

Multi-Objective Optimized Controller for Torque Ripple Minimization of Switched Reluctance Motor Drive System

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Abstract

Background/Objectives: In this paper, BC based optimized PID controller is developed for torque ripple minimization of SRM drive system. The proposed control algorithm comprised two optimized PID controllers for speed error and current error regulation loops of the SRMD control system. The proposed control algorithm is also optimizes the commutation angles for reducing the high torque ripples. **Methods/Statistical Analysis:** A new control algorithm for Torque Ripple Minimization of Switched Reluctance Motor (SRM) Drive system is proposed. The proposed control algorithm comprised two optimized Proportional, Integral and Derivative (PID) controllers for speed error and current error regulation loops of the SRMD control system. The proposed control algorithm is also optimizes the commutation angles for reducing the high torque ripples. In the proposed optimized controller, Artificial Bees Colony algorithm (ABC) is the optimization algorithm implemented to tune the gains of both PID controllers and commutation angles of the converter circuit. For tuning the accurate gains and angles, the multi objective functions are developed. The effectiveness of the proposed BC algorithm is implemented in the MATLAB/SIMULINK platform. **Findings:** The proposed control algorithm is based on the optimized PID controller for the speed and the current loops of the SRM drive system. The proposed control algorithm was used to optimize the gain parameters of the PID controller along with the commutation angles of the inverter. Here, the minimization of the error values of speed and torque serves as the objective functions. The advantages of the proposed method are robust performance as well as the increased level of reliability and flexibility in solving more complex problems. **Applications/Improvements:** The results obtained include superior performance with degradation in torque ripple and settling time. These merits are produced with elitism and a high-speed global search methodology, thus enhancing the dynamic performance of the SRM drives.

Keywords: Bees Colony Algorithm, PID Controller, SRM Drive, Torque Ripple Minimization

1. Introduction

The Electrical Drives (EDs) are very significant part of industry automation for successful productivity. The requirement of EDs depends upon the available mains and load characteristics for that particular application¹. In industrial use, the EDs are usually required to run at very high speeds. For such applications, the Switched Reluctance Motor Drives (SRMDs) have drawn more interest of research. It is due to the reasons of economical alternative to Permanent Magnet Brushless Motor Drives

(PMBLMDs), mechanically and electrically more rugged than the conventional AC and DC motors like Induction Motors (IMs) and Synchronous Motors (SMs)²⁻⁵. Other than industrial automations, SRMDs are also accommodated in household applications, hybrid and electric vehicles, wind power plant, aeronautical and aircraft applications etc⁶.

SRMDs have the merits of simple structure, inexpensive manufacturing and reliability capability, high degree of independence between phases, short end-turn and low inertia with capability to operate in harsh environment like

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coal mining even with a wide speed range⁷⁻¹⁰. Generally, the SRMD is a doubly salient-pole machine which runs on the principle of variable reluctance¹¹. Here, the torque is produced by the tendency of the rotor to reach a position where the inductance and the flux produced by the energized winding are maximized^{12,13}. But, in SRMD, its phase inductance is a nonlinear function of winding current and rotor position and also time-varying¹⁴. For this, the control structure requires rotor position information for an optimal phase excitation sequence.

Even though the SRMDs can produce high torque at low speeds, they suffer from inherent high torque ripples which cause vibrations and acoustic noise¹⁵⁻¹⁷. In order to reduce these torque ripples, various control strategies are derived to the inverter of the SRMDs along with rotor position tracking. The control logic provides activation signals for the power semiconductor switches in the inverter that are synchronized with the rotor position¹⁸. In this scenario, a control strategy must achieve two actions simultaneously: Adjusting the motor speed using voltage Pulse Width Modulation (PWM) and regulating the advanced firing angles as a function of the desired motor speed¹⁹. Nevertheless, SRMDs have highly nonlinear and dynamical behavior which makes them difficult to control²⁰.

2. Recent Research Work

In²¹ have developed a Brain Emotional Learning Based Intelligent Controller (BELBIC) to control the Switched Reluctance Motor (SRM) speed. Here, control was designed without position sensor of the rotor. The rotor position was estimated by Adaptive Neuro Fuzzy Inference System (ANFIS) from the inputs of phase flux linkages. Motor parameter changes, operating point changes, measurement noise and open circuit fault in one phase and asymmetric phases in SRM were simulated to show the robustness and superior performance of BELBIC. It was compared with Fuzzy Logic Controller (FLC) for validating its superiority.

