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Research on New Operation Policy and the Influence of Different Proportion of Pumped Storage Station

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Abstract: Large-scale integration of wind power has been warmly discussed as the fast development of renewable energy. In the report of the 12th Five Year Plan in China, it is said that over 70000MW wind farm would integrate into state grid. Wind energy is random and uncertain which would bring a lot of safety problems when it is involved in a large system. In this study, a new operation policy was proposed to smooth the output of wind power through pumped-storage station. The output of wind and pumped-storage replaces that of wind with strong fluctuations. We solve the optimal problem aiming at the reducing the operation cost through particle swarm optimization algorithm. Based on the new operation policy, we compared the different wind-pumped output and the operation cost of power system with different proportion of wind and pumped-storage and obtain the approximate optimal proportion. As a result of simulation and calculation, our policy is proved to be reasonable and economical.

Key words: Operation policy, pumped-storage, optimal proportion, particle swarm optimization

INTRODUCTION

In the report of the 12th Five Year Plan in China, it is said that four onshore large wind farms and two offshore wind farms would have been founded to integrate into the power grid till the end of 2015. It's the promotion of the strategy in renewable energy, energy-saving and environmental protection that leads to the explosive development of wind energy. But wind energy is closely linked to the local climatic condition. As the randomness and uncertain of wind power, it is a great challenge for the safety and economic of operation to integrate large-scale wind into state grid. At the present, the fluctuation of wind power is adjusted through the participating of thermal units which is a waste of fossil energy and uneconomic. We can use pumped-storage stations to smooth the fluctuation of wind and decrease the thermal units' cost of start and stop which would make operation more efficient and environmental.

Much attention has been devoted to pumped-storage station by foreign researchers. The benefit of the wind-pumped storage station in isolated island has been investigated by a number of authors. Bueno and Carta (2005) discussed the operation model of wind and pumped-storage station in the island of EI Hierro which took an advantage to improve the wind and pumped-storage. Dursun *et al*. (2011) studied the contribution of wind-hydro system in Turkey. A lot work has been done on the scheduling policy of wind in China (Yuan *et al*., 2010; Sun *et al*., 2009; Ai and Liu, 2011), they held the view that thermal units could afford the intermittent and peak-valley differences of wind power. These conclusions can be applied to system with little wind capacity. Few papers have been published concerning the operation policy of pumped-storage station in big wind-hydro-thermal system.

In this study, we proposed a new scheduling policy to smooth the fluctuation of wind and arrange the output of all kinds of energy. The new approach here not only aims at reducing the fluctuation and operation cost but also improving the power generation of clean energy such as wind and water. Through the simulation cases based on IEEE RTS-96, the new policy described here is proved to be reasonable. We calculate the operation cost with six different proportions of pumped-storage stations and obtain the approximate optimal proportion in this test case.

MODEL DESCRIPTION

The Wind-pumped-hydro-thermal system is a large-scale model which is complex and nonlinear. We divide this scheduling problem into two subsystems as wind-pumped-hydro subsystem and thermal subsystem. The wind-pumped-hydro subsystem aims at the maximum generation of water and minimum output fluctuation of thermal units. The thermal subsystem aims at minimum operation cost as same as the goal of whole model. We solve these subsystems respectively and coordinate them to get an optimal scheduling plan in the end.

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Objective Functions of the System: In this study, the original scheduling system sets the minimum operation cost as a target. It is shown as follows:

$$\min F_C = \sum_{t=1}^{T}\sum_{i=1}^{Nt} u_{i,t}F_{i,t}(P_{Gi,t}) + \sum_{t=1}^{T}\sum_{i=1}^{Nt} S_{i,t} \quad (1)$$

$$F_{i,t}(P_{Gi,t}) = a_i P_{Gi,t}^2 + b_i P_{Gi,t} + c_i \quad (2)$$

$$S_{i,t} = u_{i,t} \times (1 - u_{i,t-1}) \times (\alpha_i + \beta_i[1 - e^{x_{i,t-1}/\tau_i}]) \quad (3)$$

In the equation above, $F_{i,t}$, $S_{i,t}$ represent the fuel cost start and stop cost of unit i at time t. $P_{Gi,t}$ represents the output of thermal unit I at time t. a_i, b_i, c_i are the fuel cost coefficients of generator i, α_i, β_i are the start and stop cost coefficients of generator i. τ_i is the cool-time time of generator I.

