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PI Controller Based Switching Reluctance Motor Drives using Smart Bacterial Foraging Algorithm

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Abstract

Optimization algorithms are commonly used in the industry. The optimization strategy, if key elements are ignored, can quickly render the solution unfeasible. As a result, various optimization strategies are applied at all aspects of the industry level. The switched reluctance motor is the most affordable of all motor types. The high torque density attribute of induction motors is one of the market's major drivers. Switched reluctance motors are also employed in high-volume and high-starting torque appliances. The Smart Bacterial Foraging Algorithm (SBFA) mimics the chemotactic behavior of E. Coli bacteria for optimization purposes. This method is used to calculate the coefficient of a typical Proportion–Integration (PI) speed controller for SRM drives while accounting for torque ripple reduction. The results of the modeling and experiments reveal that the modified PI controller with SBFA performs better. The proposed optimization strategy results in increased performance when compared to regular BFA.

Keywords: smart bacterial foraging algorithm, SRM motors, optimization, PI controller, PWM inverter.

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1. Introduction

The Smart Bacterial Foraging Algorithm (SBFA) controls the drive of a switching reluctance motor (SRM). SBFA mimics the chemotactic behavior of E.Coli bacteria to optimize its performance. This technique is used to calibrate the coefficients of a classic Proportion–Integration (PI) speed controller for SRM drives. Bacteria Foraging Optimization (BFO) is a novel type of biologically supported global search strategy that mimics E. coli bacteria's foraging behavior [1]. Switched reluctance motor is the least expensive of all the motor types. Air conditioning systems that are environmentally friendly for passenger trains, advanced weaving machine techniques, motor blower for vacuum cleaners, and food processor compact drives are some of the applications of switched reluctance motors. Switched reluctance motors are also used in high-volume appliances and those with a high starting torque. High torque density compared to induction motors is a major market driver [2].

A bacteria can engage in one of two foraging behaviors: tumbling or swimming. Swimming and tumbling are used to create chemotaxis. Swarming occurs when bacteria spread out from their positions in a ring of cells by reducing mean square error to a minimum value. To optimize means to find the optimum answer to a certain situation. Deterministic approaches are based on the computation of functions, derivatives, or approximations to those functions. Stochastic approaches use an "oriented random" approach to find the best result. Examples include engineering issues requiring low cost, great performance, and little loss. Researchers are attempting to combine BFOA with various other algorithms to investigate both its local and global search features. It has already been used to solve a variety of real-world issues, demonstrating its efficacy over a wide range of GA and PSO variations. Future studies on BFOA may include mathematical modeling, adaption, and modification of the method. For determining the best FACTS device rating, there are a variety of optimization techniques. The following is a list of the different types.:

- Genetic Algorithms
- Simulated Annealing
- Ant Colony Optimization
- Particle Swarm Optimization
- Differential Evolutionary Algorithm
- Tab Search
- Fuzzy Logic Control
- Artificial Neural Networks and
- Bacterial Foraging Optimization Algorithm

To obtain the best rating of FACTS devices, the Bacterial Foraging Optimization Algorithm (BFOA) is proposed in this paper [3]. The Bacterial Foraging Optimization Algorithm (BFOA) (Kevin Passino 2002) is suggested to discover the appropriate rating of FACTS devices to minimize actual power loss, FVSI, L-index, and overall cost. In numerous instances where traditional analytical approaches failed to converge, our algorithm converged to the best answer. This method offers several advantages, including a lower computing burden, global convergence, a shorter computational time required, and the ability to handle a larger number of objective functions [4].

2. Literature Survey

A novel optimization technique dubbed smart bacteria foraging algorithm (SBFA) is created to improve the regular BFA. In contrast to the BFA, a new word intelligently identifies the bacterium's travel orientation. Except for the finest bacterium, all bacteria go through an elimination and dispersal process. The Smart Bacteria Foraging method was used to optimize the coefficients of the PI speed controller for SRM drive-by resolving a multi-objective function. The Bacteria Foraging Optimization Algorithm (BFOA) is a new member of the family of nature-inspired optimization techniques. BFOA's central idea is to imitate the chemotactic movement of virtual bacteria in the problem search space. Chemo taxis are bacteria that migrate by taking little steps while searching for food [1][3].