In²² have adopted advanced Proportional-Integral (PI) and Proportional-Differential (PD) controllers for speed and position controls respectively for SRM drives. A gain-scheduling technique was adopted in the speed controller design. In order to improve the set-point tracking, a low-pass filter was included in the position controller. The proposed four-quadrant control scheme was based on the average torque control method. The turn-on and turn-off

angles were online determined through simple formulas so as to reduce the torque ripple at an acceptable level over a wide speed range.

In²³ have proposed two modified PI-like Fuzzy Logic Controllers with output Scaling Factor (SF) self-tuning mechanism based on the redevelopment of control rule base for application in SRM drive system. For both types of controllers, the output SF of the controller could be tuned continuously by a gain updating factor, whose value was derived from the fuzzy logic reasoning, with the plant error and the error change ratio as the input variables. The rule bases were created based on the knowledge of the SRM's dynamic behavior and practical experience. In²⁴ have presented a novel Adaptive Takagi-Sugeno-Kang (TSK)-Fuzzy Controller (ATSKFC) to regulate the speed of a SRM. The proposed controller comprised two parts: A TSK-Fuzzy Controller and a compensated controller. The TSK-Fuzzy Controller was the main controller used to approximate an ideal control law. The compensated controller was designed to compensate the approximation error between the TSK-Fuzzy Controller and the ideal control law. The parameter variations and the external load of the SRM drive were considered to ensure the robustness of the proposed scheme. An online tuning methodology based on Lyapunov was utilized to adjust the parameters of the ATSKFC, so that the stability of the control system could be guaranteed.

In²⁵ have presented a novel Adaptive Fuzzy Cerebellar Model Articulation Controller (AFCMAC) to regulate the speed of a SRM. The proposed controller comprised two parts: A fuzzy Cerebellar Model Articulation Controller (CMAC) and a compensating controller. The fuzzy CMAC learnt and approximated system dynamics; the compensating controller compensated the approximation error of the fuzzy CMAC. The parameters of the AFCMAC were adjusted online according to adaptive rules, which were derived from Lyapunov stability theory, so that both the stability of the control system and error convergence can be guaranteed.

Thus there are various kinds of control structures for speed regulation and Torque Ripple Minimization of SRMD system. The reviewed techniques are BELBIC, PI-PD controllers with gain scheduling, PI-like Fuzzy Logic Controller, ATSKFC controller, AFCMAC, etc. The sole purpose of these controllers is to minimize the error between set speed and actual speed of SRMD system. In the reviewed techniques, except PI-PD controller, all are Artificial Intelligence (AI) based techniques only. All

these techniques are model free and capable of working with different kind of dynamic nonlinear systems. But, they lag behind with respective drawbacks such as trainings, tunings, membership selections, etc. Here, BELBIC has the disadvantage of training process with inaccuracy. Coming to PI-like fuzzy logic controller, ATSKFC and AFCMAC; they belong to the family of fuzzy logic theory which are exclusively depend on fuzzy rules designs, membership functions, linguistic terms selections, etc. These fuzzy based design structures greatly depend on expertise knowledge and needs adaptive measures for nonlinear systems like SRMD systems. The mentioned issues about reviewed techniques represents their immature and incapability for control purposes. This leads to false regulation process and involves the greater loss of productivity to the industry. On the other hand, the control structure needs a simple and easy design for understanding to a common user. In this context, PID controllers have attracted more attention in industry automata. But, they are incapable of handling the real time measures of nonlinear SRMD system when tuned inaccurately.

In the paper, BC based optimized PID controller is developed for speed regulation of SRM drive system. The proposed control algorithm comprised two optimized PID controllers for speed error and current error regulation loops of the SRMD control system. The proposed control algorithm is also optimizes the commutation angles for reducing the high torque ripples. In the proposed optimized controller, ABC is the optimization algorithm implemented to tune the gains of both PID controllers and commutation angles of the converter circuit. For tuning the accurate gains and angles, the multi objective functions are developed.

