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Adaptive Cuckoo Search Algorithm for the Speed Control System of Induction Motor

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Abstract

Optimization techniques are becoming more popular for the improvement in control of induction motor. Many intelligent algorithms have been used to improve performance of induction motor, Cuckoo search algorithm as an optimization algorithm can be used to find the optimal parameters of PID controller for induction motor. In this paper, cuckoo search algorithm is proposed to obtain optimized parameters of PID for indirect vector control in induction motor drive system. Normally, the parameters of the CS are fixed constants which may result in affecting the algorithm efficiency. To cope with this issue, we properly tune the parameters of the CS and propose an adaptive cuckoo search algorithm to enhance the convergence rate and accuracy of the CS. Compared with cuckoo search algorithm，genetic algorithm, and particle swarm optimization，the simulation results show that the proposed

method has excellent dynamic and static performance.

Keywords：Induction motor; PID controller; Cuckoo Search algorithm (CS); Adaptive cuckoo search algorithm (ACS)

I. INDUCTION

Widely used in industrial control, induction motor has the advantages of solid, reliable, cheap, and high efficiency [1]. The structure of induction motor is simple but its mathematical model is complicated, which leads to the difficult to realize high performance control [2]. Induction motor system is a multi-variable, strong nonlinear and strong coupling complex system, how to control the speed is one of the hot spots [3]. With the advantages of simple algorithm, high reliability and easy realization, PID control is widely used in all kinds of industrial control [4].

Recently more and more modern meta-heuristic algorithms are emerging and they are increasingly used in more fields, for example, genetic algorithm (GA) [5], particle swarm optimization (PSO) [6]. As a new meta-heuristic optimization algorithm, the cuckoo search algorithm is an efficient approach to solve continuous function optimization problems [7]. However, just like other artificial intelligence algorithm, basic cuckoo search algorithm easily trapped into local optimal solution especially for multi-modal function [8].

In this paper，an adaptive cuckoo search algorithm is proposed to optimize PID controller for accurate speed control in induction motor. Simulations show that the PID controller designed by the adaptive cuckoo algorithm to control the induction motor can be obtained good stability, robustness and dynamic performance.

The rest of this paper is organized as follows. In Section II, the induction motor and procedure of CS algorithm is briefly presented. In Section III, the adaptive CS algorithm is provided. In Section IV, the design of cuckoo algorithm PID speed control system is developed. In Section V, simulations and performance of the proposed algorithm are presented. The paper ends with some conclusions in Section VI.

II. Induction Motor Model and Cuckoo Search Algorithm

In this section, the theoretical knowledge of the motor model and the cuckoo algorithm are developed.

A. Induction Motor Model

Induction motor is the most used electric driven tools in the industry, for its robustness and high-speed operation transformation technology, is usually used to transform induction motor from three phases to its equivalent model to predigest mathematical analysis.

The field orientation was made according to the rotor flux vector. The magnitude of the rotor flux is obtained using a flux observer, but the frequency of the rotor field is neither computed nor estimated but it is imposed depending on the load torque value i.e. the slip frequency, and then integrated to obtain the imposed rotor flux position (angle θ_r). The mathematical model of induction motor is given below [9]:

$$\theta_e = \int \omega_e = \int \left(\omega_r + \omega_{sl} \right) = \theta_r + \theta_{sl} \tag{1}$$

The rotor circuit equations of the induction motor in d-q frame are given by:

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r} R_{r.} i_{ds} - \omega_{sl.}\psi_{qr} = 0 \tag{2}$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r} R_{r.} i_{qs} - \omega_{sl.}\psi_{dr} = 0 \tag{3}$$

For decoupling control, the stator flux component of current i_{ds} should be aligned on the d^e axis, and the torque component of current i_{qs} should be on the q^e axis, that leads to $\psi_{qr} = 0$ and $\psi_{dr} = \psi_r$ Then:

$$\frac{L_R}{R_r} \cdot \frac{d\psi_r}{dt} + \psi_r = L_{m.} i_{ds} \tag{4}$$

The slip frequency can be calculated as:

$$\omega_{sl} = \frac{L_{m.} R_r}{\psi_r L_r} i_{qs} \tag{5}$$

The decoupling can be achieved if the above slip angular speed command is used for making the field orientation. The control rotor flux ψ_r and $\frac{d\psi_r}{dt} = 0$ can be substitute in equation (4), so that rotor flux set as

$$\psi_r = L_m i_{ds} \tag{6}$$

The electromagnetic torque developed in the motor is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(i_{qs}.\psi_{dr}) \tag{7}$$

