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Research on AC Asynchronous Motor Vector Control Speed Control System Based on Labview

Song Ren-Yin* and Liang Guo-Xiang

Ningde Normal University, Fujian NingDe, China

Abstract: During the process of using traditional particle swarm optimization (PSO) to identify electric parameters, the algorithm can be easily caught in locally optimal solution, thus leading to relatively large identification result error. Therefore, the article proposes a simulated annealing particle swarm optimization (SA-PSO) algorithm to integrate the advantages, namely the strong global optimization capability of simulated annealing (SA) algorithm and the fast convergence speed of PSO algorithm, in order to improve the traditional PSO algorithm, and uses simulated annealing principle to determine inertia weight of PSO algorithm. Meanwhile, DFIG with the unit capacity of 1.5MW has been taken as the research object for simulation analysis. The test system employs LabVIEW software for experiment design, and the result shows: compared with the identification result of traditional PSO algorithm, SA-PSO algorithm can rapidly and accurately identify DFIG electric parameters and the identification result has higher precision.

Keywords: Doubly-fed asynchronous wind power generator, electric parameter identification, particle swarm optimization (pso) algorithm, simulated annealing particle swarm optimization (SA-PSO) algorithm.

1. INTRODUCTION

At present, the methods for identifying the electric parameters of generators is basically divided into frequency domain identification method, time domain identification method and intelligent identification method, wherein the frequency domain identification method has relatively strict requirement for input drive signal and cannot accurately reflect the nonlinearity in the operating process of wind power generator; the time domain identification method has the features of complicated encoding process, relatively difficult operation, long simulation time and relatively low parameter identification precision [1]. Along with the development of intelligent control, people pay more and more attention to the research on the electric parameter identification of generators carried out on the basis of genetic algorithm (GA), ant colony algorithm (ACO), artificial neural network (ANNs), PSO algorithm, etc. Therein, PSO algorithm, as a random optimization algorithm based on swarm intelligence, has the features of simple algorithm and easy realization, so it has bright application prospect in the field of electric parameter identification of generators; but PSO algorithm can be easily caught in local extremum point and has such disadvantages as slow convergence speed, poor identification precision, etc. in later period [2]. Various improvement methods have been proposed in order to conquer these defects of PSO algorithm. For example, the breeding and subgroup PSO algorithm has been proposed in some articles to combine the traditional speed & location updating rules and the breeding strategy thought, and such algorithm has realized faster convergence speed and better potential solution capability. For DFIC, namely a multivariable, nonlinear and strong coupling system, this article introduces SA algorithm into PSO algorithm and proposes SA-PSO algorithm for identifying DFIG electric parameters, and such algorithm has integrated the advantages, namely the strong global optimization capability of SA algorithm, the fast convergence speed and the simple realization of PSO algorithm. In order to improve the convergence speed and the parameter identification precision of the algorithm, the problem that PSO algorithm can be easily caught in locally optimal solution should be to avoided [3-8]. This article introduces the parameter identification process of SA-PSO algorithm in detail and constructs the objective function for the state variables according to DFIG data actually measured in the wind power plant. Compared with traditional PSO algorithm, the simulation analysis shows that DFIC electric parameters identified by SA-PSO algorithm can better reflect the variation tendency of electric parameters of generators and have high precision.

*Address correspondence to this author at the Ningde Normal University, Fujian NingDe, China; Tel: 0593-6558609; Fax: 0593-6558609;
E-mail: Renyinson@163.com

2. DFIC MATHEMATICAL MODEL

Take stator side and rotor side respectively as generator convention and motor convention to obtain DFIG mathematical model under dq coordinate system.