Objective functions of the wind-pumped-hydro subsystem: The subsystem aims at reducing the fluctuation of thermal and increasing the output of water, the objective function is as follows:

$$\begin{cases} \min f_1(P_{Hi}) = \sum_{t=1}^{T}\left|\Delta\left(P_{Lt} - \left(\sum_{i=1}^{Nh} P_{Hi,t} + \sum_{i=1}^{Nw} P_{Wi,t} + \sum_{i=1}^{Nps} P_{Pi,t}\right)\right)\right| \\ \max f_2(P_{Hi}) = \sum_{t=1}^{T}\sum_{i=1}^{Nh} P_{Hi,t} \end{cases} \quad (4)$$

In Eq. 4, P_{Lt}, $P_{Hi,t}$, $P_{Wi,t}$, $P_{Pi,t}$ represents the load, power of hydro unit I, power of wind unit I, power of pumped-storage unit t at time I, respectively.

Constraints of the model: In this model, there are two kinds of constraints. One is the constraints of power balance:

$$\sum_{i=1}^{N_g} u_{i,t}P_{Gi,t} + \sum_{i=1}^{N_h} P_{Hi,t} + \sum_{i=1}^{N_w} P_{Wi,t} + \sum_{i=1}^{N_{ps}} P_{Pi,t} = P_{L,t} \quad (5)$$

$$\sum_{i=1}^{Ng} u_{i,t}(P_{Gimax} - P_{Gi}) + \sum_{i=1}^{Nh} (P_{Himax} - P_{Hi}) \geq P_{Rt} \quad (6)$$

In Eq. 5 and 6, $P_{L,t}$ is the load at time t, P_{Rt} is the reserve of system at time t. Equation 5 is the constraints of power balance, Eq. 6 is the constraints of spinning reserve.

The other kind is the constraints of all kinds of energy:

$$\begin{cases} P_{Gimin} \leq P_{Git} \leq P_{Gimax} & x_{i,t} > 0 \\ P_{Git} = 0 & x_{i,t} < 0 \end{cases} \quad (7)$$

$$|P_{Gi,t} - P_{Gi,t-1}| \leq ramp_i \times \Delta t \quad (8)$$

$$P_{Hi\,min} \leq P_{Hi,t} \leq P_{Hi\,max} \quad (9)$$

$$S_{min,i} \leq \int_{t=1}^{T} Q_{i,t} \leq S_{max,i} \quad (10)$$

$$P_{Hi,t} = A\eta Q_{i,t}h_{i,t} \quad (11)$$

In the Equations above, Eq. 7~8 are the constraints of thermal generators, Eq. 9~11 are the constraints of hydro generators. $P_{Gi\,max}$, $P_{HI\,max}$ are the maximum output of thermal generator i and hydro generator i.$P_{Gi\,max}$, $P_{HI\,max}$ are the minimum output of thermal generator i and hydro generator i. $Q_{i,t}$ represents the average water flow used by hydro station i at time t.

NEW OPERATION STRATEGY OF PUMPED-STORAGE STATION

In this study, we attempt to make full use of the pumped-storage station to smooth the output of wind. We set an adaptation value parameter named P_{AR}. Pumped-storage station pumps the water to storage energy when the wind output is higher than P_{AR} and generates when the wind output is lower than P_{AR}. We should set some constraints to make sure that the water storage in the Pumped-storage station is enough and the sum output of wind and pumped-storage is flat:

$$P'_{P,t} = P_{AR} - P_{W,t} \quad (12)$$

$$P_{P,t} = \begin{cases} -P_{Ppmax} & P_{P,t}' \leq -P_{Ppmax} \\ P_{P,t}' & -P_{Ppmax} \leq P_{P,t}' \leq -P_{Ppmin} \\ 0 & -P_{Ppmin} \leq P_{P,t}' \leq P_{Pgmin} \\ P_{P,t}' & P_{Pgmin} \leq P_{P,t}' \leq P_{Pgmax} \\ P_{Pgmax} & P_{P,t}' \geq P_{Pgmax} \end{cases} \quad (13)$$

In Eq. 12, we obtain the template output of pumped-storage station $P'_{P,t}$ and then revise it through Eq. 13. In Eq. 13, P_{Ppmax}, P_{Ppmin} are the maximum and minimum pumping output and P_{Pgmax}, P_{Pgmin} are the maximum and minimum generating output. $P_{P,t}$ is the final output of pumped-storage station.