In [5] SRM motor modeling, simulation, and control Modelling and simulation, which incorporate as many practical non-ideals as feasible, substantially minimize the time and expense involved with intensive testing. Harmonic elimination using a hybrid least-squares–fuzzy bacterial foraging method. By examining the foraging activity of E. coli bacteria in our gut, the approach predicts the harmonic components included in power system voltage/current waveforms. The bacterial-foraging optimization algorithm (BFOA) attempts to replicate the collective and individual behavior of E. coli bacteria. A bacterium's simulated chemotactic movement might be thought of as a guided random walk or as a type of stochastic hill climbing. One of the most recent nature-inspired algorithms for optimization problems is based on the artificial bee colony (ABC)[6]. This research provides novel ABC algorithms for parameter adaption that take advantage of chaotic maps. It has also been demonstrated that the recommended approaches have improved the quality of the solutions. Thyristor Controlled Series Capacitor (BFTCSC) for oscillation suppression in a multi-machine power system based on the Bacterial Foraging Optimization Algorithm (BFOA). The ideal controller settings are determined using BFOA [7].

The improved bacterial foraging algorithm for cost-effective wind power dispatch. The feeding habits of E. coli bacteria in the human intestine inspired the concept [3]. This paper describes a unique bacterial foraging algorithm (BFA)-based technique for the robust and optimal design of a PID controller coupled to a power system stabilizer (PSS). Depending on the foraging behavior of E. coli bacteria, this study aims to optimize three PID-PSS parameters (*Kp*, *Ki*, and *Kd*) [8].

The simulated chemotactic movement is an important stage in BFOA. Chemo taxis is a foraging approach that involves a type of optimal solution in which bacteria aim to ascend the nutrient concentration to avoid undesirable compounds and seek routes out of neutral conditions. To speed up and narrow the search, a larger number of bacteria must be put at certain points in the optimization domain [9]. The chemotaxis serves as the foundation for local search, and the reproduction process speeds up the convergence, which is approximated by the classic BFO. While chemotaxis and reproduction are insufficient for global optima searching, because bacteria can become stranded in the beginning sites or local optima, the variety of BFO can change gradually or abruptly to eliminate the possibility of being stranded in the local optimal [3][10]. A novel and improved Torque Sharing Function (TSF) is presented in this study to reduce torque ripple in switched reluctance motors (SRM). This proposed method has a lot of flexibility in terms of adapting to different types of SRMs with varying characteristics. The torque generated was of outstanding quality, with a ripple of one-third that of fuzzy TSF [19]. To produce a rapid and accurate prediction of the performance of the SRM drive system, the method employs a Genetic Algorithm (GA) based Artificial Neural Networks (ANN) approach that is used for its interpolation capabilities for highly nonlinear systems used in [20]. The Beetle Antennae Search algorithm is used to improve the excitation current of the multi-coils to reduce current excitation and construct a higher uniformity gradient magnetic field[21].

The major goal of this study is to manage the speed using a unique optimization approach (Smart Bacterial Foraging) and compare the performance to traditional controllers such as PI, PID, and intelligence controllers such as Fuzzy and neural fuzzy systems. Find its applications for both constant and variable loads.

Decrease the peak rising time and the high overshoot time. Minimize overshoot and undershoot issues [5][11].

3. Optimization Method- Bacterial Foraging Algorithm

One of the earliest bio-inspired approaches was the genetic algorithm (GA). Motility is accomplished by a set of elastic flagella during foraging in actual bacteria. Flagella assist an E[1]. coli bacterium in its two primary functions of tumbling and swimming. GA is utilized in simulation experiments to optimize the PI speed controller coefficient design[12]. Figure 1 displays a bacterium moving clockwise and counterclockwise in a nutritional solution.

To tackle the optimization challenge, optimal foraging of bacteria is employed. For communal foraging, a creature requires communications infrastructure. It can benefit by being in a community, and the gathering can generate a form of collective intelligence. Despite its merits, GA takes a long time to identify the best solution. GA may occasionally establish a local minimum rather than a global minimum[9][13].