3. Optimized Control System for SRM Drive

Torque Ripple Minimization system that is based on two optimal PID controllers is designed. For this purpose, a model of the SRM drive is designed first. From the designed model, the Torque Ripple Minimization system is developed. In the Torque Ripple Minimization system, multi-objective fitness functions are determined. It is assisted by fuzzy theory. Then, the fuzzified fitness functions are minimized simultaneously by the proposed BA to optimize the control tools in the Torque Ripple Minimization system. Now, the modeling of the SRM drive system is explained as follows:

3.1 Modeling of SRM Drive

SRM is an electrical motor that has double salient poles in the stator and the rotor. The copper phase windings are concentrated in the stator poles. The rotor is made of laminated silicon steel and therefore, it has no windings or permanent magnets²⁴. In this subsection, the modeling of the proposed SRM drive system is elucidated and the cross section of a typical 6/4 poles SRM drive is also analyzed. The circuit diagram of the SRM drive system is shown in Figure 1. The SRM drive system consists of a power source in DC form. The DC form can be achieved from either the direct DC source or the rectified AC supply. This DC power is inverted as per the requirement of the SRM drive. The requirement is fed in terms of PWM signals to the Voltage Source Inverter (VSI) circuit. These PWM signals are derived from the speed regulation system of the SRM drive and it is depicted clearly in subsection 3.2. The mathematical derivations of the SRM drive system are given below:

The voltage equations of the SRM drive is comprised of three phases and they are:

$$v_A = R_A * i_A + L_A(\theta, i_A) * \frac{di_A}{dt} + e_A \quad (1)$$

$$v_B = R_B * i_B + L_B(\theta, i_B) * \frac{di_B}{dt} + e_B \quad (2)$$

$$v_C = R_C * i_C + L_C(\theta, i_C) * \frac{di_C}{dt} + e_C \quad (3)$$

Where, v_{ABC} and i_{ABC} are the input three phase voltages and currents of the SRM drive. R_{ABC} , L_{ABC} are the respective resistances and inductances of the three phases. Here, θ is the rotor position and e_{ABC} is the Back EMFs of the SRM drive. The inductance of each phase depends nonlinearly on its current as well as the rotor position. Equations

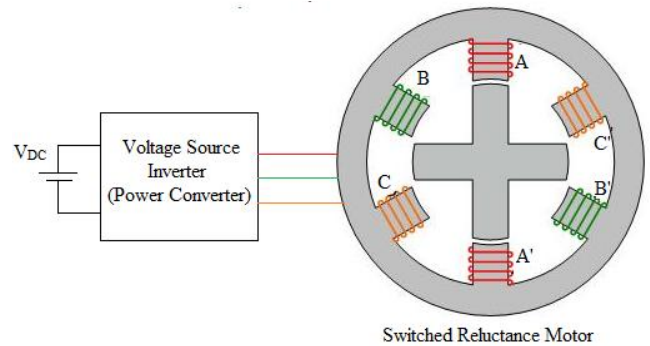


Figure 1. The circuit diagram of the SRM drive system.

(1-3) states that the supplied voltage is consumed by the resistive voltage drop, the inductive voltage drop and the induced EMF. The electromagnetic torque of the SRM drive is given as follows:

$$T_{EM} = \sum_{x=A,B,C} 0.5 * i_x^2 * \frac{dL(\theta, i_x)}{d\theta} \quad (4)$$

In the above equation, T_{EM} represents the total electromagnetic torque that is present in the SRM drive due to the three phase currents. This equation can be used to derive the mechanical system in the SRM drive and it is specified below²¹:

$$\frac{d\omega_r}{dt} = \frac{1}{J} \cdot (T_{EM} - T_{load} - B * \omega_r) \quad (5)$$

Here, ω_r is the angular velocity. J , B are the moment of inertia and friction co-efficient respectively. Moreover, T_{load} refers to the load that is applied on the SRM drive. With the change in the load torque, the change in the total load to the SRM drive can be accomplished. In order to meet such an increased or a decreased load, the total electromagnetic torque input should be provided accordingly. This can be performed by regulating the phase currents such that the desired torque can be achieved to meet the load. The proposed speed regulation system for the SRM drive is given in following subsection:

3.2 Torque Ripple Minimization System of SRM

In this subsection, the Torque Ripple Minimization system for the SRM drive is achieved. For the simple understanding of the proposed control strategy, a block diagram is demonstrated in Figure 2. The DC power is fed to the SRM drive via the VSC block. The purpose of using the VSC block in the SRM drive system is to control the input voltages of the SRM drive such that the SRM

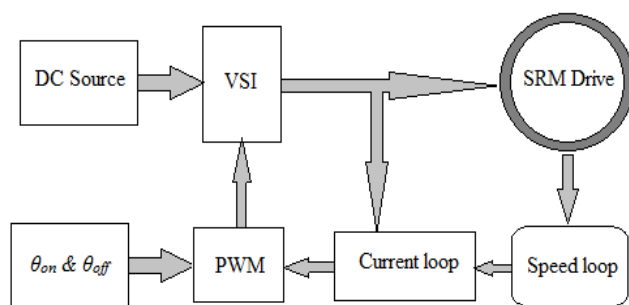


Figure 2. The block diagram of proposed system.

drive achieves the desired speed with less impact from the torque ripples. The control structure is comprised of commutation angles block and the speed as well as the current loops for determining the respective PWM signals from the VSC. Figure 3 shows the actually proposed Torque Ripple Minimization scheme.