DFIG voltage equation is:

$$\begin{cases} U_{sd} = -R_s I_{sd} + p\psi_{sd} - \omega_1 \psi_{sq} \\ U_{sq} = -R_s I_{sq} + p\psi_{sq} + \omega_1 \psi_{sd} \\ U_{rd} = \quad R_r I_{rd} + p\psi_{rd} - \omega_s \psi_{rq} \\ U_{rq} = \quad R_r I_{rq} + p\psi_{rq} + \omega_s \psi_{rd} \end{cases} \tag{1}$$

DFIG flux linkage equation is:

$$\begin{cases} \psi_{\mathrm{sd}} = -L_{\mathrm{s}} I_{\mathrm{sd}} + L_{\mathrm{m}} I_{\mathrm{rd}} \\ \psi_{\mathrm{sq}} = -L_{\mathrm{s}} I_{\mathrm{sq}} + L_{\mathrm{m}} I_{\mathrm{rq}} \\ \psi_{\mathrm{rd}} = \ \ L_{\mathrm{r}} I_{\mathrm{rd}} - L_{\mathrm{m}} I_{\mathrm{sd}} \\ \psi_{\mathrm{rq}} = \ \ L_{\mathrm{r}} I_{\mathrm{rq}} - L_{\mathrm{m}} I_{\mathrm{sq}} \end{cases} \tag{2}$$

DFIG electromagnetic torque equation is:

$$T_{\mathrm{e}} = \frac{3}{2} n_{\mathrm{p}} L_{\mathrm{m}} (I_{\mathrm{sq}} I_{\mathrm{rd}} - I_{\mathrm{sd}} I_{\mathrm{rq}}) \tag{3}$$

Voltage equation, flux linkage equation and electromagnetic torque equation jointly constitute integral DFIG mathematical model under dq coordinate system. Take DFIG stator current, rotor current and generator rotor speed as state variables and combine the voltage equation and the flux linkage equation to obtain DFIG state equation:

$$(L_{\mathrm{s}} L_{\mathrm{r}} - L_{\mathrm{m}}^2) \begin{bmatrix} \dot{I}_{\mathrm{sd}} \\ \dot{I}_{\mathrm{sq}} \\ \dot{I}_{\mathrm{rd}} \\ \dot{I}_{\mathrm{rq}} \end{bmatrix} = \begin{bmatrix} -R_{\mathrm{s}} L_{\mathrm{r}} & A & -R_{\mathrm{r}} L_{\mathrm{m}} & B \\ -A & -R_{\mathrm{s}} L_{\mathrm{r}} & -B & -R_{\mathrm{r}} L_{\mathrm{m}} \\ -R_{\mathrm{s}} L_{\mathrm{m}} & C & -R_{\mathrm{r}} L_{\mathrm{s}} & D \\ -C & -R_{\mathrm{s}} L_{\mathrm{m}} & -D & -R_{\mathrm{r}} L_{\mathrm{s}} \end{bmatrix} \cdot \begin{bmatrix} I_{\mathrm{sd}} \\ I_{\mathrm{sq}} \\ I_{\mathrm{rd}} \\ I_{\mathrm{rq}} \end{bmatrix} + \begin{bmatrix} -L_{\mathrm{r}} & 0 & L_{\mathrm{m}} & 0 \\ 0 & -L_{\mathrm{r}} & 0 & L_{\mathrm{m}} \\ -L_{\mathrm{m}} & 0 & L_{\mathrm{s}} & 0 \\ 0 & -L_{\mathrm{m}} & 0 & L_{\mathrm{s}} \end{bmatrix} \cdot \begin{bmatrix} U_{\mathrm{sd}} \\ U_{\mathrm{sq}} \\ U_{\mathrm{rd}} \\ U_{\mathrm{rq}} \end{bmatrix} \tag{4}$$

Therein:
$$\begin{aligned} A &= \omega_1 L_{\mathrm{s}} L_{\mathrm{r}} - \omega_2 L_{\mathrm{m}}^2 \\ B &= L_{\mathrm{m}} L_{\mathrm{r}} (\omega_2 - \omega_1) \\ C &= L_{\mathrm{m}} L_{\mathrm{s}} (\omega_1 - \omega_2) \\ D &= \omega_2 L_{\mathrm{s}} L_{\mathrm{r}} - \omega_1 L_{\mathrm{m}}^2 \end{aligned}$$

In the formula, p is differential operator; ω_1 is synchronous angular spin rate; ω_2 is angular spin rate of rotor; R_{s} is stator resistance; R_{r} is rotor resistance; L_{s} and L_{r} are respectively the self-inductances of equivalent stator winding and rotor winding under dq coordinate system; L_{m} is mutual inductance between equivalent rotors under dq coordinate system; U_{sd} and U_{sq} are quadrature-direct axis voltages of stator; U_{rd} and U_{rq} are quadrature-direct axis voltages of rotor; ψ_{sd} and ψ_{sq} are quadrature-direct axis flux linkages of stator; ψ_{rd} and ψ_{rq} are quadrature-direct axis flux linkages of rotor; I_{sd} and I_{sq} are quadrature-direct axis currents of stator; I_{rd} and I_{rq} are quadrature-direct axis currents of rotor; n_{p} is number of motor pole pairs; and T_{e} is electromagnetic torque.

