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Particle Swarm Algorithm Based Economic Scheduling Strategy for Pumped Storage Wind Farms

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Abstract: With the goal of maximizing the benefits of Contained Storage wind farm, a particle swarm algorithm based simulation analysis is proposed for the optimized operation of Contained Storage wind farm . The simulation results show that the optimized operation and power supply of Contained Storage Wind Farm not only improves the benefit of the wind farm, but also smoothes the power output of the wind farm, which will be helpful to increase the share of wind power in the power system.

Keywords: particle swarm algorithm , pumped storage, wind farm, economic dispatching

1. Introduction

In order to improve the power supply quality of wind farms and increase the benefits of power generation, the use of energy storage technology for wind farms to configure an energy storage system is one of the more important measures to solve the problem. Wind power storage technology has pumped storage, compressed air storage, superconducting magnetic storage, fluid battery pack, electrolysis of water to produce hydrogen, etc., of which pumped storage is a more mature technology of a kind of energy storage, and small-scale hydroelectric power generation system investment is not big, so for the use of wind farms containing pumped storage power supply mode is not a preferred option [1].

Literature [1] used the analysis of the new energy operation volatility of the power grid, and the dynamic adjustment of the local terrace hydropower optimization to achieve the scientific and strategic scheduling. Literature [2] A genetic algorithm was used to solve the model to realize the optimal design and scheduling of the wind-solar-storage-integrated hydropower cogeneration system. Literature [3] A Pelican Optimization Algorithm (POA) is used to achieve the optimal solution of the system, avoiding the waste of resources as much as possible. Literature [4] used the Big M method and segmented linear fitting method to show the competitiveness and economy of hybrid pumped storage in the wind-water storage complementary system.

Based on the above background, the particle swarm algorithm based containing pumped-storage wind farm proposed in this paper is to use pumping to store energy, configure a hydroelectric power generation system for the wind farm, and store a part of the wind energy in the form of potential energy in the reservoir when the value of the available wind energy is larger, and then go through the hydroelectric power generator set when the value of the available wind energy is smaller or the feed-in tariff is higher to transport the stored energy to the power grid. Then when the value of available wind energy is small or the feed-in tariff is high, the stored energy will be delivered to the grid by the hydroelectric generator unit, so as to realize the optimized output of the wind farm power, which on

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the one hand smoothes the output fluctuation of the wind farm, and on the other hand also makes full use of the wind energy and increases the benefit of the wind farm.

2. Optimized operation model of wind-hydro power combination

It is assumed that the initial power output of the wind farm without the configuration of pumped storage system and the capacity of the hydroelectric units after the configuration of pumped storage system are both determined. According to the national conditions of China's wind power industry development, we establish the following model with the purpose of increasing the efficiency of the wind farm and smoothing the power output of the wind farm:

Objective function:

$$F_{\mathrm{Max}} = CP_{\mathrm{w}} + CP_{\mathrm{h}} - C_{\mathrm{p}}P_{\mathrm{p}}$$
$$= \sum_{i=1}^{n} \left(C_iP_{\mathrm{w}i} + C_iP_{\mathrm{h}i} - C_{\mathrm{p}}P_{\mathrm{p}i}\right)$$

The objective function describes a benefit maximization model that seeks to optimize the scheduling of wind turbines, hydropower and hydroelectric generators in a wind farm for a given wind resource in order to maximize the profitability of the wind farm and to smooth the output of the wind farm. The model does not take into account some fixed costs, such as the fixed investment cost of pumped storage system and other fixed investment costs that may be involved. The meanings of the variables in the model and the constraints of the model are as follows:

Constraints:

$$P_{\mathrm{min}} \leqslant P_i \leqslant P_{\mathrm{max}}$$
$$P_{\mathrm{gmin}} \leqslant P_{\mathrm{w}i} + P_{\mathrm{p}i} \leqslant P_{\mathrm{gmax}}$$
$$P_{\mathrm{hmin}} \leqslant P_{\mathrm{hi}} \leqslant \min\left(P_{\mathrm{hmax}}, \frac{E_i}{t}\eta_{\mathrm{h}}\right)$$
$$P_{\mathrm{pmin}} \leqslant P_{\mathrm{p}i} \leqslant P_{\mathrm{pmax}}$$
$$0 \leqslant E_i \leqslant E_{\mathrm{max}}$$
$$P_{\mathrm{DL}} \geqslant 0$$
$$P_i = P_{\mathrm{w}i} + P_{\mathrm{h}i}$$
$$P_{\mathrm{v}i} = P_{\mathrm{w}i} + P_{\mathrm{p}i} + P_{\mathrm{D}i}$$
$$E_{i+1} = E_i + t\left(\eta_{\mathrm{p}}P_{\mathrm{p}i} - \frac{P_{\mathrm{h}i}}{\eta_{\mathrm{h}}}\right)$$

Where:$P_i - i$ - total power delivered to the grid by wind farms in the time slot;P_{wi}— i - power delivered directly to the grid by wind turbines in the time slot;

$P_{\mathrm{h}i}$— i Hydropower generated in the time slot;$P_{\mathrm{p}i}$— i pumping power in the time slot;P_{s} - installed capacity of the farms;P_{DLL}— i discarded power in the time slot;E_i - reservoir storage in the$i$ time slot;η_{p} - water spring pumping efficiency;η_{h} - hydropower generation efficiency; - feed-in tariff; - length of each time slot; - length of each time slot; - feed-in tariff. efficiency;t - length of each time slot;$C_i - i$ feed-in tariff for the time slot;C_{p} - pumping costs.

3. Particle swarm algorithm

In solving the operation problem of the pumped storage-containing wind farm, we adopted a hybrid optimization method based on the particle swarm optimization (PSO) algorithm and combined it with the parameter settings in the actual problem to achieve satisfactory results.

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The PSO algorithm operates on a collection of feasible solutions consisting of particles, called a population. It searches for the global optimal solution in the search space by updating the position and velocity iterations of the particles. Each particle adjusts its motion direction through its own experience and global optimum information, thus achieving cooperative optimization of the population.

In the simulation process, the parameters of the model are first set, including the available wind energy of the wind farmP_v , the installed capacity of the wind farmP_g , the pumping efficiency(η_p), the hydroelectricity generation efficiencyη_h , the length of each time period t, the feed-in tariffC_i and the pumping costC_p . These parameters provide the basis for subsequent optimization calculations.

Key parameters of the PSO algorithm such as acceleration factors c1 and c2, inertia weights w, maximum number of iterations and population size. The setting of these parameters balances the global and local search ability of the algorithm and improves the solution efficiency.

In the implementation of the algorithm, the particle swarm is first initialized according to the range of values of the variables. Each particle contains three components of pumping power$P_{\mathrm{p}i}$, fan powerP_{wi} and hydroelectric power$P_{\mathrm{h}i}$. During the iterative process, the particles update their position and velocity according to the value of the fitness function F. The fitness function takes into account various constraints of the system, including the boundary conditions of wind power and hydro generator power, the efficiency of the pumped storage system and the energy balance. The solutions that do not satisfy the constraints are processed using a penalty function that reduces their fitness values, thus guiding the algorithm to search in the direction of satisfying the constraints.

The design of the fitness function takes into account the economic efficiency of the system and various constraints, including grid power limitations, wind farm installed capacity limitations, power limitations of pumps and hydroelectric generating units, reservoir storage limitations, and wind farm output smoothness. In each iteration, the fitness value of each particle is evaluated and the global optimal solution and the historical optimal solution of each particle are recorded until the set maximum number of iterations is reached. In this way, the PSO algorithm is able to search for a global optimal solution that meets the accuracy requirements in a short time.

After several iterations, the optimized allocation schemes of fan powerP_{wi} , pumping power$P_{\mathrm{p}i}$ and hydroelectric power$P_{\mathrm{h}i}$ are finally obtained. The simulation results show that the optimized system not only improves the economic efficiency, but also the output power is smoother and significantly reduces the indicators such as deviation rate and standard deviation.

4. Analysis of calculation results

4.1. Model parameterization

PSO-specific parameters include acceleration factors c1 = 2 and c2 = 2, inertia weights fromdecreasing linearly to$w_{start} = 0.9 w_{end} = 0.4$, maximum number of iterations$maxgen = 300$ and population size$sizepop = 500$

In the analysis of the optimization in this paper, the initial energy storage in the reservoir is assumed $E_1 = 0$, the power limit of the grid is$3\mathrm{MW} < P_i < 8\mathrm{MW}$, and the other parameters are set as shown in Table 1.

