Application of Improved Particle Swarm Optimization Algorithm in Parameter Identification of Pitch Wind Turbine System

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Abstract. The application of particle swarm optimization algorithm in parameter identification has a good performance, but there are still some problems such as partial localization and slow convergence. In this paper, the complex multi-parameter problem of the pitch wind turbine system is presented. The improved particle swarm optimization algorithm is used to identify the parameters and reconstruct the model. In the parameter identification, the parameter identification strategy of the descending dimension and the contraction boundary is proposed, and the accurate identification effect is obtained. In model reconstruction, adaptability is verified.

1. Introduction
The variable pitch wind turbine is a complex mechatronic system. The pitch control of the wind turbine is to make the operation of the wind turbine safer and more efficient. Accurate mathematical models allow the pitch wind turbine system to be easily controlled and easily monitored. In order to obtain a more accurate description of the mathematical model of the pitch wind turbine system, it is important to parameterize the system[1].

2. Pitch wind power system model
The mathematical model of the variable pitch wind turbine system mainly includes the wind energy conversion system, the transmission system and the control system.

2.1 Wind energy conversion system
In the wind turbine, it is difficult for the wind wheel to capture all the wind energy through the wind wheel sweep and the surface, and there is a wind energy utilization coefficient[2].

\[
C_p = C_1 \left[ \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \right] c_2 - c_3\beta - c_4 e^{-\left( \frac{1}{\lambda + 0.08\beta} \right)^{0.035}} + c_5\lambda
\]  (1)

Where, \( c_1, c_2, \ldots, c_6 \) is the parameter to be identified in the wind energy conversion system, \( \beta \) is the pitch angle and the tip speed ratio is
According to the aerodynamic Betz theory, under the action of three-dimensional wind speed, the wind energy captured by the wind wheel sweeping surface is

$$ P_r = \frac{1}{2} \rho \pi R^2 v^3 C_p(\beta, \lambda) $$

Where $\rho$ is the air density, $R$ is the wind turbine radius, $v$ is the wind turbine wind speed, and $\omega$ is the wind turbine speed.

### 2.2 Transmission system

The mechanical torque generated by the wind turbine impeller is $T_r = \frac{P_r}{\omega}$. It and secondary drive shaft $T_m$ and total brake torque $T_b$ are

$$ T_r - kT_m - T_b = J_r \omega $$

Among them, $k$ is the gear ratio, $J_r$ is the moment of inertia of the wind wheel, and $b_1, b_2, b_3$ are the parameters to be identified in the transmission system.

$$ T_b = b_1 + b_2 \omega + b_3 / \omega $$

The characteristics of the speed increasing gearbox are

$$ \omega_g = k \omega $$

The characteristics of the generator module are

$$ J_g \omega_g = T_m - T_r $$

Among them, the generator moment of inertia is $J_g$, the generator mechanical speed is $\omega_g$, and the generator torque is $T_r$. If the drive shaft is rigid, then the total equivalent moment of inertia of the drive system is

$$ J = J_r + k^2 J_g $$

### 2.3 Control System

The wind turbine hydraulic pitch system of this paper adopts the valve control cylinder system. The system is mainly composed of hydraulic pump, electric motor, overflow valve, proportional valve, hydraulic motor, hydraulic cylinder, crank linkage, fuel tank, etc. Among them, the length of the connecting rod is $l_0$, the length of the crank is $r_0$, the displacement of the piston of the hydraulic cylinder is $y_a$, and the displacement of the slider is $s$. 
The proportional electromagnet transfer function and the pilot-stage force balance equation are

\[ i = k_i x \]  \hspace{1cm} (9)

\[ q_1 = k_i x - k_j p \]  \hspace{1cm} (10)

In the formula, \( i \) is the proportional electromagnet input current, \( k_i \) is the current displacement amplification factor, \( x \) is the electro-hydraulic proportional directional valve displacement, \( q_1 \) is the electro-hydraulic proportional valve flow, \( k_j \) is the flow amplification factor, and \( p \) is the load differential pressure. The formula for the flow continuity in the hydraulic cylinder chamber is

\[ q_1 = a \frac{d y_a}{dt} + \frac{v_a}{4 \beta_e} \frac{dp}{dt} + c_a p \]  \hspace{1cm} (11)

Laplace transform

\[ q_1 = a y_a s + \frac{v_a}{4 \beta_e} p s + c_a p \]  \hspace{1cm} (12)

In the formula, \( a \) is the piston area of the hydraulic cylinder, \( y_a \) is the piston displacement of the hydraulic cylinder, \( v_a \) is the total volume of the hydraulic cylinder, \( \beta_e \) is the equivalent volume elastic modulus, and \( c_a \) is the total leakage coefficient.

In the case of ignoring the resistance loss, regardless of the viscous damping coefficient of the elastic load, piston and load motion, the equilibrium equation of the hydraulic cylinder subjected to the Laplace transformation is

\[ a p = M y_a s^2 \hspace{1cm} a p = M y_a s^2 \]  \hspace{1cm} (13)

Where \( M \) is the total mass of the piston and load projected on the piston. Then, the hydraulic pitch mechanism closed-loop transfer function is available.

\[ G(s) = \frac{k_d}{s^2 + \frac{2 \xi h}{\omega_h} s + \frac{1}{\omega_h}} + k_d k_s \]  \hspace{1cm} (14)

In the formula, $k_d$ is the electro-hydraulic proportional amplification factor, $\omega_h$ is the hydraulic natural frequency, and $\xi_h$ is the hydraulic mechanism damping ratio.