Simplify formula (4) as:

$$\dot{\boldsymbol{I}} = E\boldsymbol{I} + F\boldsymbol{U} \quad (5)$$

Therein:

$$E = \frac{1}{(L_{\mathrm{s}} L_{\mathrm{r}} - L_{\mathrm{m}}^2)} \cdot \begin{bmatrix} -R_{\mathrm{s}} L_{\mathrm{r}} & A & -R_{\mathrm{r}} L_{\mathrm{m}} & B \\ -A & -R_{\mathrm{s}} L_{\mathrm{r}} & -B & -R_{\mathrm{r}} L_{\mathrm{m}} \\ -R_{\mathrm{s}} L_{\mathrm{m}} & C & -R_{\mathrm{r}} L_{\mathrm{s}} & D \\ -C & -R_{\mathrm{s}} L_{\mathrm{m}} & -D & -R_{\mathrm{r}} L_{\mathrm{s}} \end{bmatrix}$$

$$F = \frac{1}{(L_{\mathrm{s}} L_{\mathrm{r}} - L_{\mathrm{m}}^2)} \cdot \begin{bmatrix} -L_{\mathrm{r}} & 0 & L_{\mathrm{m}} & 0 \\ 0 & -L_{\mathrm{r}} & 0 & L_{\mathrm{m}} \\ -L_{\mathrm{m}} & 0 & L_{\mathrm{s}} & 0 \\ 0 & -L_{\mathrm{m}} & 0 & L_{\mathrm{s}} \end{bmatrix}$$

According to DFIG state equation in formula (5), the electric parameters to be identified have five vectors as follows:

$$\boldsymbol{\theta} = [R_{\mathrm{s}} \quad R_{\mathrm{r}} \quad L_{\mathrm{s}} \quad L_{\mathrm{r}} \quad L_{\mathrm{m}}]^{\mathrm{T}} \tag{6}$$

DFIG input vector is:

$$\boldsymbol{V} = [U_{\mathrm{sd}} \quad U_{\mathrm{sq}} \quad U_{\mathrm{rd}} \quad U_{\mathrm{rq}}]^{\mathrm{T}} \tag{7}$$

DFIG state vector is:

$$\boldsymbol{X} = [I_{\mathrm{sd}} \quad I_{\mathrm{sq}} \quad I_{\mathrm{rd}} \quad I_{\mathrm{rq}} \quad \grave{u}_2]^{\mathrm{T}} \tag{8}$$

3. SA-PSO ALGORITHM

The standard PSO algorithm is a swarm intelligence based evolutionary computation method proposed by Kennedy and Eberhart in 1995 and mainly used for optimization solution [9-14].

The basic principle of standard PSO algorithm is to take particles as basic component unit, then initiate a group of random particles and finally search the optimal solution through iterative search. Under the assumption that the particle swarm is composed of m particles and each particle is formed by D-dimensional solution space, the position vector of the i-th particle in the particle swarm is: $x_{\mathrm{i}}=(x_{\mathrm{i1}},x_{\mathrm{i2}},\ldots,x_{\mathrm{iD}})$; velocity vector is: $v_{\mathrm{i}}=(v_{\mathrm{i1}},v_{\mathrm{i2}},\ldots,v_{\mathrm{iD}})$; individual extremum is: $p_{\mathrm{i}}=(p_{\mathrm{i1}},p_{\mathrm{i2}},\ldots,p_{\mathrm{iD}})$; global extremum is: $p_{\mathrm{g}}=(p_{\mathrm{g1}},p_{\mathrm{g2}},\ldots,p_{\mathrm{gD}})$. The fitness function is used as the basis for particle evaluation, and different fitness functions are set in different application environments in actual engineering application, and particle employs individual extremum and global extremum to update its own speed and location in each iteration process, as shown in the following formula:

$$\begin{cases} v_{iD}(t+1) = v_{iD}(t) + c_1 \times r_1 \times (p_{iD}(t) - x_{\mathrm{iD}}(t)) + \\ \qquad\qquad c_2 \times r_2 \times (p_{gD}(t) - x_{\mathrm{iD}}(t)) \\ x_{iD}(t+1) = x_{\mathrm{iD}}(t) + v_{iD}(t+1) \end{cases} \tag{9}$$