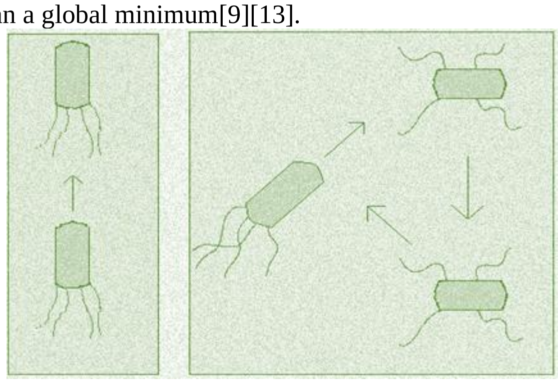

Figure 1. Swimming and Thumbling

3.1. Initialization [Step -1]

i. The number of parameters that must be optimized (B).
ii. The number of bacteria (S) to be employed in the whole region search.
iii. Swimming length Ns, followed by chemotactic tumbling of bacteria.
iv. *N*, the number of chemotactic loop iterations to be performed (*K<Nc*).
v. The maximum number of reproductions to be carried out by *E*.
vi. *Ned* will enforce a maximum number of elimination and dispersion events on microorganisms.
vii. The likelihood that elimination and dispersion events will be enforced on microorganisms.
viii. The location of each bacterium *J(B,0,0)* is specified by random numbers on [-1, 1].
ix. The value of *C(i)* is assumed to be constant.

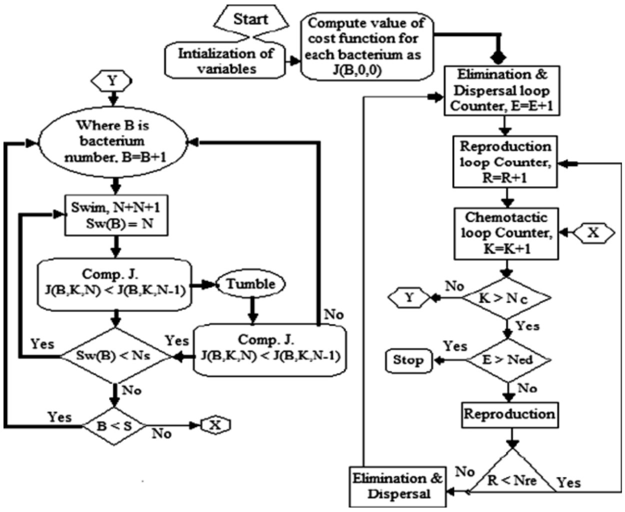

Figure 2. Schematic Diagram of Proposed SBFA Algorithm

This method is used by bacteria to discover food, as seen in Figure 1. A detailed flow chart of the proposed work is depicted in Figure 2. Each bacterium's flagella determine if it should swim or tumble. The rotation of flagella determines the cost function of each action. In particular:

$$\alpha^{i}(j+1,k,l)=\alpha^{i}(i,k,l)+C(i)\varphi(j) \tag{1}$$

Where;
ai(i,k,l): position of *i-th* bacterium of S (total population of bacterium) at *j* is the chemotactic,*k-th* reproductive, and *i-th* elimination and dispersal step.
J(a): main cost function, for a bacterium at the position (A). *'c(i)'* which is calculated based on the cost function *J(ai)* for *i-th* bacterium [1].

$$c(i)=\max(C_{\min},\frac{|J(i)-J_{o}|}{K_{1}} \tag{2}$$

J0: global optimum solution
J(i): cost function value for I the bacteria (*K1*_|*J*|)
C(i): cost function for each bacterium,

$$\varphi(i)=\beta(i)\frac{\Delta(i)}{\sqrt{\Delta^{T}(i)\Delta(i)}} \tag{3}$$

As swarming bacteria operators, attractants and repellents are utilized in equation (4). To mimic cell-to-cell signaling, an extra function is used. The healthier half of bacteria (with the lowest value of the cost function) are permitted to remain, while the other half perish [1].

$$J_{cc}(\alpha_{gm}(j,k,l),\alpha(j,k,l)) = k(\Sigma_{i=1}^{s}[-d_{att}.exp(-watt\,\Sigma_{m=1}^{p}(\alpha_{m_{gm}}-\alpha_{m}^{i})^2)] + \Sigma_{i=1}^{s}\left[h_{rep}.exp\left(-\omega_{rep}\,\Sigma_{m=1}^{p}\left(\alpha_{m_{gm}}-\alpha_{m}^{i}\right)^2.\right)\right] \quad (4)$$

3.2. Elimination and Dispersal [Step-2]

Since this proposed algorithm SBFA implies that bacteria foraging occurs in a lab environment, the probability calculation is only conducted for harmful bacteria. Each bacterium is distributed with a fixed frequency 'B' for each elimination-dispersal occurrence by equation (1)(2). When compared to traditional BFA, it results in quicker and more accurate convergence [10].

