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Synchronous condenser excitation system parameter identification based on improved artificial bee colony algorithm

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Abstract. The quality of excitation control of the synchronous condenser directly determines the reactive power regulation ability and control support performance of the power grid.Aiming at parameter identification of non-linear links such as limit and saturation in the synchronous condenser excitation system, a parameter identification method of the synchronous condenser excitation system based on improved artificial bee colony algorithm is proposed.Firstly, the order of the phase modulation operation is deduced, and the mathematical model of the synchronous condenser excitation system is established based on it.Then the artificial bee colony algorithm is improved and applied to the parameter identification of the synchronous condenser excitation system. A parameter identification strategy based on sensitivity analysis is proposed for the unstable and multi-solution situation of multi-parameter identification results. Analysis of parameter sensitivity and identification based on parameter sensitivity. Finally, the identification parameters and the overall identification results obtained after sensitivity analysis are compared and analyzed. The results show that the proposed method can effectively identify the parameters of the non-linear link and has strong robustness. It can provide accurate models and parameters for power system stability analysis.

1. Introduction

With the extensive application of UHVDC transmission, especially the voltage stability problem.It is mainly manifested in the insufficient dynamic reactive power support during the fault period, which objectively requires large-scale DC active power transmission and must match large-scale dynamic reactive power[1]. At present, synchronous condenser, static var compensator (SVC) and static synchronous compensator (SVG/STATCOM) are mainly used in large-scale reactive power compensation devices in power system[2,3].To study the influence of the access of the synchronous condenser on the stability of the power system, it is necessary to have a suitable synchronous condenser excitation system model and accurate parameters .Therefore, it is of great theoretical and practical value to study an effective method for identifying model parameters of the synchronous condenser excitation system.

The synchronous condenser is essentially a synchronous motor with excitation control and no mechanical load. All its electrical performance is controlled by excitation system.The excitation

control parameters of the synchronous condenser directly determine the reactive power regulation and control support performance of the synchronous condenser[4,5].Literature[6] By systematically analyzing the influence of various electrical parameters on the transient and sub-transient characteristics of the synchronous condenser, the key technical parameters and measures for optimizing the dynamic performance of the synchronous condenser are extracted.In reference [7], the model and parameters of the field excitation system are introduced into the stability calculation of power grid, which improves the authenticity and precision of the simulation research.At present, there are some studies on the electrical parameters of the phase modulator, but there are relatively few studies on the parameter identification of the synchronous condenser excitation system.With the development of identification technology, great progress has been made in the model and parameter identification of generator excitation system. These identification methods can be used as reference for parameter identification of synchronous condenser excitation system.Literature [8,9] identifies the non-linear link of generator excitation system using genetic algorithm, which proves the feasibility of using artificial intelligence algorithm to identify excitation system parameters.In reference [10], adaptive particle swarm optimization (APSO) is applied to identify the parameters of excitation system, which improves the convergence rate.These artificial intelligence algorithms have some advantages in solving complex non-linear parameter identification, but there are still some problems, such as slow convergence speed, easy to fall into local optimum, unstable identification results and so on.

In view of the above problems, this paper combines the mathematical model of generator excitation system. Firstly, according to the operation mode, derivation of transfer function order in phase modulation operation. On the basis of constructing the mathematical model of the synchronous condenser excitation system, an improved artificial bee colony algorithm is proposed to identify the parameters of the non-linear link of the model.Then, by analyzing the trajectory sensitivity of each parameter under disturbance, a parameter identification strategy based on sensitivity analysis is proposed.Finally, simulation experiments are used to verify the effectiveness and accuracy of the proposed method.

2. Construction the model of the synchronous condenser excitation system

Although the excitation mode of the synchronous condenser is the same as that of the generator, the structure and electrical characteristics of the synchronous condenser and the generator are different.This paper refers to Professor Liu X,L's linearized model based on the fifth-order description of synchronous generators, taking into account the effect of damper winding[11].As shown in Figure 1.
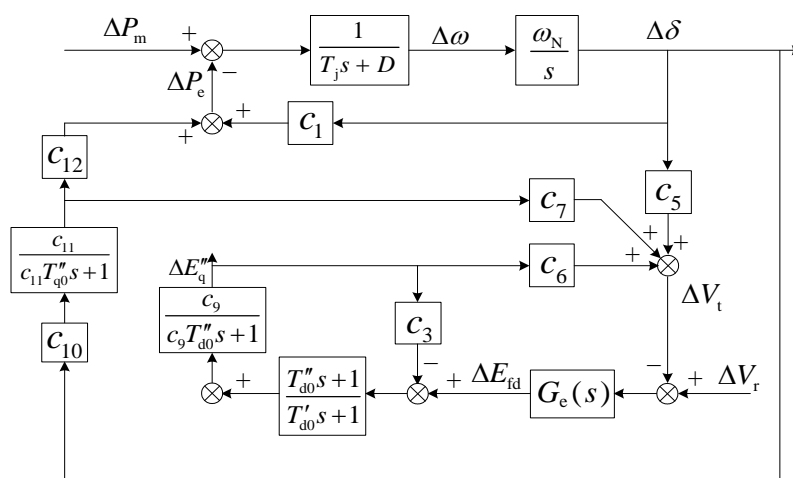