In Figure 3, the proposed Torque Ripple Minimization system is presented with three major parts of control actions. They are speed loop, current loop and commutation. These are the control tools used in the proposed Torque Ripple Minimization system of the SRM drive. Each control tool has its own distinct parameters to perform a specific task. In speed loop, the PID controller is used to determine the reference currents for the three phases of the SRM drive based on the speed error. Here, the three parameters, namely, proportional (K_p), integral (K_i) and derivation (K_d) are called as the gains that help in processing the speed error and for determining the reference currents. These current references manage the control action to be performed for minimizing the speed error that is originated. Then, these references are compared with the actual SRM drive currents and are fed to the current loop. In the current loop, again, another PID controller is rested for processing the current errors and for determining the control signal. This control signal is fed to the PWM block for modulating the VSI. Here also, the same three parameters, namely, proportional (K_p), integral (K_i) and derivation (K_d) are used and they are termed as the gains that are used to process the speed error and for determining the reference currents. These current references hold the control action to be performed for minimizing the speed error that is originated. Another significant control action is performed near the PWM block only. It represents the determination of commutation angles from the knowledge of the rotor position. The mathematical representations of both the PID controllers are given as follows:

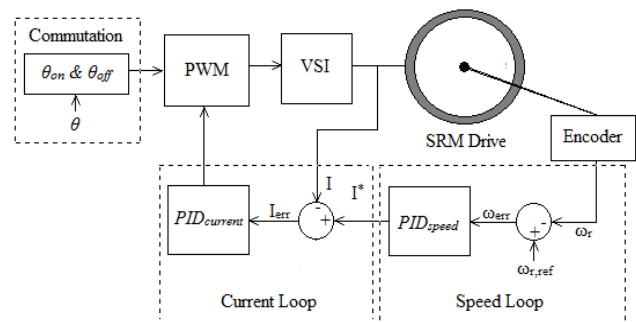


Figure 3. Proposed scheme.

$$I^*(t) = K_{Ps} \cdot \omega_{error}(t) + K_{Is} \cdot \int_0^t \omega_{error}(t) + K_{Ds} \cdot \frac{d}{dt}(\omega_{error}(t)) \quad (6)$$

$$u(t) = K_{Pi} \cdot I_{error}(t) + K_{Ii} \cdot \int_0^t I_{error}(t) + K_{Di} \cdot \frac{d}{dt}(I_{error}(t)) \quad (7)$$

Where, $u(t)$ represents the instantaneous control signal that is fed to the PWM block for minimizing the speed error and the current error. Equation (6-7) states that the gains of both the PID controllers are the control parameters to be tuned for getting an accurate performance from the Torque Ripple Minimization system of the SRM drive. However, the selection of proper commutation angles has an impact on the reduction of braking torque in the SRM drive that lowers torque ripples. Therefore, the control parameters to be optimized are $(K_{Ps}, K_{Is}, K_{Ds}), (K_{Pi}, K_{Ii}, K_{Di})$ and (q_{on}, q_{off}) . In order to determine the optimal values of the above parameters, BC algorithm is used. In this context, the multi-objective functions are determined. The multi-objective functions to be optimized are the speed error and the current error that includes the torque ripples. The mathematical forms of the above functions are given as follows:

$$OF_{speed} = \omega_{error} = \omega_{r,ref} - \omega_r \quad (8)$$

$$OF_{current} = I_{error} = I^* - I \quad (9)$$

$$OF_{torque} = \frac{T_{max} - T_{min}}{T_{mean}} \quad (10)$$

Where, OF_{speed} , $OF_{current}$ and OF_{torque} are the objective functions for speed error, current error and torque ripple. T_{min} , T_{mean} , and T_{max} are the minimum, the mean and the maximum values of the total electromagnetic torque. These are the three objective functions to be optimized for determining the optimal controller, which can be used for Torque Ripple Minimization system. For simplifying and distinguishing the effect of each objective function on speed regulation, these formulated multi-objective functions are transformed into fuzzy values. These fuzzified functions are used as the fitness functions of BC algorithm. Now, the determination of fitness functions to decide on the optimal control parameters of the speed regulation system of the SRM drive is given in the following subsection.