3.3. SBFA Assessment and Execution [Step-3]

Smart foraging, as demonstrated by operator b, is one of its distinctive traits *(i).* This operator directs each bacterium to the optimal method, such that if swimming in a specific direction results in equation (3) in a better solution, it will continue in that direction [1][2].

3.4. Harmonic Analysis [Step-4]

The Fourier transform is used to examine the harmonics of SRM current with torque. The SRM current in steady-state may be represented to use the Fourier series as follows in equation (5)[1]:

$$I_J = a_0 + \sum_{k=1}^{\infty} a_k \cos(k\omega_0 t) + b_k \sin(k\omega_0 t) \quad (5)$$

The fundamental frequency f0 = x0/2p of the current is presented as follows:

$$f_0 = \frac{P_R \omega_{rpm}}{60} \quad (6)$$

where P_R and *Wrpm* indicate the rotor poles and speed, correspondingly. Figure 3 depicts Total Harmonic Distortion (THD) and FFT current analysis. THDs for 200 rpm reference speed is roughly 62.65 % and 65.43 % when SBFA and BFA are used, respectively. *Tj* is a periodic electromagnetic torque that can be expanded in the Fourier series, as shown below. As a result, in terms of reliability concerning the BFA-PI controller, the suggested methodology exceeds the current ways of controlling an electronic control unit (EPCU) [13][18].

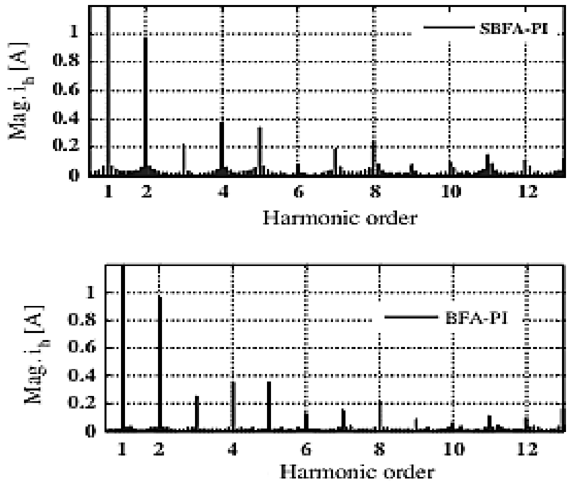

Figure 3. Winding Current Harmonic Order at 200 RPM

When these figures are compared, it is seen that the suggested technique outperforms the BFA-PI controller depicted in Figure 6 Furthermore when a constant and position-periodic actuation current is used, the electromagnetic torque *Tj* is periodic and can be extended in Fourier series as shown below in equation (7) [1][9].

$$T_J = g_0 + \sum_{k=1}^{\infty} g_k \cos(kN\omega_0 t) + L_k \sin(kN\omega_0 t) n \quad (7)$$

3.5. PWM Inverter integration [Step-5]

The PWM inverter uses a PWM wave as a switching signal rather than a square wave. Square wave inverters are often installed at multiples of the carrier signal frequency, which is typically in the kHz range [2].

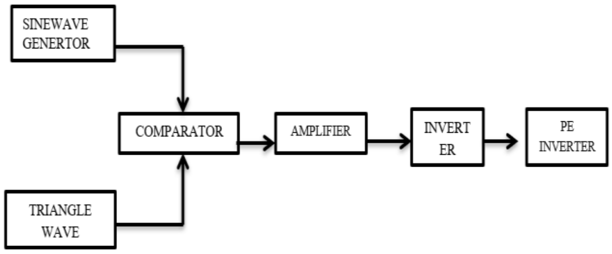

Figure 4. Block Diagram of PWM Inverter for the Proposed Work

Figure 4 shows a comparison of a sine wave and a triangle wave fed to a comparator to create a PWM signal. T1,T2 use the same signal, while T2,T4 use the inverse signal of T1. Figure 5 depicts the inverter output feeding the IGBTs and MOSFETs [1][8].

