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A New Method of Speed Control for Induction Motor Based Improved Particle Swarm Optimization

LingZhi Yi
Wind power equipment and power conversion 2011 Collaborative Innovation Center
Xiangtan University
XiangTan, China
ylzwyh@xtu.edu.cn

YongBo Sui
Key Laboratory of Intelligent Computing & Information Processing Ministry of Education
Xiangtan University
XiangTan, China
straccy@163.com

WenXin Yu
School of Information and Electrical Engineering
Hunan University of Science and Technology
XiangTan, China
13874894700@163.com

***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 so for including particle swarm optimization. However, the improved performance may be limited on account of inertia coefficient in particle swarm optimization, which lead to the unbalance between the searching step and searching precision. In this paper, a variable-step nonlinear dynamic inertia weight of particle swarm optimization speed controller is proposed to improve the performance of an induction motor. The experiment results show that the proposed method has excellent performance.**

Keywords*—induction motor; vector control; particle swarm optimization (PSO)

I. INTRODUCTION

With the excellent performances of simple control, high robustness and cheap price, induction motor (IM) is widely used in industry. The Proportion-Integration-Differentiation (PID) control method is a very important and effective way to get desirable performances in vector-control technology of induction motor [1]. The optimal parameters often can not by manual adjustment. The domestic and foreign scholars have proposed several advanced control methods to improve PID controller, such as intelligent control [2], variable structure control (VSC) [3] and self-tuning PI controllers [4]. Among to intelligent control, particle swarm optimization and various improved methods have been proposed in past literatures. In [5], Sakthivel et al. proposed a modified fitness function of particle swarm optimization by modeling approximate circuit to represent induction motor. In [6], Solly Aryza1 et al. proposed a hybrid particle swarm optimization (HPSO) to optimize PI speed controller for induction motor speed estimation. However, the differentiation in PID should be of consideration in most of actual situations. Above those literatures, the improved methods mainly come from fitness function and combination with other algorithms, regardless of the searching step and searching precision for particles. Linear method of inertia coefficient is proposed in [7]. This modified method has improved the optimized performance in consideration of the searching step and searching precision for particles in a degree. But the linear method can't be fit for much better value of the searching step and searching precision. In [8] is presented a nonlinear modulation index dynamic inertia weight modified particle swarm optimization. Although this method can improve optimized performance of particle swarm optimization, the best value of nonlinear modulation index can't be chosen expediently. In this paper, a nonlinear dynamic inertia weight of particle swarm optimization algorithm is proposed for accurate speed control of induction motor. The performance will be investigated with simulations for comparison with the conventional PID controller.

II. INDUCTION MOTOR MODEL AND PARTICLE SWARM OPTIMIZATION

In this section, the basic mathematical model of the induction motor and the basic theory of particle swarm optimization algorithm will be introduced.

A. *Induction Motor Model (IMM)*

Induction motor is the most used electric driven tools in the industry, for its robustness and high-speed operation Transformation technology, like Park or Clark, is usually used to transform induction motor from three phases to its equivalent model to predigest mathematical analysis [9].

From the introduction, the ideal model of induction motor can be got [10]:

Voltage equations are shown:

$$\begin{aligned} u_{ds} &= R_s i_{ds} + \frac{d\lambda_{ds}}{dt} - \omega\lambda_{qs} \\ u_{qs} &= R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega\lambda_{ds} \\ 0 &= R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega - \omega_r)\lambda_{qr} \\ 0 &= R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega - \omega_r)\lambda_{dr} \end{aligned} \tag{1}$$

Where u_{ds} , u_{qs} are the d and q -axis stator voltages, i_{qs} and i_{ds} are the q and d -axis stator currents, u_{dr} and u_{qr} are the d and q -axis rotor voltages, i_{dr} and i_{qr} are the d and q -axis rotor currents, R_s and R_r are the stator and rotor resistance per phase, respectively. λ_s and λ_r are the stator and rotor flux, respectively, including to d -axis and q -axis. And ω and ω_r are reference and rotor electrical angular speed.

