Biogeography Based Optimization for Tuning FLC Controller of PMSM

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Abstract. In this paper we embody the simulation of the Fuzzy Logic Controller. The controller governs the speed of a permanent magnet synchronous motor PMSM, which is employed in an elevator with different loads. This work aims to obtain the optimal parameters of FLC. Biogeography-Based-Optimization (BBO) is a new intelligent technique for optimization; it can be used to tune the parameters in different fields. The main contribution of this work is to show the ability of BBO to design the parameters of FLC by shaping the triangle memberships of the two inputs and the output. The results show the optimal controller (BBO-FLC) compared with the other controllers designed by genetic algorithm (GA). GA is a powerful method that has been found to solve the optimization problems. The implementation of the BBO algorithm has been done by M-file/MATLAB. The complete mathematical model of PMSM system has carried out using SIMULINK/MATLAB. The calculation of finesses function can be done by SIMULINK, and it linked with M-file/MATLAB to complete all steps of BBO. The results show the excellent performance of BBO-FLC compared with the GA-FLC and PI controller; also, the proposed method was very fast and needed only a few iterations.

Keywords: Biogeography Based Optimization (BBO) · Genetic Algorithm (GA) · Fuzzy Logic Controller (FLC) · Permanent Magnet Synchronous Motor (PMSM)

1 Introduction

In a new high-rise building, an elevator becomes the essential service facility. With the continuous improvement of running speed, the elevator's dynamic performance is closely related with human comfort, which is increasingly a cause for concern. Improving the elevators' comfort, and reducing vibration and noise during operation has become a hot research topic at home and abroad [1]. The development in microprocessor schemes and semiconductor technologies makes the AC drive give a high performance of speed control. This system is an excellent opportunity to use AC motors [2]. In the last few years, PMSM has become popular in the medium range of an AC machine and its drive. Nowadays, this technology has become the first choice because of its inherent advantages. These advantages include high torque to current

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ratio, large power to weight ratio, higher efficiency and robustness. There are many applications of PMSM in elevators, wind energy, EV drive, etc., because it allows an enlarged speed range with an inverter size that is lower than in a conventional flux-oriented induction motor drive [3]. In [4], the adaptive dynamic surface control (DSC) has been presented for the feedback controller of PMSM. Also, some control methods have been studied to stabilize the PMSM systems, such as the sliding mode control (SMC) [7], deferential geometry method [8], and passivity control [9, 10]. The tangible benefit of choosing the controller is its simplicity in implementation. It is not easy to find another controller with such a simple structure that is comparable in performance. Fuzzy rule-based models are easy to comprehend all applications of PMSM because it uses linguistic terms as well as the structure of if-then rules [11]. A very important step in the use of controllers is the controller parameters and tuning process [12]. Unfortunately, in spite of this, a large range of tuning techniques and the optimum performance cannot be achieved. In recent years many intelligent optimization techniques have emerged and have received much attention from researchers concerning genetic algorithm (GA), particle swarm optimization (PSO) techniques bee colony optimization (BCO), ant colony optimization (ACO), simulated annealing (SA), and bacterial foraging (BF) [13]. GA was the most used in the control field, such as in the search for optimal parameters of an FLC controller. But it still requires an enormous computational effort. In this paper we suggest a new computational theory named Biogeography-Based Optimization (BBO) to tune parameters of the FLC controller. This controller can govern a non-linear system.

2 PMSM Mathematical Models and the Vector Control

The basic idea of vector control is to manage the analog DC motor torque. Also, the control law is used in the ordinary three-phase AC motor. For magnetic field directional coordinates, we break down the current vector into the exciting current component, which produces the magnetic flux and torque.

