72 to 0.76 sec. The measured output of torque and speed variations is publicized in figure 9 (a) and (b). In the SRM drive system, the speed graph is somewhat rises at reference speed condition.

II.CASE 2 ANALYSIS

In this second case, the reference speed is cogitated as 1500 rpm at the time range is t= 0 to 1.5 sec. The rotor rotational angle is spotted by a rotary encoder. The measured phase current, phase flux linkage, speed and torque indicated in figure 10 and 11 at the reference speed of 1500 rpm.

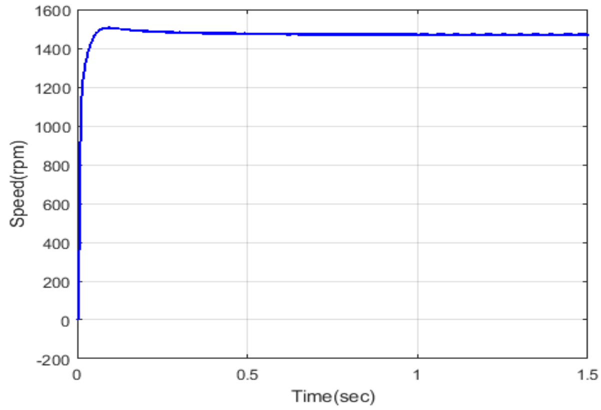


(a)

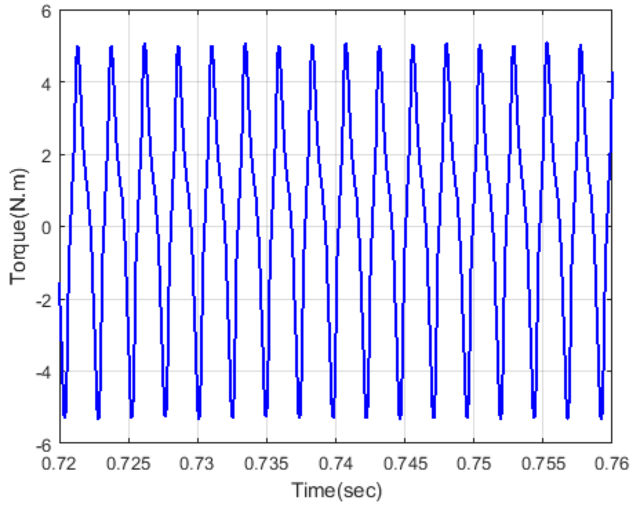


(b)

Figure 10: Illustrations of (a) Current and (b) Flux using proposed method in SRM system at case 2



(a)



(b)

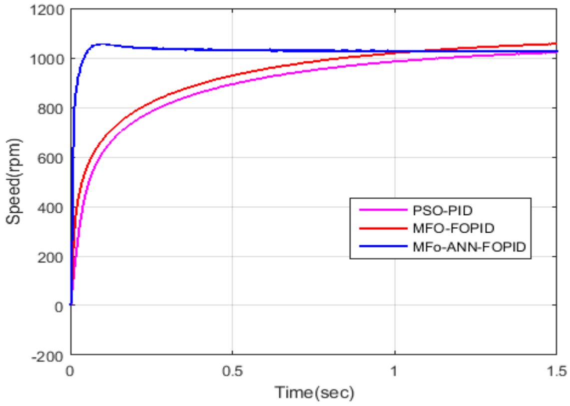
Figure 11: Simulation result of (a) Speed and (b) Torque using the proposed method in case 2

The speed, current and torque of the SRM are the parameters that are occupied into account in the multi-objective function. In this sector at time t= 0.72 to 0.76 sec the current flow is scope at 15 A as displayed in figure 10 (a). The optimal gain parameters have fetched about a large reduction in the current disturbances amid the phases. The reduction of disturbances in planned flux waveform is presented in figure 10 (b). By the proposed way of SRM speed and torque is labelled in figure 11 (a) and (b). With the aim of analysis, torque and speed variation of the proposed controller has been analyzed. Now the SRM drive system is worked in the reference speed 1500 rpm. To give the reference condition the settling time is extent at 0.35 sec. Additionally the torque variations are also examined at time t= 0.72 to 0.76 sec as flashed in figure 11 (b). Advanced, the comparison analysis of the existing and proposed tactics is enlightened in the successive part.