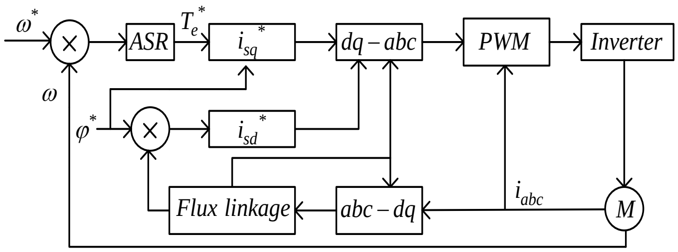

Fig. 1. The block diagram of vector-controlled induction motor.

Fig. 1 shows the block diagram of a vector-controlled induction motor with the conventional PID speed controller. Fig. 2 shows three-phase voltage source inverter, which ASR is a speed controller with PID. The induction motor is fed by a current-controlled PWM inverter, which operates as a three-phase sinusoidal current source. The motor angular speed ω is compared to the reference ω^* and the error is processed by the speed controller to produce an electromagnetic torque command T_e^*. Likewise, i_{qs}^* can be calculated using error of the reference flux linkage φ^* and the motor flux linkage φ. Finally, the PWM inverter can produce a control signal to the motor in order to adjust the speed of the motor.

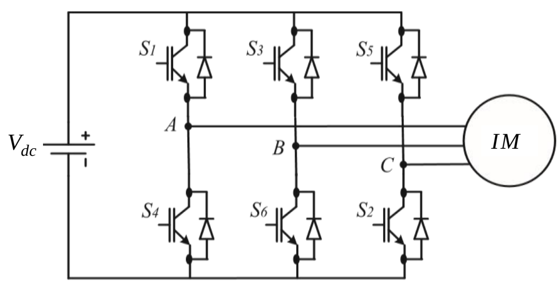

Fig. 2. Three-phase voltage source inverter.

B. Particle Swarm Optimization (PSO)

PSO is an evolutionary algorithm originating by social behavior, and every particle stands for a potential solution in state space by 'flying' [11]. The particles will update their positions on the basis of the fitness value at every iteration, and particles will record their 'best' positions so far, and then update velocities and positions using global optimal position and the individual optimal position.

The velocity of each particle could be calculated as follows:

$$v_{t+1}^k = wv_{t+1}^k + c_1 r_1 (P_t^k - x_t^k) + c_2 r_2 (G_t - x_t^k) \quad (2)$$

The mathematical equation of updates position is as follows:

$$x_{t+1}^k = x_t^k + v_{t+1}^k \quad (3)$$

Where v_t^k is the velocity of k -th particle at t -th iteration, w is the inertia factor. c_1 and c_2 is the weighting factor belonging to (1,2). Using the above equation, a certain velocity, the global optimal position and the individual optimal position can be calculated with above evolutions.

III. The Design of Particle Swarm Optimization Speed System

In this section, is described the design of particle swarm optimization PID speed control system in detail.

Accurate mathematical model is necessary for PID optimized control. This paper realizes an improvement to speed control system based on particle swarm optimization PID control: a nonlinear dynamic inertia weight of particle swarm optimization algorithm, which can balance the searching step and searching precision for particles. At earlier stage of the evolutionary process, the point should be on the searching step, which allows particles move drastically, while the searching precision should be taken into consideration for high precision at the later stage.

So, according to above thought and description, the inertia coefficient method is defined:

$$\omega = \omega_{\max} - (\frac{n}{m})^2 (\omega_{\max} - \omega_{\min}) \quad (4)$$

Where n , m , $\omega_{\max}$ and $\omega_{\min}$ are the current iteration number, the maximum iteration, the upper limit value and lower limiting value of inertia factor, respectively. The Fig.3 shows the inertia coefficient curve with $\omega_{\max} = 0.9$, $\omega_{\min} = 0.4$, the Max Generation $m = 30$.

