Parameters Tuning of Photovoltaic Power Generation System with Static Synchronous Compensator Based on Chaos Orthogonal Particle Swarm Optimization

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Abstract. China is a country rich in solar energy resources, with good natural conditions for the utilization of solar energy. At present, the main application mode of photovoltaic power generation system is grid-connected photovoltaic power generation. In order to maintain the voltage stability of the common connection point (PCC), STATCOM is mainly added to the PCC of photovoltaic power station. It can be regarded that the photovoltaic system and STATCOM constitute a whole and are integrated into the grid, and the unified coordination and optimization of the overall control system becomes particularly important. In this paper, the parameter tuning strategy of PI controller for photovoltaic grid-connected system with STATCOM is studied. Taking the optimal overall performance of DC capacitor voltage and PCC point voltage of photovoltaic inverters as the optimization objective, chaotic orthogonal particle swarm optimization algorithm is used to optimize the parameters of PI controller of the system, and simulation is carried out under the condition of voltage variation to verify the effectiveness of the optimization strategy.

1. Introduction
As we all know, in the pursuit of low-carbon life today, photovoltaic power generation capacity accounts for a higher and higher proportion of total power generation. In order to reduce the negative impact of new energy power generation on the power grid, it is urgent to carry out the research on the control strategy of its integration into the large power grid. In order to meet the security, reliability and economic operation objectives of power system, STATCOM is widely used in grid-connected operation control of new energy generation system for its advantages of continuous regulation, small harmonic, low loss, wide operation range and fast regulation speed [1-4]. STATCOM is mainly added to the common connection point (PCC) of photovoltaic power plant to maintain the voltage stability of PCC. From the network side, it can be seen as a whole connected to the grid with STATCOM, and the unified coordination and optimization of the overall control system becomes particularly important. Generally, multiple PI controllers are used to participate in the overall control.

The PI parameter setting of photovoltaic power generation system has a great influence on the overall performance of the system. The research results at home and abroad show that it is effective to apply
various intelligent optimization algorithms to the PI controller parameter setting of photovoltaic power generation system [5-8]. The basic intelligent optimization algorithms applied to the new energy power generation system mainly include fuzzy algorithm, artificial neural network algorithm, genetic algorithm, particle swarm optimization algorithm, etc. Fuzzy algorithm is an intelligent control method that imitates human fuzzy reasoning and decision-making process in behavior. It needs to accumulate more fuzzy rules compiled by operators or experts. Artificial neural network algorithm is a kind of information processing method which is based on imitating the structure and function of human brain. However, the advantages and disadvantages of the optimization results are highly correlated with the learning and training situation of the initial samples, and more training samples are needed. Genetic algorithm is an intelligent algorithm developed by simulating the evolutionary process of a population, and the optimal solution is screened by global probability. However, crossover and mutation algorithms often make individual values worse when they complete reproductive operations. As one of the swarm intelligence algorithms, particle swarm optimization (PSO) has the advantages of being easy to implement without many parameter adjustments and can be successfully applied to many practical problems. But occasionally we get caught up in local optimization. In this paper, PSO algorithm is adopted as the basic algorithm, and the corresponding improvement is made to effectively improve its optimization ability.

This paper proposes a parameter setting strategy of PI controller in photovoltaic power generation system with STATCOM. The overall performance optimization including photovoltaic inverter DC capacitance voltage and PCC voltage was determined as the optimization objective function. The parameters of 8 PI controllers are adjusted by using chaotic orthogonal particle swarm optimization. The simulation model of the photovoltaic power generation system with STATCOM is established, and the simulation is carried out under the condition of voltage variation to verify the effectiveness of the optimized tuning strategy.

2. Optimization of parameters of multiple PI controller in PV power generation system

After the photovoltaic power supply is connected to the grid, the photovoltaic inverter usually operates with unit power factor and outputs active power, but does not force it to participate in voltage regulation. In order to suppress the voltage fluctuation of the bus at PCC and adjust the reactive power output of the photovoltaic power generation system, parallel STATCOM at the PCC plays a positive role in supporting the voltage level of the power grid. Its structure block diagram is shown in figure 1.

Figure 1. Photovoltaic power generation system with STATCOM.