The natural frequency of the pitch system is much larger than the natural frequency of the fan, so the pitch hydraulic system can be approximated as a first-order process.

$$ G(s) = \frac{k_d}{s + k_d + k_s} $$

(15)

$$ y = r_0(1 - \cos \beta) + l_0 \left(1 - \sqrt{1 - \left(\frac{r_0}{l_0} \sin \beta\right)^2}\right) $$

(16)

In the formula, $k_s$ is the hydraulic cylinder displacement sensor amplification factor. It can be seen from this formula that the system has strong nonlinear characteristics, and it is difficult to design the controller directly. So we linearize the feedback on the input and output.

$$ \begin{cases} x = f(x) + g(x)u_x \\ y = h(x) \end{cases} $$

(17)

The design idea is to obtain the expression containing the input variable $b$ by repeatedly deriving the output variable $a$, and then designing the input variable to make the nonlinear term in the expression cancel[3]. First, we derive the output.

$$ u_x = \frac{w - L^2}{L_x L_y} h(x) $$

(18)

Where $w$ is an auxiliary item of the control law. So in formula (17), we can set

$$ x = \begin{bmatrix} \omega \\ \beta \end{bmatrix}, \quad u_x = \beta_v, \quad f(x) = \begin{bmatrix} \frac{\rho\pi R^2 V^2 C_p(\beta, \lambda)}{2JL} - kT_v \\ \frac{\lambda x}{t_\beta} \end{bmatrix}, \quad g(x) = \begin{bmatrix} 0 \\ \frac{1}{t_\beta} \end{bmatrix}, \quad h(x) = \Delta \omega $$

Where $\Delta \omega$ is the difference between the nominal value of the angular velocity $\omega$ of the rotor and the actual value, $\beta_v$ is the pitch angle reference input, and $t_\beta$ is the time constant.

3. Parameter identification based on Improved Particle Swarm Optimization (IPSO)

In the particle swarm algorithm (PSO), the position of the $i$-th particle in the target search space of the D-dimensional is expressed as

$$ X_i = (x_{i1}, x_{i2}, \cdots, x_{iD})^T $$

(19)

The flight speed of the $i$-th particle is

$$ V_i = (v_{i1}, v_{i2}, \cdots, v_{iD})^T $$

(20)

The algorithm searches the optimal position of the individual and the whole particle swarm to find the individual extremum and the global extremum[4]. Then update its speed and position according to equations (21) and (22).
\[ v_{id}^{k+1} = wv_{id}^k + c_1r_1(p_{id}^k - x_{id}^k) + c_2r_2(p_{id}^k - x_{id}^k) \] (21)

\[ x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \] (22)

The algorithm has high searching ability in space, but when the dimension is high and the boundary is uncertain, the particle swarm optimization is easy to fall into local optimum[5,6]. In view of the characteristics of multi-parameters and multi-system modules of variable-pitch wind turbine system, the search strategy in this paper will adopt modularization to reduce the search dimension, and compress the search space according to the least square method.

When the least square method is used to compress the search space, the mean square error of the estimated output and the measured output is taken as the objective function. The solution \( \hat{\theta} \) of the objective function at the minimum value is the least square estimation of the parameters to be identified. Then, according to the least square estimation, the dimension boundary of particle swarm optimization is set as \( \hat{\theta}(1 \pm K) \). Compared with the particle swarm algorithm, the following parameter identification results are obtained.

Table 1. Parameter identification results.

| Parameter | Original Model | PSO | IPSO |
|-----------|----------------|-----|------|
| \( c_1 \) | 0.518          | 1.22 | 0.567 |
| \( c_2 \) | 116            | 5585.33 | 104.87 |
| \( c_3 \) | 0.400          | 45.20 | 0.363 |
| \( c_4 \) | 5.00           | 245.74 | 4.50 |
| \( c_5 \) | 21.0           | 65.13 | 20.96 |
| \( c_6 \) | 0.00680        | 0.0354 | 0.00691 |
| \( b_1 \) | 1000           | 443.90 | 1005.41 |
| \( b_2 \) | 100            | 237.82 | 99.02 |
| \( b_3 \) | 1000           | 1560.95 | 993.16 |
| \( k_s \) | 0.400          | 398.53 | 0.403 |
| \( k_d \) | 10.00          | 2728.48 | 10.01 |

4. Error evaluation

After reconstructing the model according to the result of parameter identification, the coincidence degree of each module is compared with the average absolute error of output in the verification environment as a reference index to verify the accuracy of the identification strategy.

\[ e = \frac{1}{n} \sum_{i=1}^{n} \frac{|u_i - \hat{u}_i|}{u_i} \times 100\% \] (23)

Table 2. Average absolute error of each output.

| Output                  | Average absolute error |
|-------------------------|------------------------|
| Power                   | 9.99e-6                |
| Brake Torque            | 1.80e-5                |
| Piston displacement     | 3.29e-4                |
5. Simulation analysis

In the simulation process, the wind speed changes and the output comparisons are shown in the following figures.

Figure 2. Original wind speed curve.

Figure 3. New wind speed curve.

Figure 4. Output power comparison.
Figure 5. Braking torque comparison.

Figure 6. Displacement comparison of piston.

6. Conclusion
In this paper, the parameter identification of the pitch wind turbine system is carried out by the improved particle swarm optimization algorithm. This method can better fit the parameter settings of the original model. The model was reconstructed based on the parameter identification results. The reconstructed model has a strong external environment adaptability. This proves that the parameter identification strategy based on the improved particle swarm optimization algorithm has a good identification effect.

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