In the formula, t is iteration times; c_1 and c_2 are learning factors; r_1 and r_2 are random numbers in the interval of [0,1]; velocity $v_{\mathrm{iD}} \in (-V_{\mathrm{max}}, V_{\mathrm{max}})$, when $v_{\mathrm{iD}} > V_{\mathrm{max}}$, then $v\mathrm{iD} = V\mathrm{max}$; when $v_{\mathrm{iD}} < V_{\mathrm{max}}$, then $v_{\mathrm{iD}} = -V_{\mathrm{max}}$. PSO algorithm process is as shown in Fig. (**1**).

In order to strengthen the comparison of DFIG electric parameter identification results, the two following basic PSO algorithms are added to this article to be compared with SA-PSO algorithm.

In order to strengthen the global and local optimization capabilities of the particles, Y. Shi and R.C. Eberhart have introduced inertia weight to the standard PSO algorithm and accordingly proposed inertia weight containing particle swarm optimization (ωPSO) algorithm, and the iterative formula thereof is:

$$\begin{cases} v_{iD}(t+1) = \mathbf{n} \times v_{iD}(t) + c_1 \times r_1 \times (p_{iD}(t) - x_{\mathrm{iD}}(t)) \\ \qquad\qquad + c_2 \times r_2 \times (p_{gD}(t) - x_{\mathrm{iD}}(t)) \\ x_{iD}(t+1) = x_{\mathrm{iD}}(t) + v_{iD}(t+1) \end{cases} \tag{10}$$

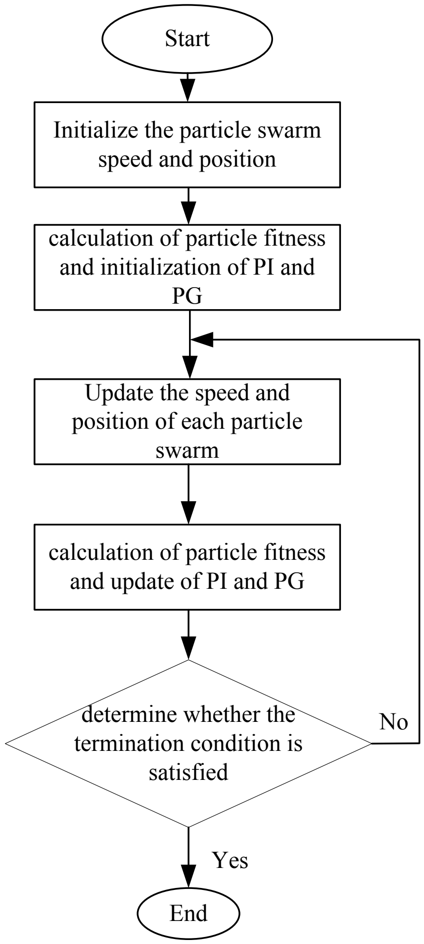

Fig. (1). Flow Chart of PSO Algorithm.

In order to ensure the convergence of PSO algorithm, M. Clerc has introduced constriction factor into standard PSO algorithm and has accordingly proposed constriction factor containing particle swarm optimization (CPSO) algorithm, and the iterative formula thereof is:

$$\begin{cases} v_{iD}(t+1) = \chi \cdot [v_{iD}(t) + c_1 \times r_1 \times (p_{iD}(t) - x_{iD}(t)) \\ \qquad + c_2 \times r_2 \times (p_{gD}(t) - x_{iD}(t))] \\ x_{iD}(t+1) = x_{iD}(t) + v_{iD}(t+1) \end{cases} \tag{11}$$

$$\chi = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|}, \qquad \varphi = c_1 + c_2, \varphi > 4$$

In the formula, χ is constriction factor; φ is usually as φ=4.1, so the constriction factor is as χ=0.729.