Figure 1. Linearized C1~C12 model for single machine infinite system.

Because there is no no idle running state of the synchronous condenser, the active angle and internal power angle are equal to zero. According to this condition, the above model is simplified, and the simplified model diagram of the synchronous condenser is obtained as shown in Figure 2.
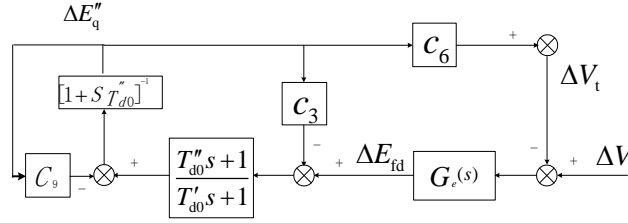

Figure 2. Simplified synchronous condenser phased operation model block diagram.

In order to obtain the relationship between the terminal voltage and the excitation potential and determine the order of the phase modulation operation of the phase modulator, the following deductions are made:

$$\frac{\Delta V_t}{\Delta E_f} = \frac{c_9(1+T_{d0}^{"}S)*c_6}{(1+T_{d0}^{'}S)(1+c_9 T_{d0}^{"}S)+c_3 c_9(1+T_{d0}^{"}S)} \tag{1}$$

To simplify the formula:

$$\frac{\Delta V_t}{\Delta E_f} = \frac{\dfrac{c_9 c_6}{1+c_3 c_9}}{1+\dfrac{T_{d0}^{'}S}{1+c_3 c_9}} \tag{2}$$

Order

$$k1 = \frac{c_9 c_6}{1+c_3 c_9} \; ; k2 = \frac{1}{1+c_3 c_9} \tag{3}$$

$$\frac{\Delta V_t}{\Delta E_f} = \frac{k1}{1+k2*T_{d0}^{'}S} \tag{4}$$

According to the above deduction, the first-order function of the phase modulation operation of the phase modulator can be obtained. Based on this, the transfer function block diagram of the excitation system of the phase modulator can be established in MATLAB as shown in Figure 3.
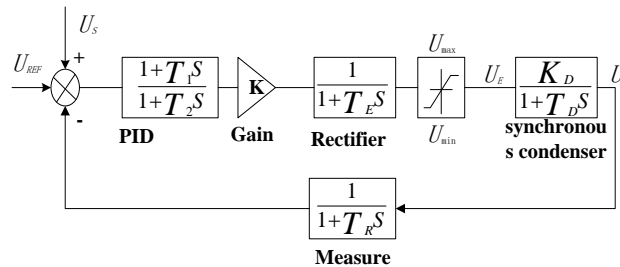

Figure 3. Transfer function block diagram of synchronous condenser excitation system.

In Fig 3, U_{Ref} is the input disturbance, U_E is the excitation terminal voltage and U_T is the phase modulator terminal voltage. In general, the design values are used for the parameters in the model. The parameters that need to be calculated or identified are PID link time constants T_1 and T_2, gain K of integrated amplification link, excitation time constant T_E, and phase modulator parameters K_D and T_D.

3. Parameter identification of synchronous condenser excitation system based on IABC

3.1. Improved artificial bee colony algorithm
The artificial bee colony algorithm(ABC)has a strong advantage in dealing with multi-parameter optimization process [13].In order to speed up the convergence speed of the algorithm and reduce the probability of the algorithm jumping out of the local extremum, the search neighborhood of the new honey source is improved in the algorithm, and an intermediate factor is added. If the adaptation of the previous generation is worth updating, it shows that the search direction tends to be correct, then the search direction is continued; on the contrary, the search direction tends to be opposite.The specific operation is shown in the formulas (5, 6).
When the honey source of the previous generation is updated, let n=1, otherwise n=0; m record the positive and negative sign of the previous generation φ_b .