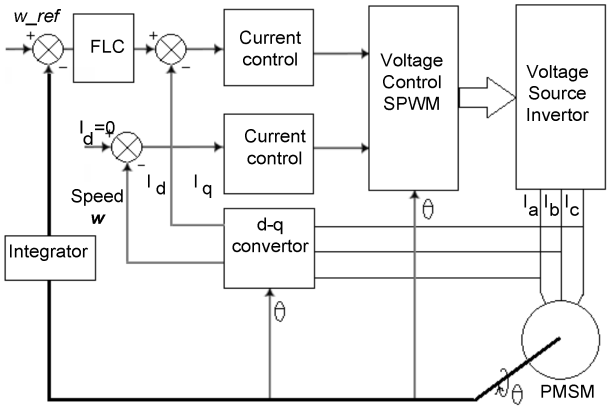

Fig. 1. Schematic diagram of the PMSM vector control

After coordinate transformation, the three-phase stator coordinate system (a-b-c coordinate) is varied to d-q coordinate. The two components (d-q coordinate) are perpendicular to each other and independent of each other. They are then adjusted respectively. Thus, the torque control of the AC motor is similar to the DC motor regarding their principles and characteristics. Therefore, the key for vector control is still both magnitude and the spatial location control of the current vector. Figure 1 shows the schematic diagram of the PMSM vector control.

3 Fuzzy Logic Controllers

Fuzzy logic controllers have the following advantages over the conventional controllers: they are cheaper to develop, they cover a wide range of operating conditions, and they are more readily customizable in natural language terms. In Mamdani type FIS, the crisp result is obtained by defuzzification [14]; the Mamdani FIS can be used for both multiple input and single output and a multiple inputs/multiple outputs system, as shown in Figure 2.

The usefulness of the fuzzy controller is adopted particularly in a complex and nonlinear system. The rules of conventional FLC produced depend on the operator's experience or general knowledge of the system in a heuristic way. The thresholds of the fuzzy linguistic variables are usually chosen arbitrarily in the design process. An improper controller value leads to an adverse consequence, unstable mode, collapse and separation. This work proposed BBO to design an optimal fuzzy logic controller (OFLC), where the optimized criteria are how to minimize the transient state.

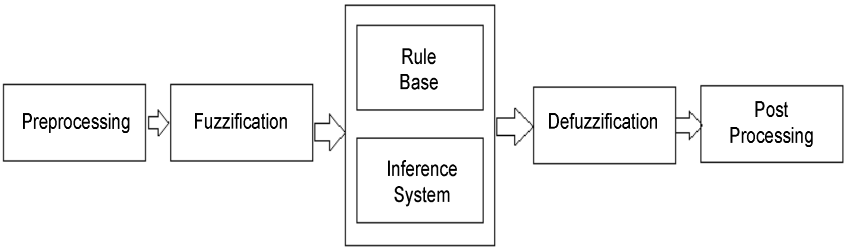

Fig. 2. Arrangement of fuzzy logic controller

4 Biogeography Based Optimization

Inspired by biogeography, Simon developed a new approach called Biogeography-Based-Optimization (BBO) in 2008. This algorithm is an example of how a natural process can be modeled to solve optimization [15]. In BBO, each possible solution is an island; the features that describe habitability are named the habitat suitability index (HSI). The goodness of each solution is named Suitability Index Variables (SIV). For example, concerning the natural process, why do some islands tend to accumulate many more species than others? Because they posses certain environmental features that are more suitable to sustaining them than other islands with fewer species. It is axiomatic that the habitats with high HSI have large populations, a high immigration rate, and a large number of species that migrate to other habitats. The rate of immigration will be lower if these habitats are already saturated with species. On the other hand, habitats with low HSI have a high immigration and low immigration rate, because of the sparse population.

The fitness function FF is associated with each solution of Biogeography Based Optimization BBO, which is analogous to the HSI of a habitat. A good solution is analogous to a habitat having a igh HSI, and a poor solution represents a habitat having a low HSI. The best solutions share their geographies of the lowest solutions throw migration. The best solutions have very small change compared with the lowest solutions, while the lowest solutions have a large change from time to time and accept many new features from the best solutions.

The immigration rate and emigration rate of the j^{th} island may be formulated as follows, in equations 1 & 2.

$$\lambda_j = I\left(1 - \frac{j}{n}\right) \quad (1)$$

$$\mu_j = \frac{E.j}{n} \quad (2)$$

is Where μ_j , λ_j are the immigration rate and the emigration rate of j^{th} individual; I is the maximum possible immigration rate; E is the maximum possible emigration rate; j is the number of species of j^{th} individual; and n is the maximum number of species [16].