Wind power prices are set as follows with reference to foreign wind power price systems:

$$\begin{array}{ll} C_i = 540¥/\mathrm{MWh} & 0 \leqslant i < 8 \\ C_i = 1038.4¥/\mathrm{MWh} & 8 \leqslant i < 22 \\ C_i = 540¥/\mathrm{MWh} & 22 \leqslant i < 24 \end{array}$$

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$$C_{\mathrm{pi}} = 0.25C_i$$

Table 1: Design of parameters of model

parameters	retrieve a value
$P_{\max}$ /MW	12
$P_{\max}$/MW	3
P_{pax}/MW	3
$E_{\max}$/MWh	24
η_{h}	$\eta_{\mathrm{s}}/\eta_{\mathrm{p}}$
η_{p}	0.8
$\eta_{\mathrm{h}} = \eta_{\mathrm{h}} \times \eta_{\mathrm{p}}$	0.75
installed capacity /MW	2×6

4.2. Analysis of results

Since the particle swarm algorithm is a coarse-precision optimization method, the final value obtained is a value near the global optimal solution, not the global optimal solution, so it is also necessary to use local optimization methods in order to ultimately find the global optimal solution.

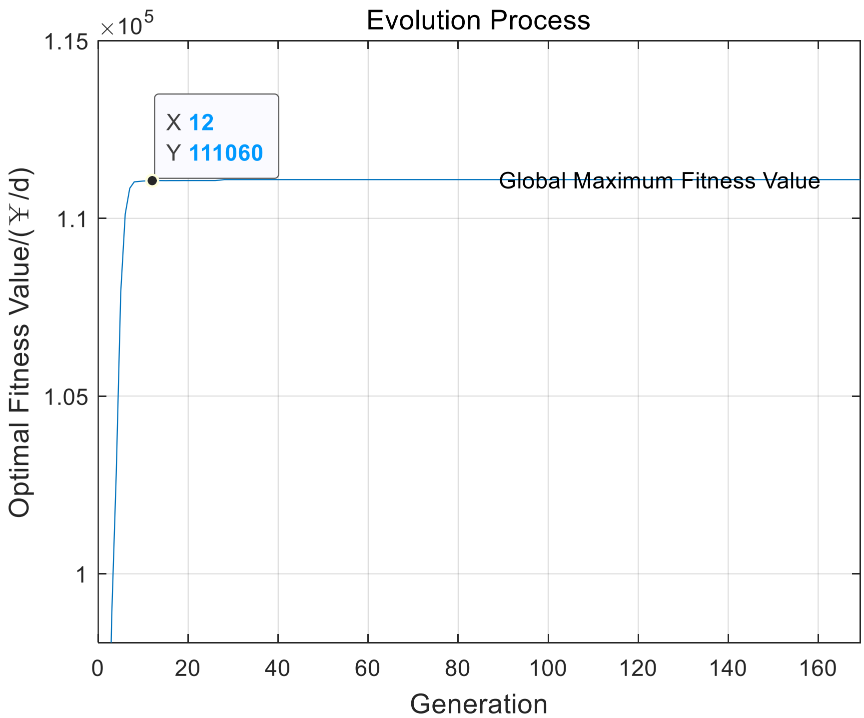

Figure 1: Convergence of optimal fitness value over generation

As can be seen from Fig. 1, when the particle swarm algorithm runs to 12 generations, the convergence iteration curve reaches the global maximum fitness, and then the maximum fitness value of the population always oscillates around the maximum value, for this reason, we choose the optimal solution of the particle swarm algorithm at the 12th generation as the initial value of , and the optimal solution of the particle swarm algorithm at the 12th generation as the initial value of .