$$z_{i,j} = x_{i,j} + \varphi_a(x_{best,j} - x_{i,j}) + \varphi_b \, | \, (x_{c1,j} - x_{i,j}) \, | \tag{5}$$

$$\varphi_b = \begin{cases} m*rand(0,1) & ,n=1 \\ -m*rand(0,1) & ,n=0 \end{cases} \tag{6}$$

In the formula, $z_{i,j}$ is the renewal solution; $x_{i,j}$, $x_{c1,j}$ is the random solution corresponding to two different food sources; $x_{best,j}$ records the current optimal solution of individuals in the population; φ_a , φ_b is the random number between [-1,1].
The improved ABC algorithm introduces a random perturbation component into the search formula (5), which can randomly change the search area and jump out of the local optimum.Then, the intermediate factor is added to the formula(6). By comparing with the previous generation honey source, the algorithm consciously develops the region rich in honey source and speeds up the convergence speed of the algorithm.

3.2. Parameter identification strategy based on sensitivity analysis
As a complex rotating element, the synchronous condenser belongs to a high-order system in parameter identification.The sensitivity of different parameters under the same disturbance must be different, and different identification order will lead to different identification results[15].Therefore, this paper considers classifying the parameters according to the sensitivity level, fixing the parameters with small sensitivity as the design value, focusing on identifying the parameters with high sensitivity. For the overall transfer function of the synchronous condenser model, the sensitivity of the parameters of the transfer function is defined as:

$$H(\theta, s) = \lim_{\theta \to 0} \frac{\Phi(\theta + \Delta\theta, s) - \Phi(\theta, s)}{\Delta\theta} \tag{7}$$

In the formula, Φ is the transfer function of the system and $\Delta\theta$ is the variation of the parameters.
The trajectory sensitivity (relative value) formula of sensitivity parameter θ_j of power system is as follows:

$$\frac{\partial[y(\theta,k)/y_0]}{\partial[\theta_j/\theta_{j0}]} = \frac{[y_1(\theta_1,...,\theta_j + \Delta\theta_j,...,\theta_m,k)}{2\Delta\theta_j/\theta_{j0}} - \frac{y_2(\theta_1,...,\theta_j - \Delta\theta_j,...,\theta_m,k)]/y_0}{2\Delta\theta_j/\theta_{j0}} \tag{8}$$

In the formula, θ_{j0} is the given value of the parameter θ_j and y_0 is the corresponding steady-state value θ_{j0} .

4. Analysis of simulation examples
The synchronous condenser excitation system as shown in Fig. 4 is built in Matlab, and the theoretical values of the parameters to be identified are set according to the range of parameters provided by the

manufacturer.theoretical value:K=200, T1=1, T2=4, TE=0.01, KD=0.29, TD=3.58, Upper and lower limit of limit link:UAMAX=6, UAMIN=-2.

The synchronous condenser excitation system include linear and non-linear parameters. When the excitation system is in a small disturbance (generally less than 5%), the system is in a linear stage. The model can be identified directly.However, when the disturbance is large (generally more than 20%), the output voltage will be limited to a certain extent (in a non-linear state), as shown in Figure 4, the limiting link will play a role in this state.
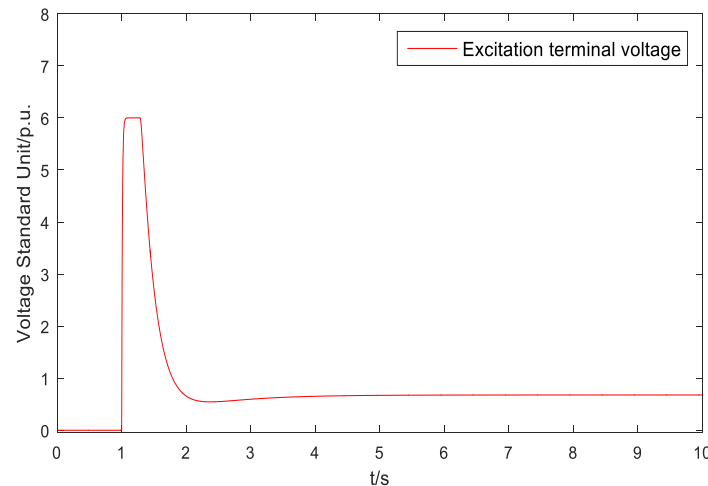

Figure 4. Exciter voltage output map.

Firstly, a 5% step disturbance signal is applied to the signal synthesis port 1s to identify the parameters of the linear link.Then,the identified parameters K, T_1, T_2 and T_E of the linear link are taken as known.The input of the system is a large step disturbance with a unitary value of ± 0.2. The output of the synchronous condenser is the output of the system. Identify U_{AMAX} and U_{AMIN}.