We choose the suitable P_{AR} through equation below:

$$\min \sum_{T=1}^{24} [(P_{W,t} + P_{P,t}) - \overline{P_{AR}}]^2 \quad (14)$$

In Eq. 14, $\overline{P_{AR}}$ is the average output of $P_{W,t}$ and $P_{P,t}$, P_{AR} should object to constraints below:

$$\int_{T=0}^{24} P_{P\Delta}(t) \geq 0 \quad (15)$$

$$P_{P\Delta}(t) = \begin{cases} P_{P,t} & P_{P,t} \geq 0 \\ \eta \times P_{P,t} & P_{P,t} < 0 \end{cases} \quad (16)$$

In Eq. 16, η equals to 0.75 which represents the conversion efficiency of pumped-storage station.

CASE I STUDY: TEST THE NEW STRATEGY

Based on the new strategy above, we choose standard IEEE RTS-96 case with 26 conventional generators to test our policy. We added five wind farms with capacity of 210, 210, 150, 150, 120 MW and an extra pumped-storage of 200 MW. The pumped-storage station available pumping power is 220 MW and generating power is 200 MW. Its minimum pumping power is 120 MW and minimum generating is 80 MW. We set the water flow as high-water period and medium-water to test our new policy. The scheduling results with pumped-storage without it based on PSO are follows:

In Fig. 1 and 2, it can be seen that the output of wind and pumped is smoother and the sum of hydro power is more in the left based on our new strategy than that in the right with wind power only. The operation cost and start and stop cost are shown in Table 1.

Table 1 shows the different performance of the new strategy proposed above in high-water period and medium-water period. The data in the table proves that the new approach to arrange the pumped-storage station is reasonable.

CASE II STUDY: RESEARCH ON THE PROPORTION OF PUMPED-STORAGE STATION

Based on our new strategy, pumped-storage station is good to improve the penetration of wind. In this part, we choose six different capacities of pumped-storage stations and obtain six scheduling plans. Assuming that the water flow is high-water period and the system is as same as case i besides the capacity of pumped-storage stations. The different output of thermal and hydro power is shown as follows:

In Fig. 3, we set the capacity of pumped-storage station as 50, 100, 150, 200, 250, 300 MW and compare the different performance in arranging the scheduling of thermal and hydro. The accurate operation cost is shown in Table 2.

Table 1: Comparation of costs with and without pumped-storage station

	High-water period		Medium-water period	
	With P-S station	Without P-S station	With P-S station	Without P-S station
Start and stop times	11.00	21.00	10.00	15.00
Operation cost ($)	48573.70	49521.39	51152.65	52270.61
Stop and start cost ($)	1470.15	2825.47	1354.35	2241.62
Total operation cost ($)	50043.85	52346.86	52507.01	54512.23

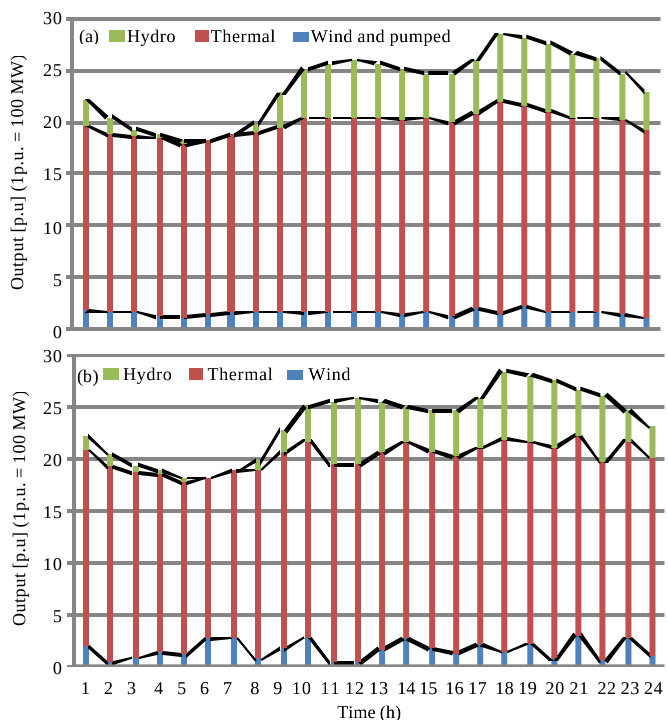

Fig. 1(a-b): (a) Scheduling plan with pumped-storage station in high-water period and (b) Scheduling plan without pumped-storage station in high-water period