3.3 Fitness Formulation using Fuzzy Theory

In this subsection, the fitness function to be optimized by the proposed BC algorithm is achieved. Here, the fitness

function is the multi-objective function, which is used for optimizing the control parameters of the Torque Ripple Minimization system. The multi-objective functions are shown from Equation 8- Equation 10. These functions are fuzzified to improve the performance of BC algorithm in the optimization process. Now, the membership functions of the multi-objective functions are given below:

In Figure 4, the objective functions of the Torque Ripple Minimization system are illustrated with its min and max values. From Figure 4, X represents the objective function and its membership function is μ_X . X_{min} and X_{max} are the respective minimum and maximum values of the objective function, X . Here, three objective functions are being optimized, namely, speed error minimization, torque ripple minimization and current error minimization. Figure 4 indicates the mathematical representations of the membership functions in the objective functions as follows:

$$\mu_X = \begin{cases} 1 & ; \text{for } X \leq X_{min} \\ 0 & ; \text{for } X \geq X_{max} \\ \frac{X_{max} - X}{X_{max} - X_{min}} & ; \text{for } X_{min} \leq X \leq X_{max} \end{cases} \quad (11)$$

Equation (11) depicts that the membership value reaches a maximum value of 1, if the objective value is less than the minimum value of X_{min} . On the other hand, if the objective value is more than the maximum value of X_{max} , then the membership value reaches a minimum value of 0. If the objective value is between the already set values of min and max, the membership value will be between 0 and 1. Therefore, the maximization of the membership value results in the minimization of its objective value. It is worth noting that the membership function is same for all the objective functions due to the minimization concern

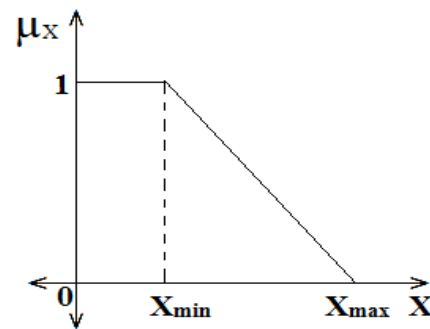


Figure 4. Membership function of objective functions.

of the objectives with respect to their min and max values. These objective function values are the responses of the SRM drive due to the respective set of control parameters in the optimization problem. It varies accordingly with the different set of control parameters and it is different for each set of parameter values.

Now, from the fuzzified objective functions, the multi-objective fitness function is determined as follows:

$$FF = \min \{ w_s * OF_{speed} + w_c * OF_{current} + w_t * OF_{torque} \} \quad (12)$$

$$\sum_{m=s,c,t} w_m = 1 \quad (13)$$

Where, w_s , w_c and w_t are the weight coefficients in the objective functions of speed error, current error and torque ripple, respectively. This coefficient method is adopted to give preference to the desired objective function. For instance, if the torque ripple minimization is our main objective, w_t should have more value than the other two coefficients. Likewise, based on the application use of the SRM drive, the coefficients are determined and the optimal control parameters are obtained using the proposed BC algorithm. The working procedure of the proposed BC algorithm is dealt in the following subsection.

3.4 Proposed BA for Optimal Controller

Recently, plenty of optimization algorithms have emerged. The BC algorithm is one among those algorithms that is simple in execution and offers improved robustness. Moreover, it is a population dependent optimization algorithm that is stochastic in nature and it imitates the smart food searching behavior of a swarm of honey bees. In 2005, Karaboga has put forth this algorithm, which serves as an optimization tool for providing solutions to a number of non-linear, highly complicated and non-convex optimization tasks. The colony of artificial bees in the BC algorithm is of three kinds, namely, the employed bees, the onlookers and the scouts. The onlookers are the bees, which remain in the dance area to determine whether a particular food source can be selected or not. The employed bees are the bees that reach the food source prior to the onlooker. Scout is a bee type, making searches in a random manner to uncover new sources. The location of a food source denotes the existence of a feasible solution to the optimization problem, while the quantity of nectar in a food source specifies how far the quality of the related solution is good. Here, quality is nothing but the

fitness. The number of onlookers or employed bees and the number of food sources/feasible solutions in the population are found to be the same in the BC algorithm^{26,27}. In this proposed scheme, the application of BC algorithm brings about optimization in the control parameters of the torque ripple minimization system of the SRM drive and the various control parameters are the gain parameters (K_{ps} , K_{is} , K_{Ds}), (K_{pi} , K_{ii} , K_{Di}) and the commutation angles (θ_{on} , θ_{off}). Equation (12) states the fitness function, which undergoes maximization for attaining the optimal control parameters in the torque ripple minimization system. The various steps involved in the BC algorithm are elucidated below:

- Step 1:** Make a random initialization of the food sources in the search space.
- Step 2:** Begin the count of the iteration.
- Step 3:** Each one of the employee bees picks up a single solution and sets out for it.
- Step 4:** After choosing a single solution, each and every employ bee does a neighborhood search in the place of that chosen solution and this involves the following steps:
- Step 5:** Make an assessment of the fitness function at every solution.
- Step 6:** Greedy operation is performed on the neighbor as well as the current solutions of the employ. bee and the employ bee retains the best solution alone.
- Step 7:** The employ bees offer this detail regarding the food sources to the onlookers.
- Step 8:** Each and every onlooker bee would choose a single solution depending on their probability value (P_p) and process with it.
- Step 9:** Each one of the onlooker does the neighborhood search at the chosen solution in a way similar to the employ bee.
- Step 10:** Make an evaluation on the fitness of each solution.
- Step 11:** Now, the onlooker does the greedy operation on the neighbor as well as the current solutions and preserves the knowledge about the best solution.
- Step 12:** A solution is discarded, if does not produce any improvisation within a specified number of generations, termed as the limit (L). The scout bee then initializes a new solution randomly, as in the initialization period.

Step 13: Iteration counts, $t = t + 1$.

Step 14: Verify whether the ceasing criterion has been met or not. If met, terminate the process. Else, make a repetition of the process from step 3.

P_r , L and $t_{\max}$ denote the user-defined parameters that are set based on the desired problem.

The procedure for the execution of the BC algorithm is shown below. Upon completing the execution, the resultant will be the optimized gains of both the loops of the PID controllers as well as the commutation angles of the VSI of the SRM drive. The computation of the gains and the angles are made using the multi-objective fitness function. Thus, the speed regulation system of the SRM drive is bestowed with a multi-objective optimized controller. The proposed optimized control system enables the minimization of speed error, in addition to the torque ripples in the SRM drive. The flow chart of the proposed scheme to accomplish the speed regulation system in the SRM drive using the BC algorithm is revealed in the following Figure 5.

Now, the validation of the proposed multi-objective optimized control system of the SRM drive is performed in the MATLAB platform and the following section describes about it.

4. Simulation Results and Discussions

Implementation of the proposed methodology is carried out in the MATLAB/Simulink 7.10.0 (R2012a) platform, 4GB RAM and Intel(R) core(TM) i5. Here, the SRM speed control has been performed by the proposed optimized PID controller. The optimization process is carried out by using the ABC algorithm based on the multi-objective fitness function. The 60 kW SRM test model is utilized for testing the proposed method and the configuration of the motor model is described in Table 1. The implemented model of SRM with the control technique is described in Figure 6. The parameters of the ABC algorithm, which are required for the optimization of the controller parameters, is described in Table 2 and the optimized gain parameters obtained using different techniques are shown in Table 3.

The simulations of the proposed methodology are performed for a period of about 0.298 seconds. However, highly précised responses require the time scale variation for inductance, phase currents and total torque to range from 0.2–0.298 seconds. Making an optimal selection of the PID controller parameters can reduce the torque