In order to verify the superiority of the improved bee colony algorithm in parameter identification, the improved artificial bee colony algorithm and other intelligent algorithms ((GA), (PSO), (DE), (ABC) are used to identify the parameters as a whole.The search interval of each parameter is within the range of [-20%, +20%].The parameters of the algorithm are as follows: population size Np = 80, population dimension N = 6, maximum iteration number GM = 50.The simulation output is shown in Figure 5., the identification results of each algorithm are shown in Table 1, and the convergence curve is shown in Figure 6.
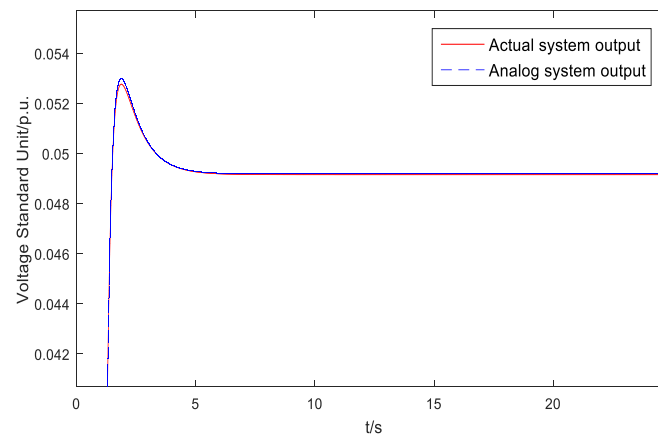

Figure 5. Synchronous condenser output voltage curve.

Figure 5. shows that the identification curve of the improved ABC algorithm fits well with the theoretical output curve. In order to better compare the algorithms, the average error of the identification results of each algorithm is analyzed as shown in Table 1.

Table 1. Overall identification results under different algorithms.

Parameter	Mean deviation	K	T_1	T_2	T_E	K_D	T_D	U_{AMAX}	U_{AMIN}
Design value		200	1	4	0.01	0.29	3.58	6.0	-2.0
GA	9.47%	189.95	0.901	4.183	0.0083	0.317	3.181	5.980	-2.013
PSO	9.41%	189.44	1.093	3.882	0.0115	0.302	4.222	6.010	-1.991
DE	9.39%	189.25	1.090	3.890	0.012	0.311	4.022	6.012	-2.002
ABC	9.16%	190.74	1.195	4.070	0.012	0.278	3.761	6.005	-1.995
IABC	8.22%	211.19	1.030	4.481	0.012	0.289	3.278	6.003	-1.994

By comparing the average deviation of the identification results (the average of the total relative errors between the parameter identification value and the design value), it can be seen that the average error of the improved ABC algorithm is smaller than that of other algorithms, and the identification accuracy is relatively high.
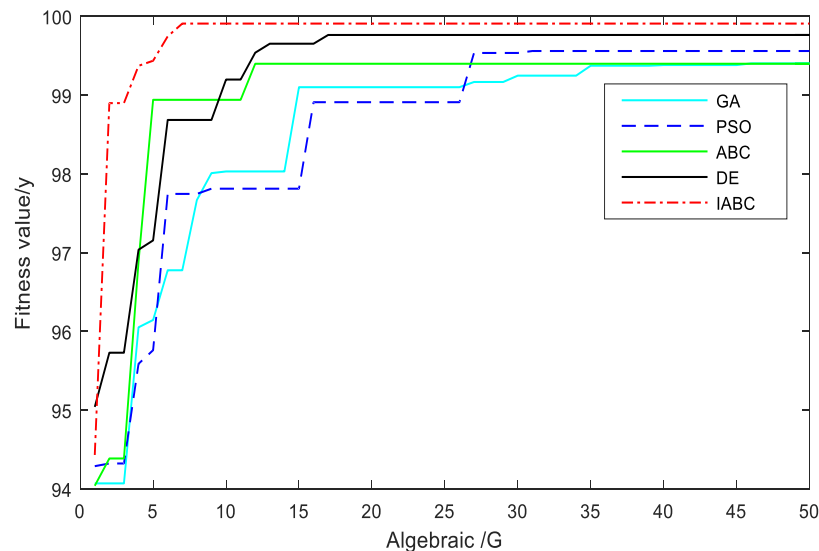

Figure 6. Convergence characteristic curve of algorithms.