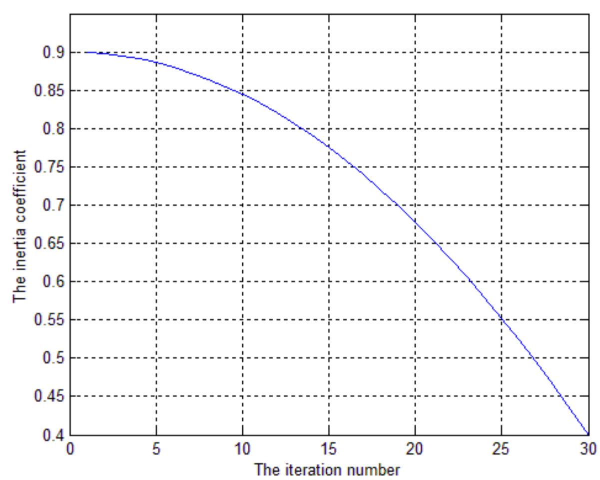

Fig. 3. The inertia coefficient curve

The construction of PID parameter and particle swarm optimization speed controller, as shown in Fig. 3. The deviation between reference angular speed ω^* and measured angular speed ω will multiply by fitness function, then the product will be repeatedly compared by particle swarm optimization with iteration , until no one can be better than the global optimal location. Finally, the optimal PID parameters could be got.

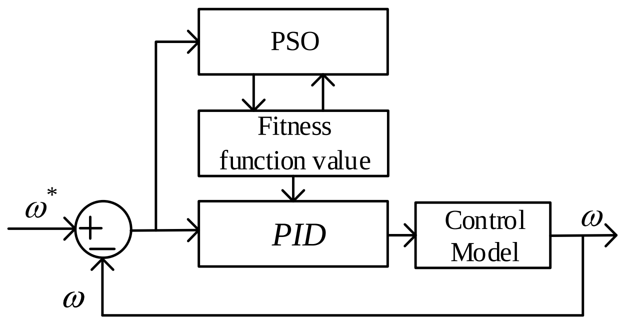

Fig. 4. The diagram of particle swarm optimization PID control structure.

The processes of the proposed method in detail are presented:

Initialization:

Step1: Initialize the parameters of particle swarm optimization algorithm. Such as the number of particle swarm n , the upper limit value $\omega_{\max}$ and lower limiting value $\omega_{\min}$ of inertia factor, the weighting factor c_1 and c_2 . And the Max Generation m .

Step2: Initialize particle swarms' locations and velocity corresponding to particles in state space, randomly.

Calculation and update:

Step3: Calculate the fitness function corresponding to particle swarm in motor mathematical model. The fitness function commonly used includes IES, IAE, ITAE and ISTE. The ITAE is chosen as the fitness function in this paper.

The ITAE is chosen as followed:

$$J = \int_0^\infty t\left|e(t)\right|dt \tag{5}$$

Where $e(t)$ stands deviation of ω^* and ω .

Step4: Find out the optimal value of every particle and the global optimal value compared to the optimal value of every particle.

Step5: Update inertia factor by (4).

Step6: Update the spatial location x and the velocity v by (2) and (3).

Step7: Calculate the fitness function of each particle in new location. And update the optimal value of every particle and global optimal value.

Judge and jump out of the iteration:

Step8: If the number of iterations is equal to the Max Generation, break to step 9; else, the iteration number plus one, back to step 5.

Step9: Output the global optimal fitness function value and corresponding PID.

Step10: Figure the curves of fitness function value and PID with iterations.

IV. The Simulation Experiment

In this section, the proposed speed controller will be simulated using Matlab. The performances, fitness value curves and PID curves will be compared and studied

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 $50Hz$. The specific parameters are: $R_s = 0.087\Omega$, $R_r = 0.228\Omega$, $L_r = L_s = 0.8mH$, $L_m = 34.7mH$. The motor is initially at stand still with no load. The reference speed is set 120 rad/s.

2) The section of particle swarm optimization: The Max iteration number and the number of particles are set as 30 and 30, respectively. The acceleration constants c_1 and c_2 are set 1.2 and 1.2. The particle initial location range is (0,300), corresponding to three-dimensional parameters of PID. The upper limit value $\omega_{\max}$ and lower limiting value $\omega_{\min}$ of inertia factor are set 0.9 and 0.4, respectively.

B. *Discussion and Analysis*

Fig. 5 shows the complete Simulink model of the speed of the controller system for three-phase squirrel cage induction motor. The induction motor is powered by a three-phase inverter with PWM control signal. The speed negative feedback loop is constituted with the particle swarm optimization speed controller and PWM signal generator. The main parameters detected in monitoring are the speed, electromagnetic torque and PWM signal. The speed of the motor in the action of speed feedback gradually is to the reference speed and comes to be stable.