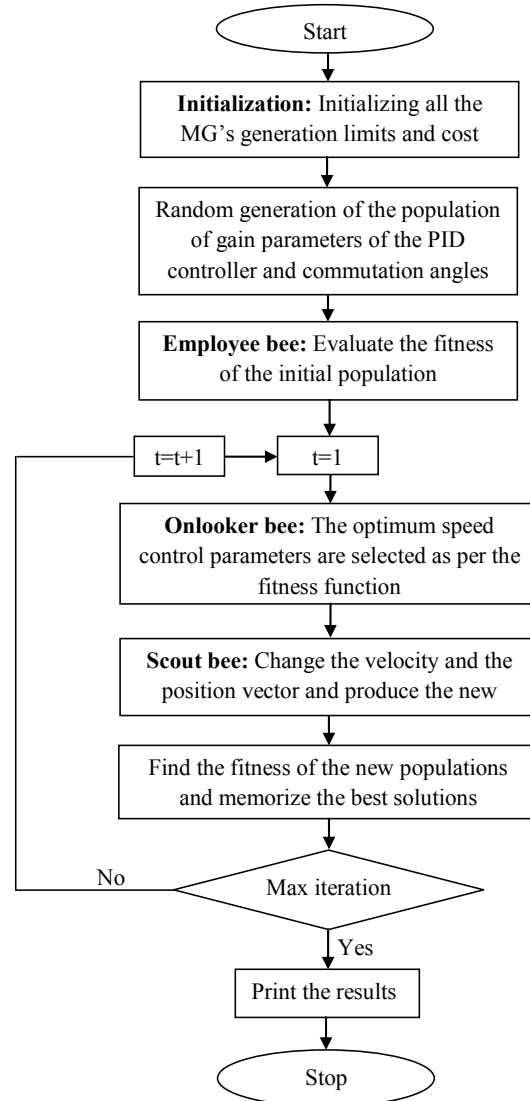


Figure 5. The flow chart of the BC algorithm for tuning the control parameters.

Table 1. SRM configuration

Parameter	Value
Power	60kW
Speed	2214rpm
Stator resistance	0.05ohm
Inertia	0.05kg.m.m
Friction	0.02N.m.s

ripples to the lowest possible value and hence, the decrease in the torque dip of the SRM can be accomplished. With Equation (4), it can be flawlessly known that the braking torque would arise with a non-zero current in any of the phases. As depicted in Figure 7, the positive torque region

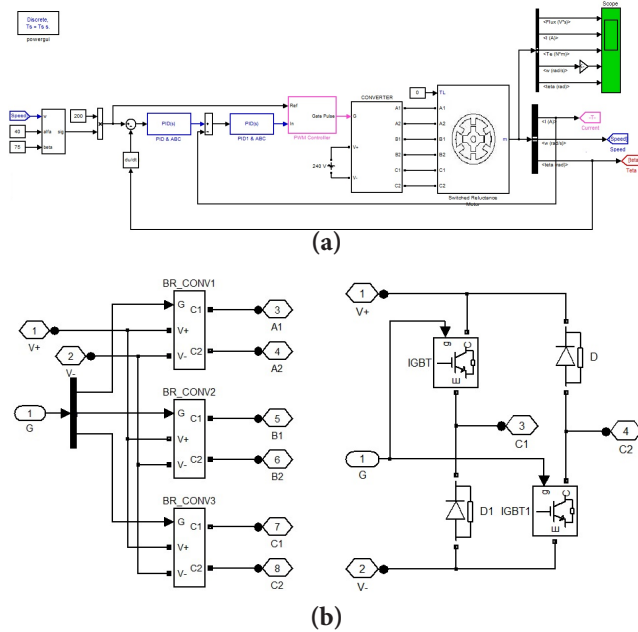


Figure 6. (a) SRM model with controller, (b) Converter structure.

Table 2. Implementation parameters of the proposed technique

Colony size =50
Number of bees= 6
Number of iterations=100
Number of reproduction steps = 4
Number of employee bees=50% of the colony
Number of onlooker bees=50% of the colony
Number of scout bees=1

Table 3. Optimal controller gains achieved using proposed technique

Optimal controller gain	Proposed controller	
	S	i
Proportional K_p	2.2150	0.4688
Integral K_i	0.7824	1.0270
Derivative K_d	1.4313	1.5548

initiates at the rotor position of 0.20055 rad and gets ended at 0.20255 rad. The inductance profile of the three phases and the rotor positions of the SRM Drives are given in Figure 8. The inductance is repetitive at every 90° angle and the separation between the phases is also 90° . This paper suggests a method with which the SRM controlling performance can be enhanced. Here, the PID control gain

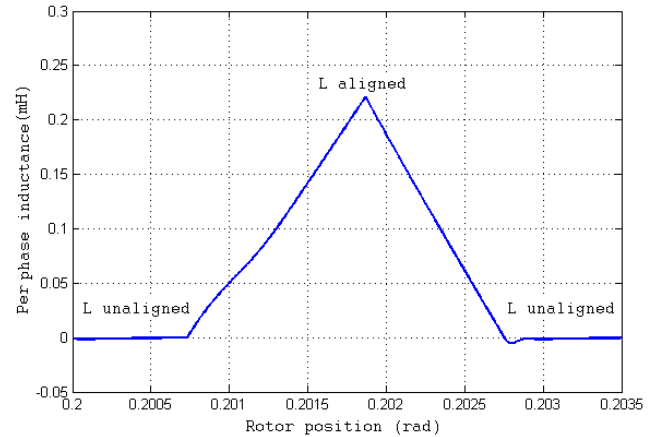


Figure 7. Per phase inductance profile SRM.