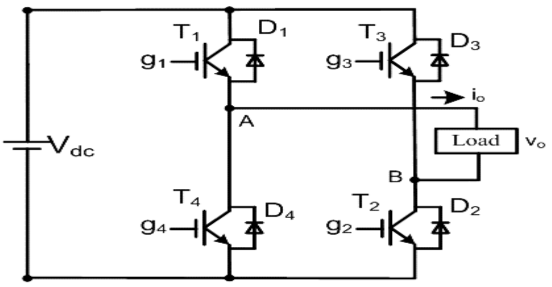

Figure 5. Circuit Diagram of PWM Inverter

4. Proposed System

The PI controller will reduce forced oscillations and stable error. The integral model has a detrimental impact on response time. The PI controller cannot forecast what will happen with the mistake soon. This difficulty can be overcome by providing a derivative mode that can forecast where the mistake will occur. This is true when dealing with higher-level capacitive processes (processes with more than one energy storage). Figure 6 shows how PI controllers are commonly employed in industry, especially where speed of reaction is not a priority [5].

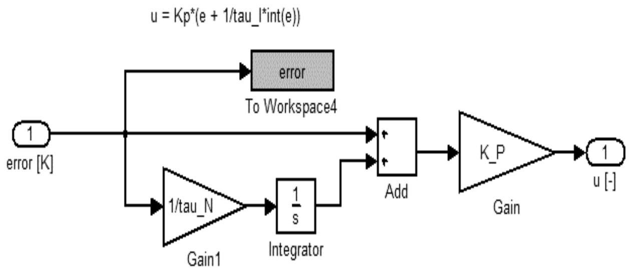

Figure 6. MATLAB Simulation Block Diagram of PI Controller

5. Results and Discussion

The Bacterial Foraging Algorithm is based on an evolutionary computing method that is unaffected by the size and non-linearity of the issue. The performance of SRM drives is evaluated in modeling and experimental experiments using improved controllers [14][17]. The modeling and experimental results supported the improved performance of the proposed technique for SRM speed control shown in Figure 7

When the reference speed is adjusted from 200 rpm to 100 rpm at t = 0.6 second N, the controller's performance is experimentally assessed and the findings are provided. This diagram depicts how the SBFA-PI controller reduces speed oscillations and thereby acoustic noise [3][5].

The angular speed and current of the SRM motor are relayed back into the position's sensor block in Figure 8, where they regulate the speed characteristics of a particular motor based on the turn on and turn off-angle. In the absence of optimization, the graph below depicts the numerous characteristic curves of the switching reluctance motor drive (SRM).

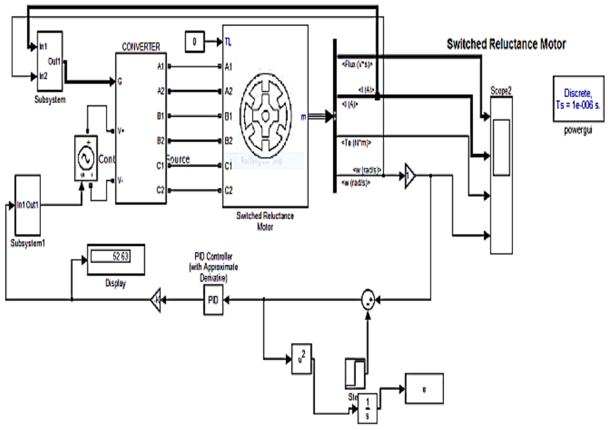

Figure 7. MATLAB – Overall Simulink Diagram of the Proposed Work

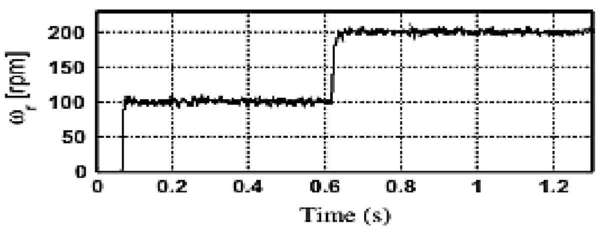

Figure 8. Results of SBFA-PI Controller in Effect of RPM

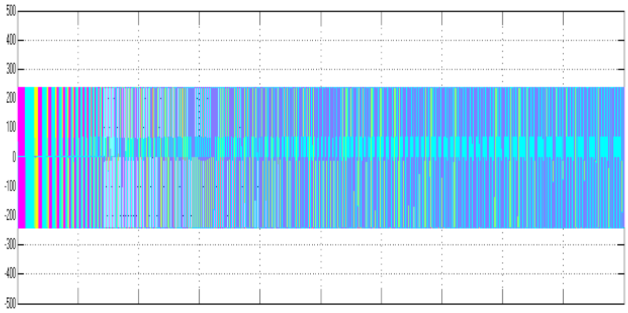

Figure 9. Stator Voltage Waveform of SRM Drives

Figure 9 shows a voltage of about 240V. Because there is a slight delay in turning on the power switch, the wave shape begins at zero and there is no further delay period. Because there is a short delay in turning on the power switch, the wave shape begins around the zero point, and no additional delay period is seen in the whole voltage graph [12].