The curves of optimized speed and initial speed are showed in Fig. 6. The optimized speed is smooth and no overshoot, opposite to a big overshoot of 50%. The initial locations and final locations are showed in Fig. 7. Almost all particles have come to near the optimal location, which meets our expectation. Fig. 8 shows the path of the optimal location as the increase of iteration with the number 1 to 8. As we can see from the figure, the step size has decreased quickly with iteration and the global optimal positon has finally come to be stable, corresponding to our proposed nonlinear method of the inertia coefficient that the step size has decreased finally, which indicates that the desirable location has been founded.

The PID parameters curves and the fitting curve have come to be stable in 20^{th} iteration, as showed in Fig. 9 and Fig. 10. When the optimized process just starts, the parameters could move drastically to search the optimal position, and the searching step has decreased rapidly and markedly to improve the searching accuracy, which meets our expectations. As we can see from Fig. 9, the global optimal PID parameters that $K_p = 251.776$, $K_i = 2.8942$, $K_d = 4.9662$, are found in 20^{th} iteration and the fitness function value has finally decreased to 15.61.

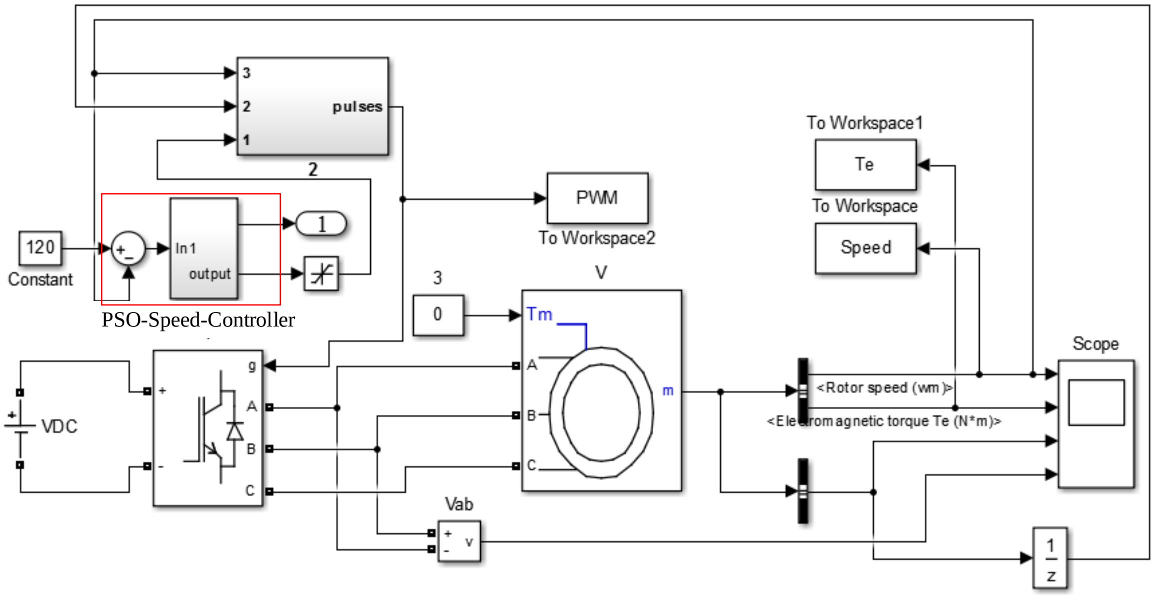

Fig. 5. Simulink model of induction motor with particle swarm optimization.

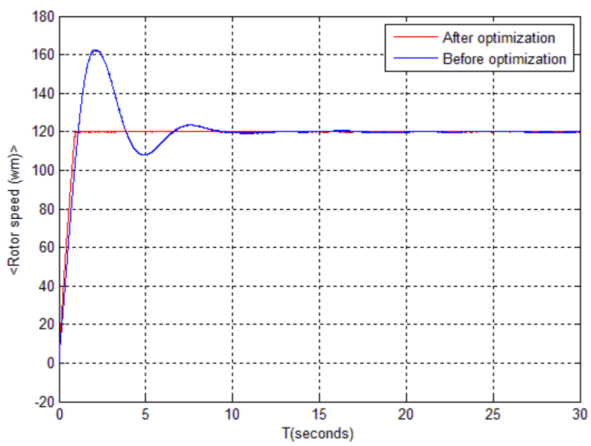

Fig. 6. The speed curves of before and after optimization.