But $\psi_{dr} = L_{m.} i_{ds}$, on substitution, $T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(i_{qs.} i_{ds})$ (8)

B. Cuckoo Search Algorithm

In the natural, the way of cuckoo breeding is very special. They lay their eggs in the nest of host birds of other species and use host birds' nest to hatch their eggs and bring up their chicks. Cuckoos usually set their eggs in the nests where host birds just laid their eggs. Unfortunately, if host birds discover the eggs which are not their own, they will throw the alien eggs away or abandon their nests and rebuild new nests [10].

In general, an animal searches food in a random or quasi-random manner in nature. Because the next move is largely based on the current state and the transition probability to the next state. A special case of random walk with heavy-tailed probability distribution can be described by the mathematical formulation of lévy flight [11]. In this form of walking, short distance explore alternate with occasionally a long walk. In the intelligent optimization algorithm, adopt lévy flight can expand search scope and increase the population diversity, which easier to jump out of local optimal point.

Cuckoo search algorithm, as a comparatively new meta-heuristic algorithm, is one of the population based methods developed by Yang and Deb in 2009[12]. In order to imitate such behavior of cuckoo, there are mainly three principle rules.

- Each cuckoo can only lay one egg，which will be dumped in a randomly chosen nest.
- The best nests with the best eggs will be retained for the next generations.
- During the whole search process, the number of available host nests is a constant number, and the host bird will find the egg laid by a cuckoo with a probability. When it happens, the laid egg will be thrown away or the host bird will abandon the nest to build a new nest.

Based on the three rules, the basic steps of the CS can be shown in the next:

Begin

Initialize the parameters of the algorithm

Calculate the fitness function

While (t<Max Generation)

Get a cuckoo randomly by Lévy flight

Calculate the new fitness function f_i

Select a new nest x_j

If($f_i > f_j$)

Replace x_j by the new solution

End

Abandon the worse solution by the discovery rate pa

Rebuild the new nests using preference for random walk

Save the best solution

End

End

The update of the bird's nest positions in cuckoo search algorithm is shown in the following formula：

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus levy(\beta) \qquad i = 1, 2, \cdots n. \tag{9}$$

Where $x_i^{(t)}$ denotes the i^{th} cuckoo for the birds' nests in the t^{th} iteration， $L(\lambda)$ means walking randomly by Lévy flight，Where α denotes the step size, which is related to the sizes of the problem of interest, and the product $\oplus$ denotes entry-wise multiplications.

A Lévy flight is a random walk in which the step-lengths are drawn from a Lévy distribution as follow:

$$L \bullet u = t^{-\lambda},\ 1 < \lambda \leq 3 \tag{10}$$

In Mantegna's algorithm, the step length S can be calculated:

$$S = \frac{u}{|v|^{1/\beta}} \tag{11}$$

Where β is a parameter between [0, 1] interval and considered to be 1.5; u and v are drawn from normal distribution as:

$$u \sim N(0, \sigma_u^2) \qquad v \sim N(0, \sigma_v^2) \tag{12}$$

$$\sigma_u = \left\{ \frac{\Gamma(1+\beta)\sin)(\pi\beta/2)}{\Gamma[(1+\beta)/2]\beta 2^{(\beta-1)/2}} \right\}^{1/\beta}, \sigma_v = 1 \tag{13}$$

Where $\beta = 1.5$ in most literature.

The parameter pa is set to discovery probability that cuckoo's eggs is found by host bird. When created uniform random number is greater than pa, then change it by the next equation.

The local random work is carried out as:

$$x_{g+1,i} = x_{g,i} + r(x_{g,i} - x_{g,k}), \tag{14}$$

Where $x_{g,i}$ and $x_{g,j}$ are two different solutions selected randomly by random permutation. r is random numbers distributed in [0,1].

III. The improvement of CS algorithm

The specific improved operations of CS are proposed in this section. Adaptive cuckoo search algorithm（ACS）is based on the original cuckoo search algorithm, through the dynamic variation of the parameters to balance the ability of global and local search, thus improving the performance of the algorithm.