4. DFIC ELECTRIC PARAMETER IDENTIFICATION BASED ON SA-PSO ALGORITHM

For DFIG observation model with unknown accurate model parameters, the electric parameter identification process is actually an optimization process. If DFIG stator and rotor voltages (input) and generator speed are unknown, then

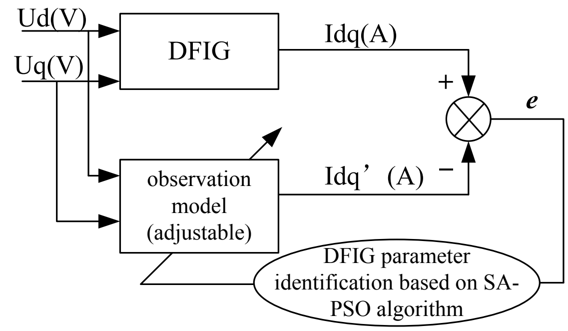

Fig. (2). Diagram of the Parameter Identification Based on SA-PSO Algorithm.

DFIG stator current (output) can be calculated or estimated according to the present and historical input-output values of the state equation. However, DFIG electric parameters are slowly changed due to the influence of temperature, saturation of magnetic circuit, skin effect, etc. during the operating process, so the estimated output current is different from the actual output current. Therefore, the following method is adopted: take the actually operating DFIG as the reference model, take the state equation of the generator as the observation model, adopt the estimated deviation of generator stator and rotor currents, and use the optimization algorithm with the fitness function as evaluation standard to narrow the gap till reaching the acceptable scope. This article adopts SA-PSO algorithm to timely adjust the electric parameters of the generator in the observation model in order to gradually converge the current deviation to zero and establish the electric parameter identification system [15]. The diagram of parameter identification based on SA-PSO algorithm is as shown in Fig. (**2**).

5. SIMULATION ANALYSIS

10 functions including equipment function, analog input function group, analog output function group, digital input/output function group, event function, port function, etc. have been developed for LabVIEW. 10 functions are divided into equipment functions and operating functions, wherein the equipment functions are responsible for acquiring hardware characteristics and switch hardware while the operating functions are responsible for acquisition, output, communication, etc. after the hardware equipment is ready. In the experiment, the designated acquisition starting channel is 0# channel and there are four acquisition channels, then Multi-ChannelINT Setup.vi will start at 0# channel to acquire four paths of signals and transmit to the background for storage. AllocDSPBuf.vi allocates cache region, which shall be released by LabVIEW, for data transmission and meanwhile displays relevant information. OverrunHandler.v processes the sampling cache region overflow during the sampling process, and after data acquisition, DeviceClose.vi closes the opened equipment. During data acquisition process, program error can be displayed in Error Message. The acquired data will be sent to the oscillogram for waveform display after

Table 1. Parameters of the DFIG.

Name	Parameter
Rated Power (kW)	1500
Rated Frequency (Hz)	50
Rated Speed (rpm)	1800
Stator Rated Voltage (V)	690
Cut-in Wind Speed (m/s)	3.5
Rated Wind Speed (m/s)	12.5
Cut-out Wind Speed (m/s)	25

Table 2. Algorithm Parameter Settings.

Algorithm	ωPSO	CPSO	SA-PSO
c_1	1.49445	1.49445	1.49445
c_2	1.49445	1.49445	1.49445
ω	0.8		[0.5,08]
χ		0.729	

Table 3. Three Algorithms Simulation Results Compared Under Rated Wind Speed (12.5m/s).