In BBO, the mutation is used to increase the diversity of the population to get the best solutions. The mutation operator modifies a habitat's SIV, randomly based on the mutation rate. The mutation rate m_j is expressed in (3).

$$m_j = m_{max}\left(\frac{1-P_j}{P_{max}}\right) \quad (3)$$

Where m_j is the mutation rate for the j^{th} habitat having *a j number* of species; m_{max} is the maximum mutation rate; P_{max} is the maximum species count probability; P_j the species count probability for the j^{th} habitat and is given by:

$$\dot{P} = \begin{cases} -(\lambda_j + \mu_j)P_j + \mu_{j+1}P_{j+1}, & j \leq 0 \\ -(\lambda_j + \mu_j)P_j + \lambda_{j-1}P_{j-1} + \mu_{j+1}P_{j+1} & 1 \leq j \leq n \\ -(\lambda_j + \mu_j)P_j + \lambda_{j-1}P_{j-1}, & j = n \end{cases} \quad (4)$$

Where μ_{j+1} , λ_{j+1} are the immigration and emigration rate for the j^{th} habitat contain j+1 species; μ_{j-1} , λ_{j-1} are the immigration and emigration rate for the j^{th} habitat contains j-1 species.

5 Implementing BBO Tuning for FLC Parameters

The implementation of BBO in this work is somewhat complex, because the performance of the system must be examined for all habitats during of the each iteration. Therefore, the optimization algorithm is implemented by the MATLAB m-file program and linked with the system simulation program in MATLAB SIMULINK, to check the system performance in the each iteration. In this paper, the problem is summarized in optimizing three variables (X1, X2 and X3 shown in Figure 6), they are: one output and two inputs (speed and the change in speed); they are represented as three dimensional spaces including the prams of the triangle memberships of FLC. A random 20 habitats were assumed and an algorithm of 100 iterations is used to estimate the optimal values of the FLC controller parameters. The fitness function FF, illustrated in equation (5), can be calculated by SIMULINK, as shown in Figure 3.

$$FF = ITSE = \int_0^t t * e^2(t)\, dt \tag{5}$$

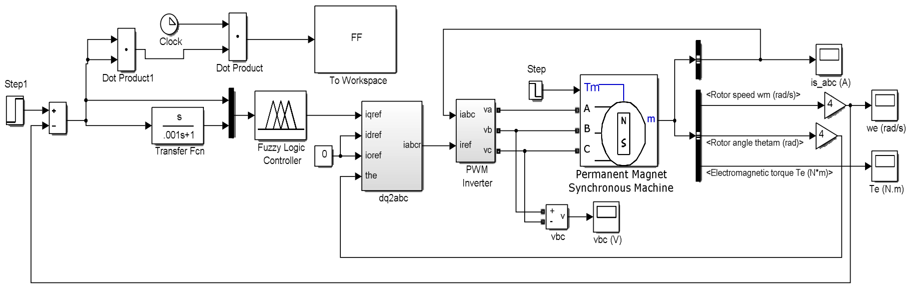

Fig. 3. System model implemented by SIMULINK/MATLAB

6 Results

Figure 4 shows the convergence of fitness function in 100 iterations and the comparison between GA and BBO. Figure 5 shows the step response with load and no

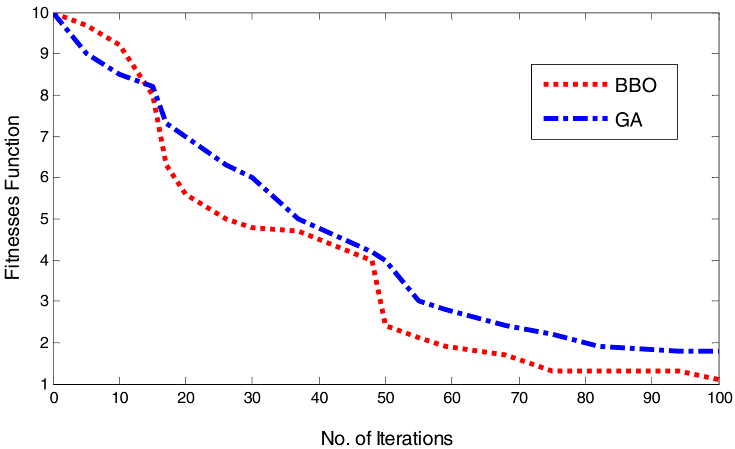

Fig. 4. The convergence of fitness function in 100 iterations

load using the proposed controller and GA-FLC, and the PI-controller tuned by conventional methods of trial and error. Figure 6 shows FLC designed by BBO, and Figure 7 shows the surface of FLC.