From the figure 6, it is more intuitive to see that GA and PSO algorithms are easy to fall into local optimum, and the convergence speed is slow, and the effect of dealing with multi-dimensional complex parameter identification problem is poor.The global search ability of DE and ABC algorithm is strong, but there are also premature problems, which need further improvement.Compared with ABC algorithm, the improved ABC algorithm has better convergence characteristics, can jump out of local optimum faster, and has obvious advantages in multi-parameter identification.

Although there is little difference between the identified trajectory curve and the theoretical value, it can be found that the relative errors of each parameter are quite different, and some of them even exceed the allowable range of errors by analyzing the relative errors of each parameter.At the same

time, it is found that the results of multi-parameter global identification are not very different, but the identification results are unstable. It can be seen that the identification results of the whole system are unstable and the errors of individual parameters are large.For this reason, an isolation identification strategy based on sensitivity analysis is proposed to identify the model parameters.

The trajectory sensitivity of the synchronous condenser parameters is calculated.Then calculate the trajectory sensitivity of each parameter. The result is shown in the figure 7.
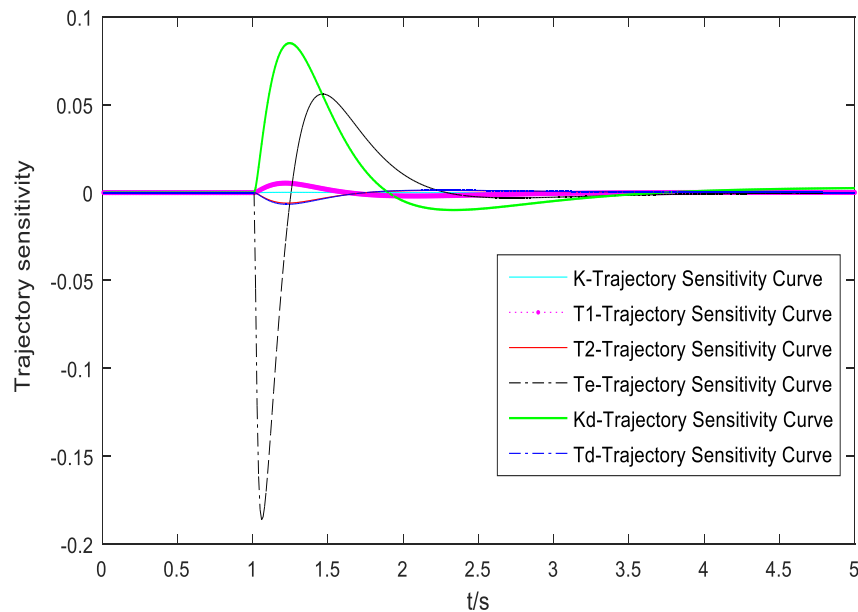

Figure 7. Parameters trajectory sensitivity curve.

Table 2. Average sensitivity of each parameter.

Parameter	K	T_1	T_2	T_E	K_D	T_D
Average sensitivity	0.0656	0.0301	0.0435	0.0054	0.0656	0.0421

It can be seen from the table that the sensitivity of parameters K and K_D is equal, while that of T_2 and T_D is close.Therefore, there may be some implicit function relationship between the two sets of parameters,which can be identified separately.The sensitivity of T_E is small, indicating that it is insensitive and can be used as a steady-state parameter.According to the structure of the model, the parameters K_D and T_D which are close to the measuring point are selected for identification.Then the values of parameters K_D and T_D are taken as known parameters. Identificate the parameters of K、 T_1 and T_2 .Finally, the results of sensitivity analysis are shown in Table 4. Its objective function value is 99.989.

Table 3. Identification based on sensitivity analysis.

Parameter	K	T_1	T_2	T_E	K_D	T_D
Design value	200	1	4	0.01	0.29	3.58
Identification value	199.39	0.974	3.914	0.001	0.289	3.561
Relative error	0.31%	0.26%	2.15%	0	0.34%	5.30%

The traditional global identification results are as follows: Table 4, It is compared with the results identified by sensitivity analysis as shown in Table 4 below.

Table 4. Comparison of different identification strategies.

Identification strategy	Mean deviation	K	T_1	T_2	T_E	K_D	T_D
Global Identification results	8.22%	211.19	1.030	4.481	0.012	0.0289	3.278
Distribution identification results	1.39%	199.39	0.974	3.914	0.001	0.289	3.561

From the comparison of the above simulation identification results, it can be found that there is a big gap between the overall identification results and the identification results based on sensitivity analysis. From the point of view of the objective function, after sensitivity analysis, its accuracy is higher, and its results are more in line with the requirements of the operation state.

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