2.1. The objective function

The control strategy of photovoltaic power generation system with STATCOM takes the DC side voltage of grid-connected inverters ($U_{PVDc}$) and the voltage of PCC ($U_{PV.PCC}$) as active and reactive power performance indicators respectively. At the same time, eight PI controller parameters are tuned, including DC voltage and current PI controller parameters ($K_{p1}$, $K_{i1}$, $K_{p2}$, $K_{i2}$) and STATCOM voltage and current PI controller parameters of grid-connected inverters ($K_{p3}$, $K_{i3}$, $K_{p4}$, $K_{i4}$). In order to ensure that each performance index is optimal at the same time and improve the overall performance of the system, the objective function is designed as follows:

$$J^* = r_j J_{U_{PVDc}.ITAE} + J_{U_{PV.PCC}.ITAE}$$

(1)
Where, $J'$ represents the adaptive value function of the overall performance index of the photovoltaic power generation system; $J_{U_{PVdc,\text{ITAE}}}$ is the integral of time multiplied by the absolute error of DC side voltage of grid-connected inverters, which can be obtained by equation (2); $J_{U_{PVPCC,\text{ITAE}}}$ is the integral of time multiplied by the absolute error of PCC voltage, which can be obtained by equation (3). $r_1$ is the weight coefficient between active and reactive power performance, which can be obtained by equation (4).

$$J_{U_{PVdc,\text{ITAE}}} = \int_0^T t |U_{PVdc}^* - U_{PVdc}| \, dt$$  \hspace{1cm} (2)$$

$$J_{U_{PVPCC,\text{ITAE}}} = \int_0^T t |U_{PVPCC}^* - U_{PVPCC}| \, dt$$  \hspace{1cm} (3)$$

$$r_1 = \frac{\sum_{U_{PVdc}} \sum_{q=1}^2 k_{U_{PVdc}}}{\sum_{U_{PVPCC}} \sum_{q=1}^2 k_{U_{PVPCC}}}$$  \hspace{1cm} (4)$$

Where, $k_{U_{PVdc}}$ and $k_{U_{PVPCC}}$ represent the average values of two performance indicators corresponding to different levels of each factor in orthogonal test, respectively; T is the time of dynamic response regulation; all superscript * values are reference values.

2.2. Parameter Optimization of Chaos Orthogonal Particle Swarm Optimization

The PSO algorithm is an intelligent algorithm that is inspired from the foraging behaviour of animal populations and used to solve planning problems. In the PSO algorithm, the relative merits of the particle is judged by the fitness value and its best position is recorded. At the same time, the best position of the whole group is recorded, as is shown in equation (5).

$$\begin{align*}
    v_{id} &= \omega v_{id} + c_1 p_1 (p_{id} - x_{id}) + c_2 p_2 (p_{id} - x_{id}) \\
    x_{id} &= x_{id} + p_{id}
\end{align*}$$  \hspace{1cm} (5)$$

Where, the velocity of a particle is $V=(v_{1id}, v_{2id}, ..., v_{Did})$, and its position is $X=(x_{1id}, x_{2id}, ..., x_{Did})$. In accordance with the size of the fitness of particles to judge the merits of particles, the local optimal solution is $P_{local}=(P_{1id}, P_{2id}, ..., P_{Did})$, and the global optimal solution is $P_{global}=(P_{1id}, P_{2id}, ..., P_{Did})$. $\omega$ is the inertial weight of the original velocity, $c_1$ and $c_2$ are used to balance the global and local optimization capability, which is usually set to 2. $p_1$ and $p_2$ are the random Numbers bounded by [0,1]. $p$ is called the constraint factor, which is usually set to 1.