A. Adaptive Step Size

According to the position update formula of the cuckoo algorithm, where α denotes the step size. Large step-length can improve the ability of global search optimization but will bring about the lower precision of local search and the worse convergence. On the contrary, small step-length can improve the ability of local search optimization but will bring about the weak ability of global search. Step-length values directly affect the size of the search scope, and CS algorithm may take them to a fixed value is not conducive to make the algorithm to keep good balance in global and local search, this will affect the performance of the algorithm. So make the parameter α from the larger to the smaller. The value of α is dynamically adjusted with the number of generation as:

$$\alpha = \alpha_{\max} - (\alpha_{\max} - \alpha_{\min}) \times \left(\frac{2t}{T} - \left(\frac{t}{T} \right)^2 \right) \tag{15}$$

Where $\alpha_{\max}$ and $\alpha_{\min}$ are respectively the upper and lower bounds of the value of α, T is the number of total iterations, and t is the current iteration.

B. Adaptive Discovery Probability

In the basic CS, a host bird could discover an alien egg with a probability pa, when created uniform random number is greater than pa, this implies that it is a bad location, and it is necessary to make cuckoo take another nest. On the contrary, it may be remained. Smaller pa will reduce population's diversity, likewise, the downside of larger discovery probability is that poor individual will stay on next generation and convergence speed become low. To cope with this issue, it is important to use dynamic model for discovery probability pa. To sum up, taking smaller pa value in the early stage of the algorithm to keep the strong global search ability; Take larger pa value in the later algorithm to keep the strong local search ability. The adaptive discovery probability pa is expressed as follow:

$$pa = pa_{\min} + (\frac{t}{T})^2 \left(pa_{\max} - pa_{\min} \right) \tag{16}$$

Where are $pa_{\max}$ and $pa_{\min}$ are respectively the upper and lower bounds of the value of pa, t and T are the current iteration and the number of total iterations, respectively.

IV. The Design of Cuckoo Algorithm PID Speed Control System

The design of cuckoo algorithm PID speed control system is using dynamic CS algorithm to produce and update the birds' nests. The cuckoo algorithm according to operation requirements of induction motor drive system to adjust PID parameters. The position of the cuckoo with three-dimensional is corresponding to three parameters of PID. And operating the PID controller, and returning the ITAE as the fitness value of the DCS algorithm. To find a better position of birds' nests, that is, to find the best parameters of PID. So the construction of PID and cuckoo search algorithm adaptive controller is shown in figure 1.

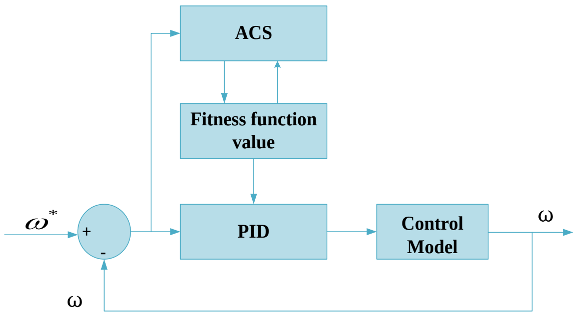

Fig. 1. The diagram of cuckoo optimization PID control structure.

The objective function value ITAE is fixed as followed:

$$J = \int_0^\infty t|e(t)|dt \qquad (17)$$

The processes of proposed algorithm is showed as followed:

Step1: Initialize the parameters of the algorithm. Such as the number of nests n, the Max Generation T, the current iteration t , and the upper and lower bounds of the value of α *and* pa.

Step2: Generate an initial population of n host nests regarded as the potential optimal PID.

Step3: Calculate the fitness function corresponding to cuckoo algorithm in motor mathematical model by ITAE, and find the current best $f_{\min}$.

Step4: Update the nest location according to the location update formula of the CS algorithm by (9), and the formula of the changing α by (15). We can get the new nest location and take them back to step 3. Get ITAE index as the fitness value, compared with the last generation. Get the current optimal position of bird's nest replace the poor bird's nest.

Step5: The discovery rate r will be generated at random. If $r > pa$, it means that host bird has found cuckoo's egg and remove them from nest, and the discovery rate's adjustment is presented in Eq. (16). Therefore, it means that cuckoo have to search for another place for laying egg, which has been shaping a new generation $x_t^{'}$. Finally, the optimal is chosen to compare with their fitness value.

Step6: If the number of iterations is equal to the Max Generation, break to step 7; else, the iteration number plus one, back to step 4.