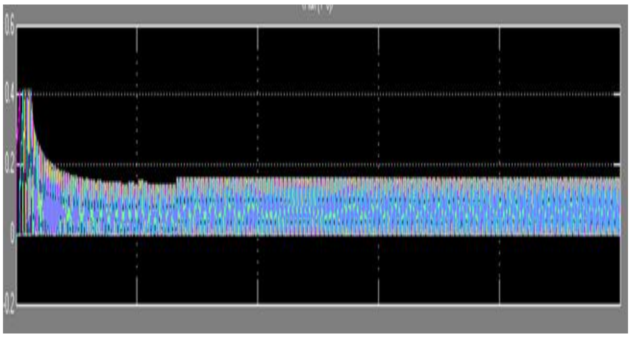

Figure 10. Flux Linkage Variation of SRM Motor Drives

The flux linkage of SRM is depicted in Figure 10, where the fluctuation of flux linkage in the stator winding concerning time is displayed. The orientation of the rotor and stator poles determines the flux linkage. There is no early delay in the graph and the result is immediately steady [4].

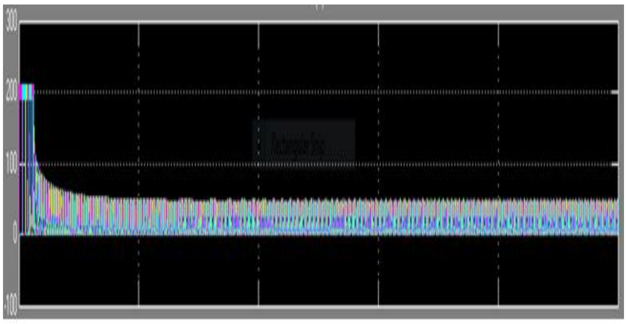

Figure 11. Stator Current Variation of SRM Motor Drives

Whereas Figure 11 shows the variation of stator current concerning time. During the initial stage, the starting current is high and it finally comes to a lower and steady value after 0.18Sec. Three different colors signify different phase currents. No delay of switching of the devices is implemented which is observed from the graph [11][17].

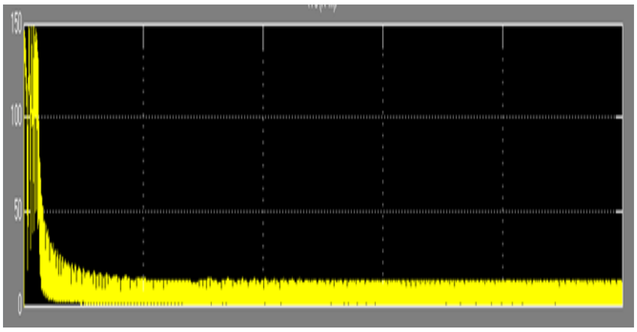

Figure 12. Torque Variations of SRM Drives

Figure 12 has the greatest torque obtained at the start is 150 N-m, indicating that the starting torque of this motor drive is quite high. Torque characteristics are determined by the time-dependent interaction between flux linkages and rotor position. The waveform shows that the torque is strong at the start but progressively decreases to 80N-m after 0:15 seconds. The rotor speed of the switched reluctance motor is shown in Figure 13, and its change for time is displayed. We discovered that the speed fluctuates at first but then becomes constant after a certain point [15][18].