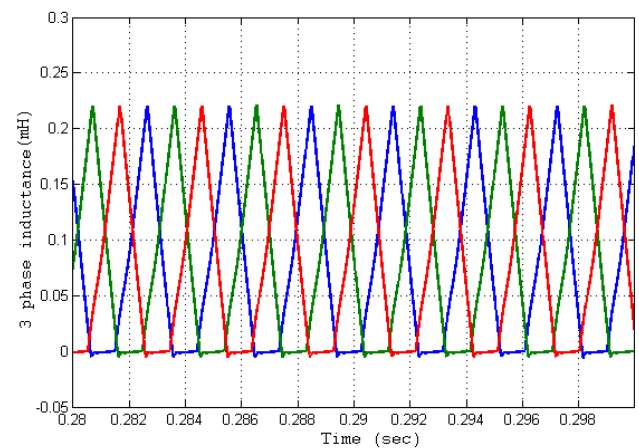


Figure 8. Inductance profile for 3 phase SRM.

parameters are optimized with a multi-objective function to obtain an optimized PID controller. The speed, the current and the torque of the SRM are the parameters that are taken into account in the multi-objective function. The optimal gain parameters have brought about a large decrease in the current disturbances between the two phases as in Figure 9. The SRM torque using the proposed method is explained in Figure 10. The proposed controller tackles the issues arising from the non-adaptive gain parameters with the help of the ABC-based optimization process. The torque ripple is lessened with the optimization procedure, when comparing it with the graphical results portrayed in²⁸. Moreover, the torque dip existing between two phases is lowered very much than the currently available controllers. It is more obvious from the graph that the settling time achieved using the proposed method is very small than the other prevailing techniques.

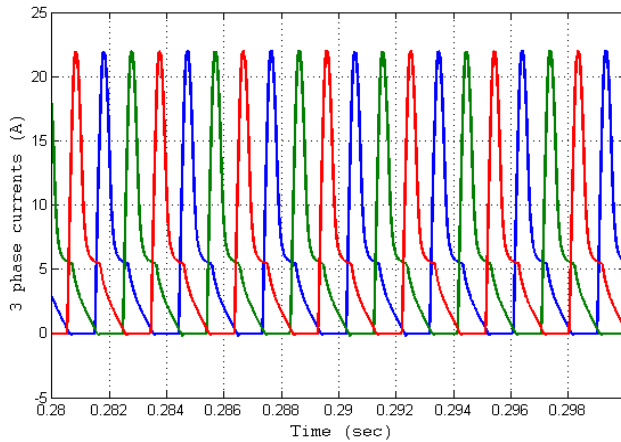


Figure 9. 3 phase current of the SRM using the proposed controller.

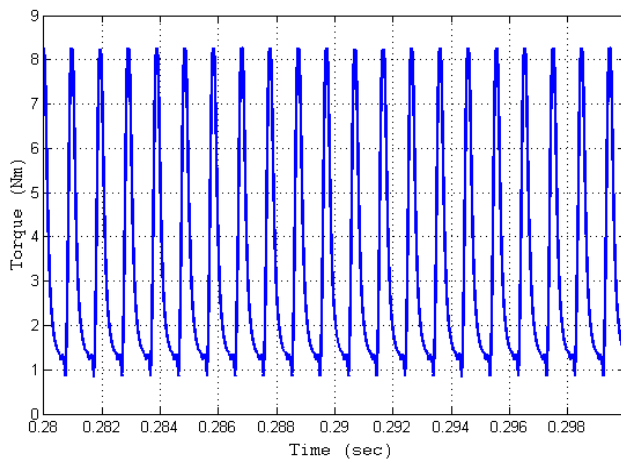


Figure 10. Torque of SRM using the proposed controller.

The speed controlling ability of the SRM has got enhanced with the proposed technique.

5. Conclusion

This paper has proposed a multi-objective based new control algorithm for the SRM drive system. The proposed control algorithm is based on the optimized PID controller^{29–33} for the speed and the current loops of the SRM drive system. The proposed control algorithm was used to optimize the gain parameters of the PID controller along with the commutation angles of the inverter. Here, the minimization of the error values of speed and torque serves as the objective functions. The advantages of the proposed method are robust performance as well as the increased level of reliability and flexibility in solv-

ing more complex problems. The results obtained after comparison includes superior performance with degradation in torque ripple and settling time. These merits are produced with elitism and a high-speed global search methodology, thus enhancing the dynamic performance of the SRM drives.

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