Step7: Output the optimal fitness function value and corresponding PID.

Step8: Figure the curves of fitness function value and PID with iterations.

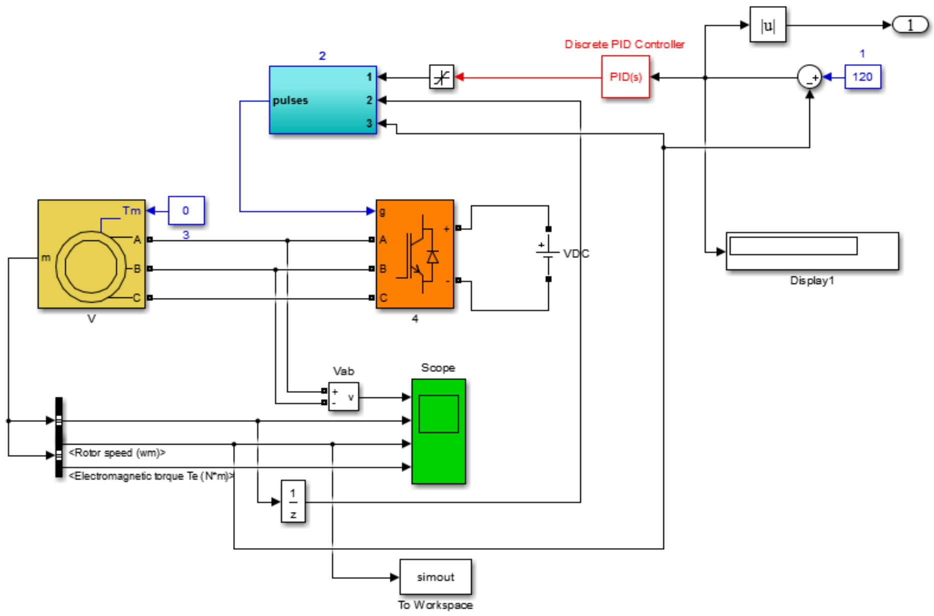

Fig. 2. Simulink model of induction motor with dynamic cuckoo search algorithm.

V. The Simulations and Experiments

In this section, the simulation of proposed speed controller for induction motor is completed by MATLAB platform. The performances, fitness value curves and PID curves will be compared and discussed.

A. Parameters Settings.

1) *The section of motor parameters:* The motor is a squirrel cage induction motor with power supply 460V, 4 pole, operating frequency 50 Hz. The specific parameters has been set as follow: $R_s = 0.087\Omega$, $R_r = 0.228\Omega$, $L_r = L_S = 0.8mH$, $L_m = 34.7mH$. The motor is initially at stand still with no load. The reference speed is set 120 rad/s.

2) *The section of adaptive cuckoo search:* The Max iteration number and the number of nests are set as 25 and 25, respectively. The upper and lower bounds of the value of α are set as 0.01 and 0.3, the upper and lower bounds of the value of pa are set as 0.1 and 0.6. The nests initial location range is (0,300), corresponding to three-dimensional parameters of PID.

3) *The section of particle swarm optimization:* The Max iteration number and the number of particles are set as 25 and 25, respectively. The acceleration constants c_1 and c_2 are set 1.8 and 1.8. The particle initial location range is (0,300), corresponding to three-dimensional

parameters of PID.

B. COMPUTATIONAL RESULTS.

Fig.2 shows the complete simulation model of three-phase squirrel cage induction motor. The induction motor is powered by a three-phase inverter with PWM control signal. Speed negative feedback loop is constituted with the cuckoo search algorithm speed controller and PWM. The main parameters are included with speed, electromagnetic torque and PWM signal in monitoring. The speed of the motor in the action of speed feedback gradually is to the reference speed and comes to be stable.

The compared speed curves based on ACS, CS, PSO and GA are showed in Fig. 4. In this figure we can see the optimized speed is smooth and no overshoot, the motor has run at a speed of 120 rad/s at 1.176Ts. Performance comparison based on proposed method and other algorithms showed that ACS is better than that of CS, GA, and PSO for the PID controller. Although the performance is similar to our proposed method, the improved mothed needs lesser responsive time than other mothed. Simulation results confirm the effectiveness of the ACS.