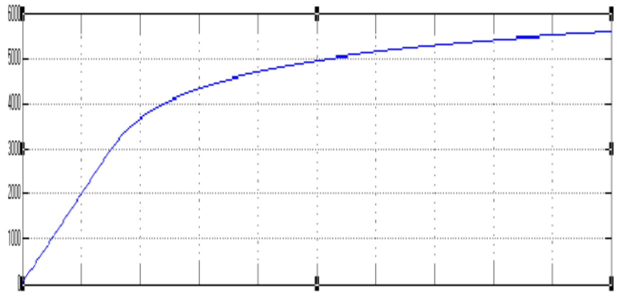

Figure 13. Rotor Speed Profile of SRM Drives

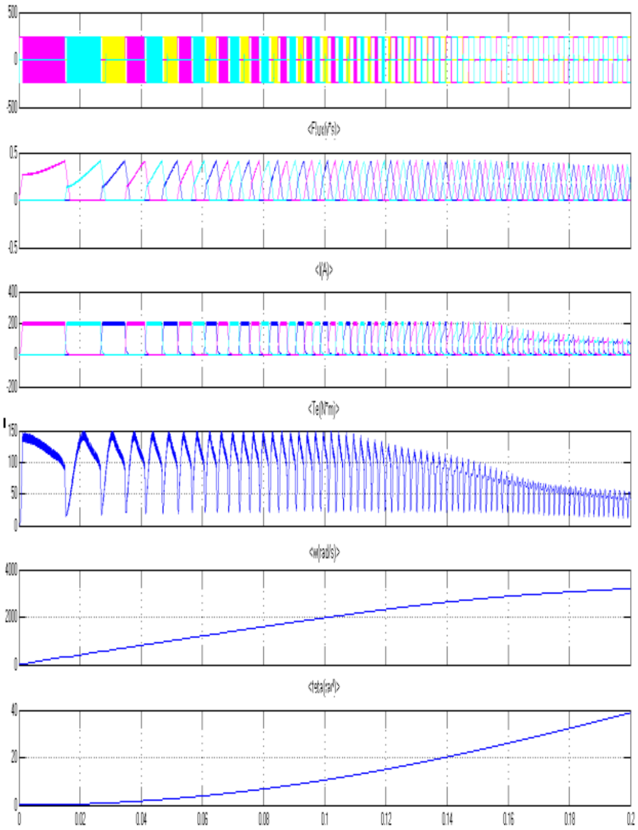

Figure 14. Optimized Output of SRM Drives

The bacterial foraging optimization approach is used to find the most ideal location of the rotor and stator that minimizes torque ripples. This torque is used as an input in the BFO objective function. After modeling the model for several iterations, with each iteration assigning a new location of the stator and rotor, an optimal position is obtained [8][16].

Figure 14 depicts the result of SRM following optimization. Ripples are apparent in every waveform, making torque nonlinear and inappropriate for high-performance servo applications.

Table 1. Comparison of Optimization Techniques with SRM Motor Improvement Parameters

Optimization Techniques	Controller	Torque Ripple	Current Ripple	Harmonics
GA	PI PID	✓		
PSO	PI PID	✓		
BFOA	PI	✓	✓	
SBFOA	PI	✓	✓	✓

Table 1 depicts the most relevant comparison on which area the SRM motors improvements taking place. Parameters such as type of the controller, Torque ripple, current ripple, harmonics are the most important for the SRM motor design. Thus, compared to all other metaheuristics optimization techniques SBFOA has particularly easily adapted for different applications and reduced torque ripple, current ripple, and harmonics with help of a PI controller.

5. Limitation and Future Scope

The speed of SRM is controlled by the PI controller. The controller has simplicity, the lowest cost, zero steady-state error, ease of implementation, good speed response, and robustness. It is extensively used in AC and DC drives where speed control is required. To provide the desired performance of SRM, a feedback control system is employed for speed control of SRM drive. The tuned values of the PI controller constants are dependent on the system. Effects of Proportional Integral (PI) controllers: Increases the type of the system by one. Rise time and settling time increase and Bandwidth decreases. The speed of response decreased. When the modified optimization techniques are merged to the controller this will adversely affect the performance.

P-I controller has some limitations such as high starting overshoot, sensitivity to controller gains, and sluggish response to sudden disturbances. So, in the future, the Integral-Proportional (I-P) controller will be used as a speed controller for induction motor drives to overcome the limitation of the P-I controller.

6. Conclusion

The proposed optimization strategy incorporates innovative terms such as adaptive swimming step and smart chemotactic procedure, resulting in increased performance when compared to regular BFA. Model and experimental results demonstrated the increased performance of the proposed strategy for SRM speed control. Based on the observed results and SBFA operational potential, the proposed optimization strategy may be easily adapted for a wide range of applications. In contrast to established approaches that rely on randomness, the proposed strategy is based on smart prediction.

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