Electric Parameter	Actual Value	ωPSO		CPSO		SA-PSO	
		Identified Value	Error/%	Identified Value	Error/%	Identified Value	Error/%
$R_s(\Omega)$	0.435	0.555	27.59	0.409	-5.98	0.468	7.59
L_s(H)	0.304	0.286	-5.92	0.338	11.18	0.313	2.96
$R_r(\Omega)$	0.816	0.579	-29.04	0.769	-5.76	0.806	-1.23
L_r(H)	0.312	0.322	3.21	0.234	-25.00	0.319	2.24
L_m(H)	0.292	0.432	47.95	0.361	23.63	0.305	4.45

filtering processing. This article adopts the sample data from April 19~21, 2015 in a certain wind power plant for sampling record every 10min in order to select 10 groups of sample data respectively for 10 kinds of wind speeds, totally 100 groups. The actually measured data are obtained from 1.5MW DFIG, and the acquired data cover the wind speed from 3.5m/s to rated value 12.5m/s and includes wind speed, generator speed, stator voltage, stator current and rotor current. DFIG data are as shown in Table **1**. In order to comparatively reflect the optimization performance of SA-PSO algorithm, this article adopts ωPSO algorithm, CPSO algorithm and SA-PSO algorithm to respectively identify DFIG electric parameters.

Under the assumption of swarm size m=30, solution space dimensions D=5, maximum iteration times $t_{\max}$=100, initial temperature T=1000 and annealing speed α=0.98, the value range of the electric parameters to be identified is ±50% of the experiment parameters. Algorithm parameter settings are as shown in Table **2**.

According to the actually measured data acquired in the field, compile .m file in MATLAB to obtain the simulation results for different wind speeds, wherein the initial values of electric parameters are: R_s=0.435Ω, L_s=0.304H, R_r=0.816Ω, L_r=0.312H and L_m=0.292H. The parameter identification results of different wind speeds based on SA-PSO Algorithm are as shown in Table **4**.

According to the acquisition of actually measured DFIG data, use three algorithms to respectively simulate DFIG mathematical model. According to the comparison of the

Table 4. Parameters Identification Results of Different Wind Speeds Based on SA-PSO Algorithm.

Wind Speed (m/s)	R_s(Ω)	L_s(H)	R_r(Ω)	L_r(H)	L_m(H)
3.5	0.439	0.232	0.683	0.275	0.295
5	0.447	0.245	0.706	0.282	0.298
6	0.458	0.253	0.735	0.287	0.300
8	0.460	0.267	0.758	0.298	0.301
9.5	0.464	0.273	0.770	0.307	0.302
12	0.467	0.278	0.793	0.312	0.303
12.5	0.468	0.313	0.806	0.319	0.305

identified electric parameter results as shown in Table **3**, compared with traditional ωPSO algorithm and CPSO algorithm, SA-PSO algorithm has higher precision and accordingly indicates that SA-PSO algorithm can conquer the problem that PSO algorithm can be easily caught in locally optional solution.

According to the simulation result comparison in Table **4**, SA-PSO algorithm can not only identify the actual value of the electric parameters under different wind speeds when DFIG suffers from external disturbance, but also analyze the variation tendency of DFIG electric parameters under different wind speeds. The electric parameters identified under different wind speeds are different from each other; compared with initial value of electric parameters, the identified electric parameters only have slight change; along with the increase of wind speed, the electric parameters are slowly increased. The reason lies in: along with the increase of wind speed, DFIG speed and generator output power are correspondingly increased, but the stator voltage is basically constant and the rotor & stator currents are increased; when DFIG speed gradually reaches to synchronous speed, the slip ratio gradually becomes smaller and accordingly causes DFIG electric parameter to be increased; meanwhile, along with the increase of wind speed, DFIG is gradually significantly influenced by temperature, frequency, magnetic saturation, stray losses and other external disturbances, thus leading to the increasing tendency of DFIG electric parameters.

CONCLUSION

In the article, 1.5MW DFIG is taken as the research object, and the disturbances brought by multiple external factors to DFIG electric parameters are removed through the establishment of generator state equation and the acquisition of actually measured data, and meanwhile .m file for DFIG electric parameter identification based on SA-PSO algorithm is compiled under MATLAB environment to realize DFIG electric parameter identification. The result shows that DFIG electric parameters identified based on SA-PSO algorithm is accurate and effective; compared with traditional PSO algorithm, SA-PSO algorithm as a mixed algorithm with strong global optimization capability has integrated the advantages, namely the strong global optimization capability of SA algorithm and the fast convergence speed of PSO algorithm, and can be used for DFIG electric parameter identification with high precision requirement.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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