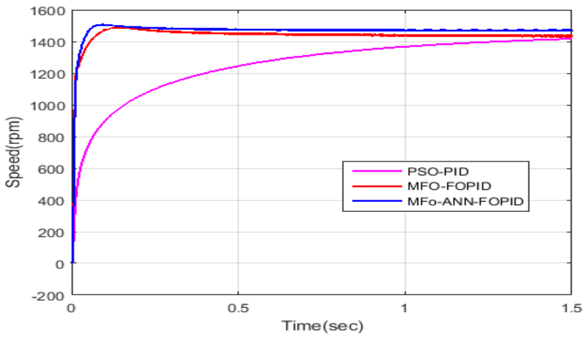
III. Comparison analysis

In the comparison analysis, the SRM parameters like speed and torque variation below the two case of enquiry are rivaled with proposed process and existing procedures. The proposed controller confrontations the error from the gain parameters with the aid of the MFO-ANN procedure. From figure 12 and 13 analyses the performance comparison of the proposed control algorithm with numerous control algorithms such as MFO-FOPID and PSO-PID in times of speed and torque vs time in sec.

Now the performance explored for the minimization of torque ripples and regulation the speed variant.

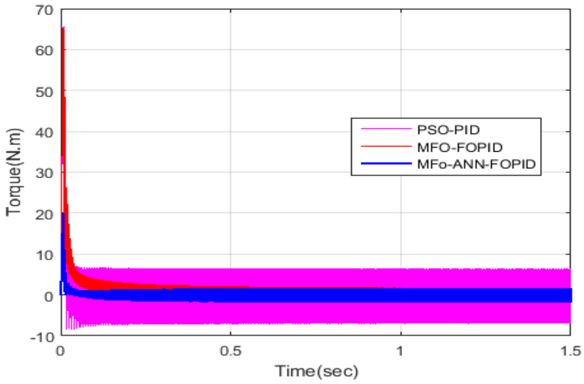


(a)

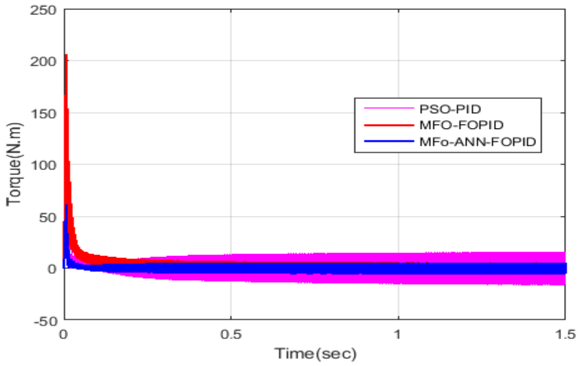


(b)

Figure 12: Comparison analysis of Speed in (a) Case 1 and (b) Case 2 using various methods



(a)



(b)

Figure 13: Comparison analysis of Torque in (a) Case 1 and (b) Case 2 using various methods

In the figure 12 (a) case 1 expressions the performance of ensued speed at 1000 rpm below the projected method, the rising time is 0 sec and the settling time is 0.03 sec at 1050 rpm. So as to associate the other algorithm the future technique of MFO-ANN based FOPID controller is lessen the settling time operation. Equally, the performance of speed in case 2 condition is studied with the regulation of speed as revealed in figure 12 (b). Besides the torque ripple is declined with the optimization procedure, whilst linking it with prevailing methods like MFO-FOPID and PSO-PID correspondingly. In the figure 13 (a) case 1 demonstrations the performance of resultant torque ripples, by concerning the proposed tactic at the time period t= 0 to 1.5 sec are presented. From the variation, minimum amount of torque ripples is achieved as match with additional existing algorithm operation. By the propositioned method, the torque ripple is 1.5 Nm at 1000 rpm nevertheless the current methods such as MFO-FOPID and PSO-PID is 5 Nm and 7.5 Nm consistently. Also case 2 torque ripple minimization is explored as publicized in figure 13 (b). Afterwards comparison analysis the percentage of torque ripple reduction in existing system is lesser than the proposed controllers. In the speed analysis, settling time attained using the proposed technique is very little than the other present techniques. And too the speed regulating aptitude of the SRM has got improved with the planned procedure. Conclusively, the recital of proposed controller stretches better control of speed and torque ripple than the offered procedures.

V. CONCLUSION

The paper presents an objective function based proposed MFO-ANN algorithm for the SRM drive system. The reflection of objective function with the proposed controller performances are tried underneath the MATLAB/Simulink platform and equate with other procedures. The optimal parameters of speed controller and torque controller are gotten by using the above optimization performances. Now the proposed control algorithm is depending on the optimized FOPID controller for the speed and torque control loop. The proposed MFO-ANN algorithm was applied to optimize the gain parameters of FOPID controller over the converter operation. So as to develop the FOIPID controller for minimize the torque ripple of SRM system. The most proficient goal of the manuscripts minimized the error value of speed and the torque correspondingly. The performance of system parameters such as speed, torque and current variations are inspected. From the gained result, the proposed MFO-ANN based FOPID controller give recovering solution for SRM system by minimizing the torque ripple and settling times aside from offers better current profile owing to its robust exploitation capability than the exiting practices. With optimized design parameters, the final rotor design conquered a torque ripple of 5.25% which is a substantial progress seeing the effortlessness of this technique.

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