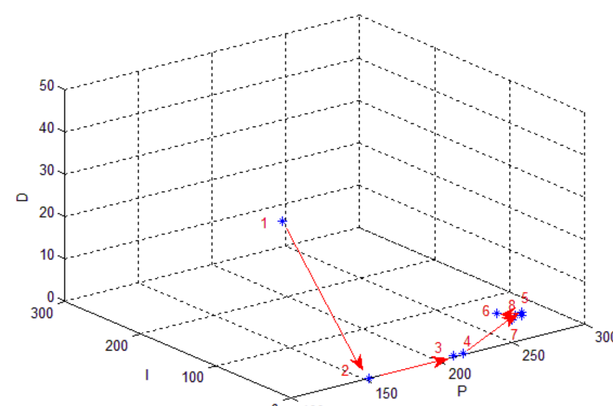

Fig. 8. Optimal locations in iteration

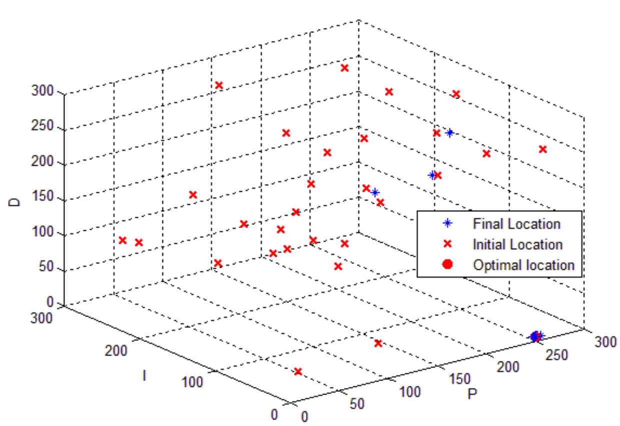

Fig. 7. The initial, final and optimal locations of particles

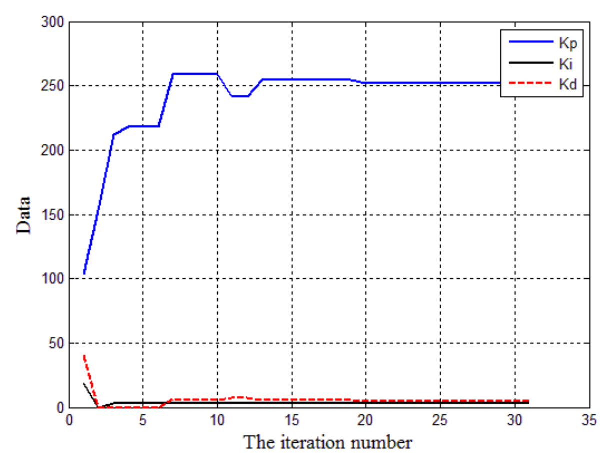

Fig. 9. The PID curves

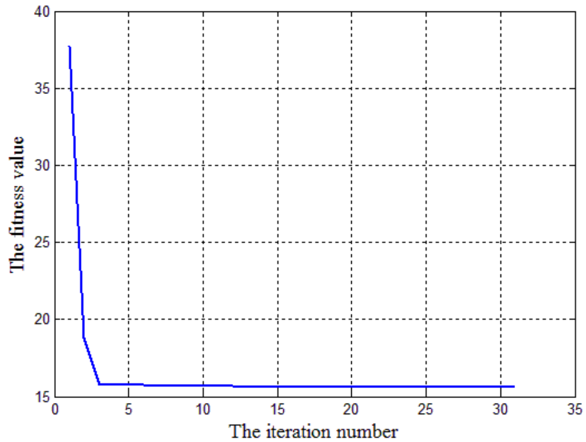

Fig. 10. The fitness value curve

V. Conclusion

This paper has focused on the optimized speed controller of induction motor. The main contribution is that a novel speed controller based on an improved particle swarm optimization: a nonlinear dynamic inertia weight of particle swarm optimization algorithm, which can balance the searching step and searching precision for particles, is proposed for proportional-integral-derivate (PID) controller for accurate speed control. The processes of proposed method has been described in detail and the simulation results show that the improved particle swarm optimization PID controller realizes a good dynamic behavior of the motor with a rapid settling time and has a better performance than conventional PID controller.

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