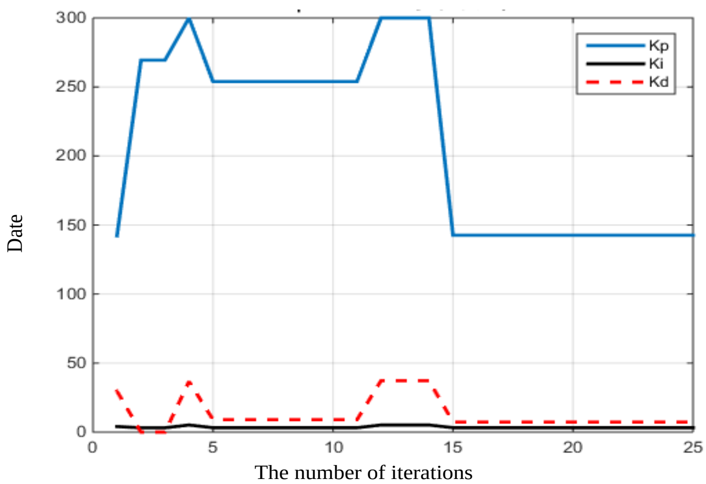

Fig. 3. The PID curves based on ACS

By running Matlab and Simulation, the fitness value and PID cures based on ACS are showed in Figure3 and Figure 5. The global optimal $K_p = 142.341, K_i = 3.211$, $K_d = 7.121$ are found in 15th iteration. And the fitness value based on ACS has declined finally tends to be stable.

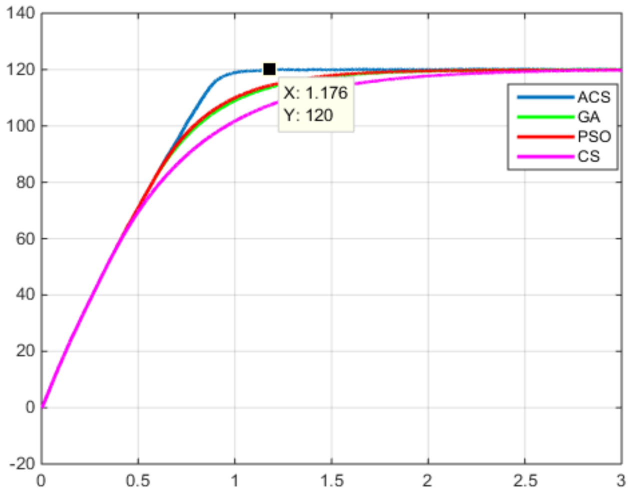

Fig.4. The compared speed curves based on ACS, CS, PSO and GA

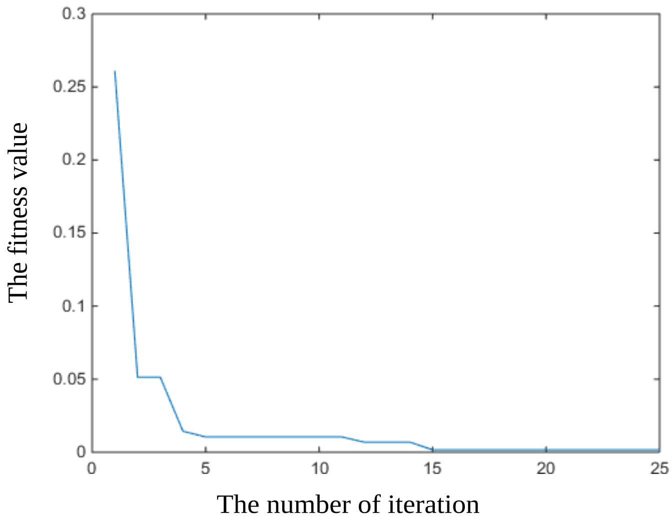

Fig.6. The fitness value curve based on ACS

VI. CONCLUSION

This paper has researched the optimized speed controller for induction motor with cuckoo search algorithm. The performance of cuckoo search algorithm PID for vector control in three-phase squirrel cage induction motor has been simulated. To enhance the convergence rate and the accuracy of the CS, an adaptive cuckoo search algorithm is developed. Unlike the original cuckoo search algorithm in which all the parameters are fixed, the ACS parameters are tuned constantly according to the algorithm iterations. Compared with adaptive cuckoo search algorithm and other algorithms, the simulation results show that the proposed PID controller can realize a good dynamic behavior of induction motor with a rapid settling time.

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