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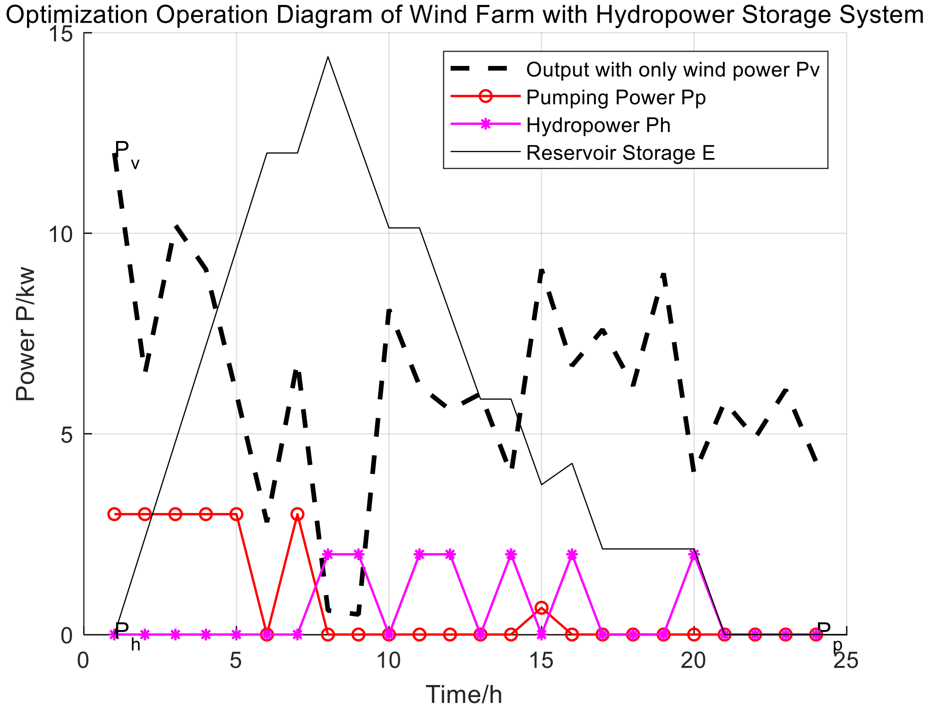

Figure 2: Power output and storage dynamics over 24 hours

Figure 2 shows that after the optimization calculation, we can get the schematic diagram of the optimized operation of the wind farm hydraulic system and the power values of the wind turbine, pumping unit, and hydroelectric generator set in each time period in 1d, so as to realize the optimized operation of the joint scheduling of the wind-hydroelectric power in the wind farm.

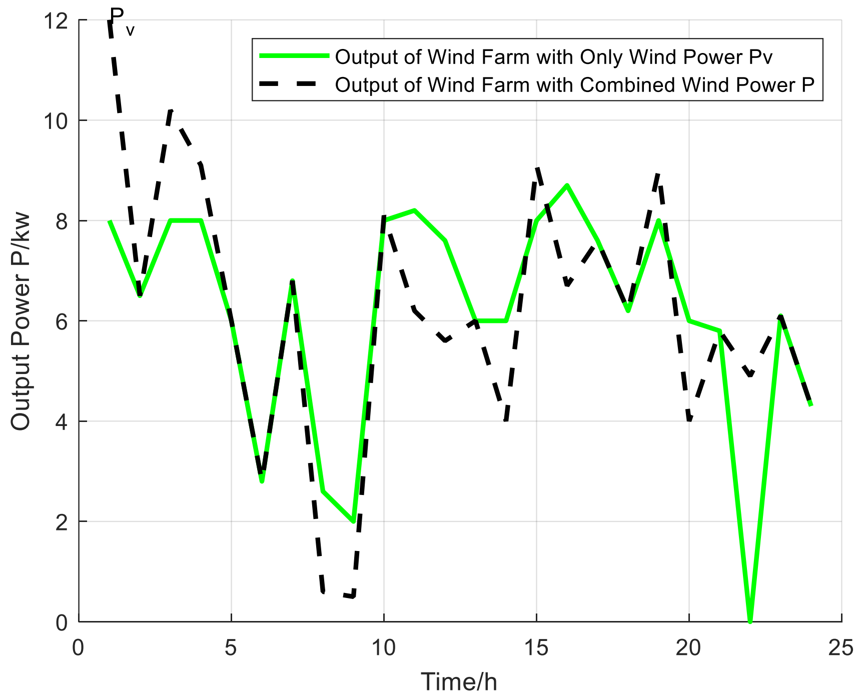

Figure 3: Comparison of wind farm output power over 24 hours

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The wind farms can be seen in Fig. 3, which shows the power output when the wind farms are operated jointly (total power) and when only the wind farms are operated (single wind farm power). The power trends in different operation modes are compared through two different curves.