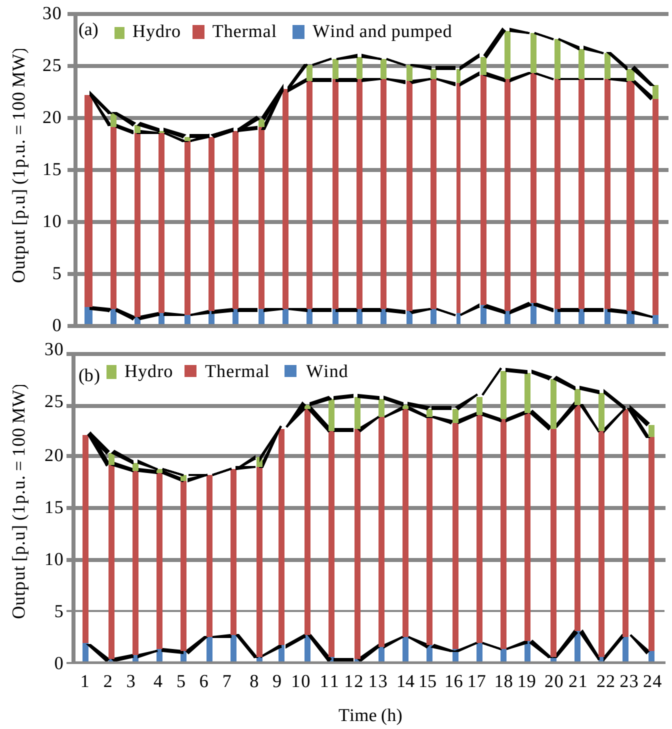

Fig. 2(a-b): (a): Scheduling plan with pumped-storage station in medium-water periodand (b) Scheduling plan without pumped-storage station in medium-water period

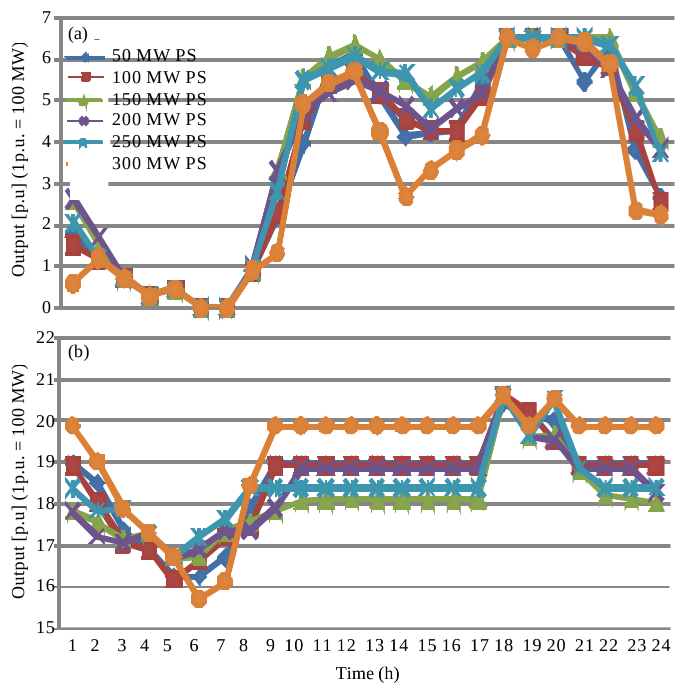

Fig. 3(a-b): (a) Scheduling thermal plan in different pumped-storage proportion and (b) Scheduling hydro plan in different pumped-storage proportion

Table 2: Operation cost with different proportion of pumped-storage stations

PS Capacity	50 MW	100 MW	150 MW	200 MW	250 MW	300MW
Start and stop times	18	12	11	10	12	18
Operation cost ($)	49478.26	48675.74	48768.27	48573.70	49233.06	50498.56
Stop and start cost ($)	2553.00	1538.35	1495.51	1470.15	1742.93	2219.61
Total operation cost ($)	52031.26	50214.09	50263.79	50043.85	50975.99	52718.17

In this table, we could come to an conclusion that 100~200 MW is approximately the optimal capacity of pumped-storage station in this test case.

CONCLUSION

The new strategy proposed here is reasonable and economic. Based on this strategy, optimal capacity of pumped-storage in the system is 200MW and proportion is about 0.25. Further research is needed to evaluate the different performance of pumped-storage in different proportion of thermal and hydro power.

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