In order to overcome the shortcomings of standard particle swarm optimization algorithm, such as premature convergence, low iteration efficiency and easy to fall into local optimal solution, a new parameter optimization method based on chaotic orthogonal particle swarm optimization is proposed to hierarchically optimize the controller parameters of STATCOM and PV. This method combines the chaos algorithm and orthogonal optimal swing optimization algorithm. That is to say, the optimal range of 8 controller parameters of PV and STATCOM and the weighting factors of each performance index are found by using orthogonal optimization method and orthogonal optimal trend method. And then, combined with the randomness of chaotic motion, a large number of groups are generated to improve the quality of the initial value. Lastly, PSO algorithm is used for iterative optimization. This optimization algorithm can reasonably determine the optimal range and optimization direction of each parameter, as well as the corresponding weight of each performance index. It can also improve the quality of the initial value and effectively reduce the number of iterations.
3. Simulation results

In order to verify the feasibility of the control algorithm in this paper under ideal power grid conditions, the operation simulation experiment of small capacity units is carried out. Take the photovoltaic power plant in a certain region as an example, and the common connection point is connected with STATCOM through the connected reactor. (The specific structure is shown in Figure 1).

The operating condition is set under a fixed working condition, under which the illumination intensity and temperature of the photovoltaic power generation system remain unchanged and the grid voltage is suddenly changed. The total simulation time is set to 1.5s, and a disturbance is given to the system at 1.15s, which reduces the system voltage to 0.8pu. The fault duration is 0.1s, and the fault is removed at 1.25s. At this time, both active power output of PV and PCC point voltage are affected. For photovoltaic power generation system with STATCOM, the parameters of 8 PI controllers in the system are optimized by using chaotic orthogonal particle swarm optimization algorithm. It is verified that the tuned controller not only has stable active power output capability, but also improves the reactive power support capability of STATCOM to power grid when the PCC point voltage is lower than the lower limit of normal fluctuation.

Orthogonal experiments were performed on $U_{PVdc}$ and $U_{PVPCC}$ by using equation (4) to obtain the weight factor $r_1=29.176$. Equation (6) and (7) are the optimal ranges of controller parameters for particle swarm optimization.

$$U_p = [60,700,10,20,5,3,60,0.8,2600,0.9,250]$$  \hspace{1cm} (6)

$$L_p = [0,500,0,0,0,500,0.1,0]$$  \hspace{1cm} (7)

Where $U_p$ is the upper limit and $L_p$ is the lower limit.

Equation (8) is the final result of the controller parameters obtained by equation (1).

$$[K_{p1},K_{i1},K_{p2},K_{i2},K_{p3},K_{i3},K_{p4},K_{i4}] = [4.39,700.00,0.42,15.42,0.81,1229.80,0.12,308.52]$$  \hspace{1cm} (8)

In figure 2-5, for the photovoltaic power plant with STATCOM, DC capacitor voltage of photovoltaic inverter, active power of PV, reactive power output of STATCOM and the voltage of PCC are compared in the two different algorithms, which are the chaotic orthogonal particle swarm optimization and the ordinary PSO algorithm.

![Figure 2. Active power comparison of the two methods.]

![Figure 3. DC bus voltage comparison of the two methods.]

![Figure 4. Comparison of reactive power of the STATCOM.]

![Figure 5. Voltage at PCC comparison of two methods.]
As can be seen from figure 2 and figure 3, compared with the standard particle swarm optimization algorithm, the overshoot of photovoltaic DC capacitance voltage and active power output is smaller and the adjustment speed is faster after parameters are set by this algorithm. The active power can be adjusted quickly and smoothly, and the system shows better active power performance after optimization. It can be seen from figure 4 and figure 5 that the voltage fluctuation range of PCC optimized is smaller by this new algorithm. And the stable value can be recovered faster, which reflects the better reactive power performance of the optimized system.

4. Conclusion
In this paper, the parameter tuning strategy of PI controller for photovoltaic grid-connected system with STATCOM is studied. Taking the optimal overall performance of DC capacitor voltage and PCC point voltage of photovoltaic inverters as the optimization objective, chaotic orthogonal particle swarm optimization algorithm is used to optimize the parameters of PI controller of the system, and simulation is carried out under the condition of voltage variation. The simulation results are compared with the results by using standard particle swarm optimization. It is found that the tracking performance by using the proposed optimization strategy is better, and the overall performance index of the system is improved. The active and reactive power performance of the photovoltaic power generation system with STATCOM can be improved comprehensively.

Acknowledgements
This work was supported in part by the project “Research and application on key technologies of multi-layer intelligent operation control for large-scale renewable energy plant” of State Grid Corporation of China (NY71-16-040).

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