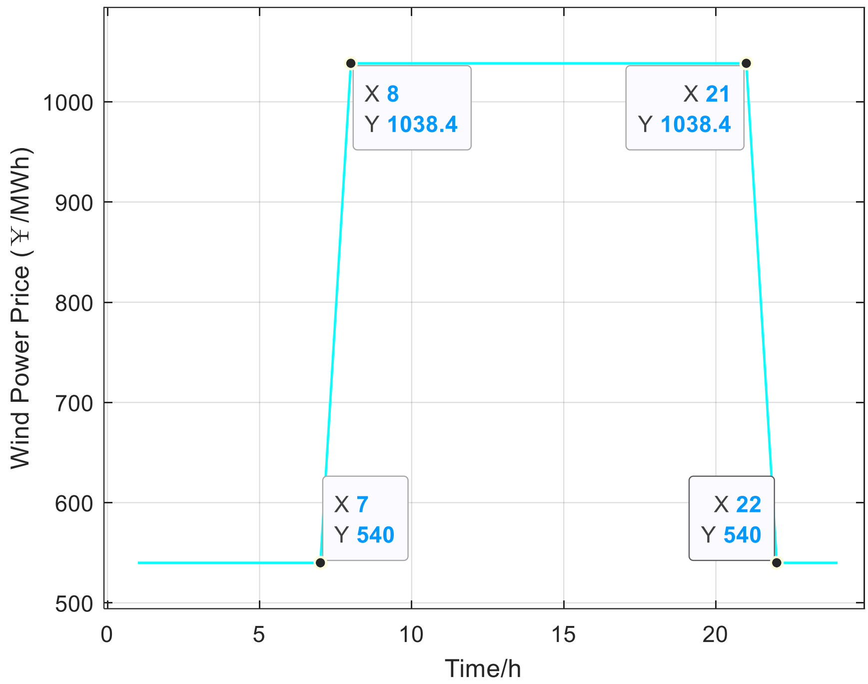

Figure 4: Fluctuations in wind power prices over 24 hours

A schematic diagram of the optimized operation of a pumped water storage system in a wind farm can be seen in Figure 4.

According to Fig. 4, we can get the following conclusions:

(1) In the period from 0:00 a.m. to 7:00 a.m., the pump is activated to pump water into the upper reservoir since the feed-in tariff for wind power is in the low price zone ($C = 540¥/\mathrm{MWh}$), and thus the reservoir storage energy is increasing (only at 6:00 a.m., the pumping power is zero sinceP_{66} is less than the grid limiting power$P_{\min}$);

2) During the period from 8 a.m. to 21 p.m., the hydro units start generating electricity because the feed-in tariff for wind power is in the high price zone ($C = 1038.4¥/\mathrm{MWh}$) , so the hydro units start generating electricity, the pumps stop pumping water, and the storage capacity of the reservoirs is decreasing (the pumps are started only at 15 p.m. and 19 p.m., because the power ofP_{v15} andP_{v9} is greater than the power limitation of the power grid$P_{\max}$, respectively);

3) At 22:00 p.m. and 23:00 p.m., the feed-in tariffs for wind power are in the low tariff zone($C = 540¥/\mathrm{MWh}$) and the available wind power is within the grid's power limits, so water tickets and hydroelectric generators are offline.

The above analysis shows that the hydroelectric system in the wind farm achieves the complementarity between the power of the wind farm in different time periods, i.e., it achieves the optimized output of the power of the wind farm, which increases the benefit of the wind farm and smoothes out the output of the power of the wind farm.

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5. Conclusions

With the rapid development of wind power industry, how to increase the benefits of wind power and improve the quality of wind power supply has become a very important issue. This paper proposes the use of wind farms containing pumped storage power supply operation mode can not only increase the operational benefits of wind farms at the same time also be able to smooth the power output of wind farms, which to a certain extent to make up for the wind energy randomness, not conducive to the control of the shortcomings of the wind power greater participation in the power supply of power systems provides an effective solution.

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