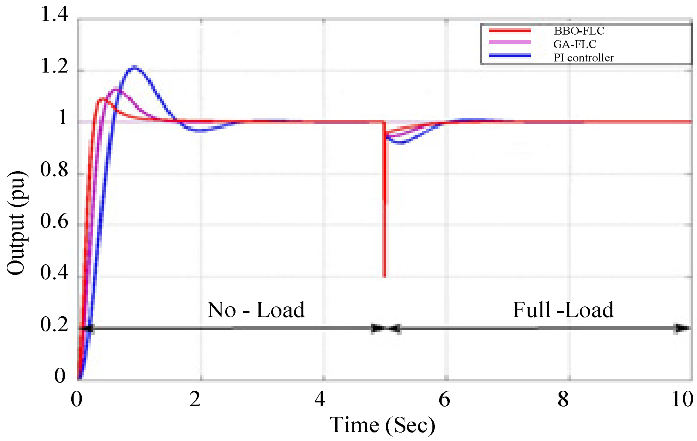

Fig. 5. Comparison performance of different controllers with proposed tuning methods

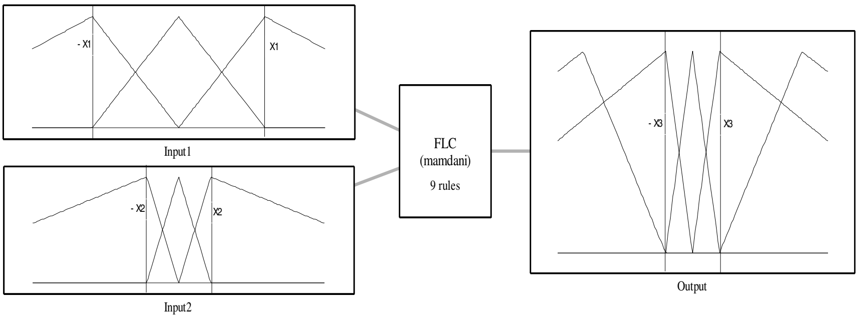

Fig. 6. FLC memberships designed by BBO

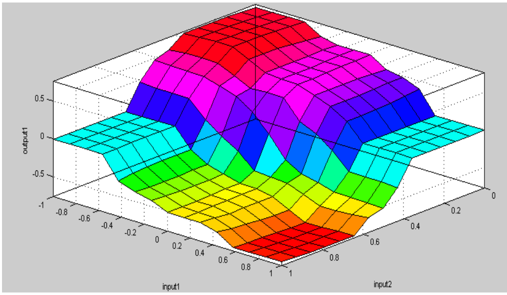

Fig. 7. The surface of FLC designed by BBO

7 Conclusions

The system responses of different tuning methods are illustrated in the simulation result, and a comparable performance between the three controllers in this research (PI controller, GA-FLC and BBO-FLC) is shown in Figure 5. We can obtain the following conclusions through simulation analysis:

1- This paper designs fuzzy logic control by a computational algorithm; it interjects control concepts of trial and error in fuzzy control and the conventional GA-FLC method, and then the control velocity modulation of an elevator.
2- Obviously, the BBO tuning of the FLC is the best intelligent method, which gives an excellent system performance, and the GA gives a good response with respect to the traditional trial and error method.
3- In addition to improving the system response, the BBO and GA can use a higher order system in the tuning process, which avoids the error of system order reduction. It gives a satisfactory solution during the first 50 iterations as shown in Figure 6.
4- The proposed method gives the control system strong flexibility, instantaneity and reliability because of the advanced prediction of the FLC predicting controller.
5- It makes the control system have a stronger real-time controllability because optimal fuzzy parameters have predicted a possible interference source. The lower the interference frequency, the more the BBO algorithm is controllable.
6- The elevator speed control system using BBO-FLC can be used as an effective complement to traditional control methods, thus, it can further enhance and improve the regulating quality for a control system with a different load torque.

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