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Study on unit commitment problem considering wind power and pumped hydro energy storage

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ABSTRACT

The stochastic and intermittent characteristic of wind power present great challenge to the operation of power system. A novel unit commitment problem (UCP) model is proposed in this paper. As the status of thermal units need to be described by binary number, Binary Particle Swarm Optimization (BPSO) algorithm is proposed to find the optimum schedule scheme. Case studies on the 10 units system illustrate the efficiency of the proposed approach.

1. Introduction

Nowadays, wind power is becoming worldwide a significant component of power system. In the United States, the adoption level of wind power in 2030 is expected as 20% [1]. In Europe, most countries have already exhibit their adoption levels in the range of 5–20% [2]. China's government set its target of integrated wind power capacity in 2015 as 100 GW, accounting for 7.14% in the total installed capacity [3]. Such a large scale integration presents great challenges to the operation of electric power system as wind power is highly intermittent and difficult to predict.

One way to mitigate the negative effects of wind power is to install energy storage system in grid. Among all the energy storage technologies, pumped hydro energy storage (PHES) is currently the only operationally available large scale storage technology. The basic principle of PHES is to utilize attitude intercept to store electric energy. The plant pumps water into a reservoir during low electricity demand periods, operating as a load, and discharging the stored water during high demand periods, working as hydraulic generator [4].

One of the most prominent issues regarding power system operation is the unit commitment problem (UCP). Specifically, UCP is a kind of problem which aims at obtaining an optimal scheme to meet the power demand at minimum fuel cost using an optimal mix of different power units. UCP in tradition is only focused on thermal power generating unit. In order to cope with the integration of wind power, UCP considering wind farms and PHES is now becoming complicated and new problems need to be addressed.

A great variety of researches have been conducted to study UCP with the consideration of wind power. Most researches on integrating wind power into UCP tend to add a secondary reserve constraint on top of the traditional $N-1$ security criterion. The amount of reserve and the formulation differs among each method. In [5], a unit commitment and economic dispatch tool is adapted to assess the impacts of large scale wind power on system operations from reliability, cost and environmental perspectives. The approach in [6–8] enforce reserve constraints outside of the main UCP optimization. If the solution of the UCP turns out to be infeasible for the reliability constraints, the variables are then modified and the UCP is run again. In [9–11], the additional reserve constraints were directly integrated into the UCP formulation. In [12], a two state model was proposed to derive a reliability measurement similar to the forced outage rate of a thermal unit. The method proposed in [13] represented wind power as multi-state unit and utilized reliability measure of all the states to implement a cost on wind power to schedule an appropriate amount of wind generation. Few research has focused on integrating storage into power system with high penetration of wind power. In [14], an optimization methodology was proposed to investigate thermal unit commitment with considerations for environmental constraints and pumped storage.

In UCPs with wind power, tradition thermal units have to be scheduled frequently in order to satisfy the fluctuation of both load and wind power output. When PHES was integrated, the security

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and economy can be greatly improved. The plan of UCP and the evaluation of the operation of system need to be restudied and new formulation need to be established. This paper carried out a detailed study on solving UCP with wind power and PHES.

The main contents are summarized as follows. First, the mathematical model of UCP with wind power and PHES will be established according to the technical differences of different generation units. It is important to note that the model mainly focuses on the certain UCP based on the wind power prediction. Second, three cases of the UCP are studied. Finally, a 10 units example system is solved by the presented Binary Particle Swarm Optimization (BPSO) algorithm.

2. Mathematical formulation

2.1. Objective function

As the technological structure of wind turbines and PHES station is quite different with thermal unit. The new UCP model makes significant difference with tradition UCP model. The model of new UCP can be described as follows.

The objective function of the optimization is to minimize the operating costs. As the cost of wind farm and PHES station is mainly reflected in the construction (almost no fuel cost), therefore the objective function do not consider wind and PHES.

$$\min F(P_{i,t}, u_{i,t}) = \min \sum_{t=1}^{T} \sum_{i=1}^{N} [f(P_{i,t}) + S_{i,t}(1 - u_{i,t})] \cdot u_{i,t} \tag{1}$$

where $F(P_{i,t}, u_{i,t})$ is the total operating cost; $f(P_{i,t})$ is the fuel cost of thermal unit; $S_{i,t}$ is the start-up cost; $P_{i,t}$ is the output power of unit i at period t; $u_{i,t}$ is a 0-1 decision variable for unit i at period t, 1 means online while 0 means off line; N is the number of available thermal units.The fuel cost can be expressed as a binomial formula of the power output. The relationship of the fuel cost and power output can be described in Eq. (2) and Fig. 1.

$$f(P_{i,t}) = aP_{i,t}^2 + bP_{i,t} + c \tag{2}$$

Start-up cost is the additional fuel consumption when the thermal unit working at start-up state. Its value is related to the time that the unit was cooled. Generally $S_{i,t}$ can be expressed as:

$$S_{i,t} = \alpha_i + \beta_i(1 - \exp(-X_{i,off}^t/\tau_i)) \tag{3}$$

where α_i, β_i is the consumption constant of unit i; τ_i is the boiler cooling time constant of unit i; $X_{i,off}^t$ is the continuous shutdown time of unit i in period t.

As Eq. (3) for start-up cost is quite complex and the consumption constant and cooling time constant is difficult to confirm, here we use Eq. (4) to describe start-up cost.

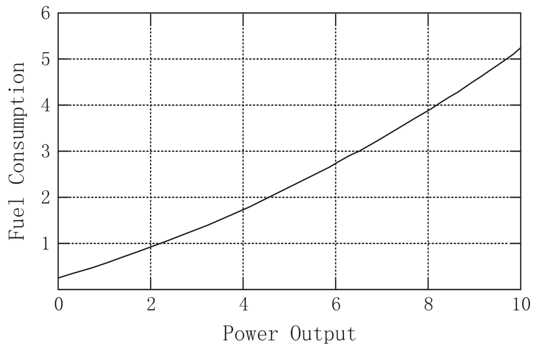

Fig. 1. Coal consumption curve of thermal power unit.

$$S_{i,t} = \begin{cases} HST_i & T_{i,down} \le T_{i,off} \le T_{i,cold} + T_{i,down} \\ CST_i & T_{i,off} \ge T_{i,cold} + T_{i,down} \end{cases} \tag{4}$$

where HST_i and CST_i are constant, which represents hot start-up cost and cold start-up cost separately.

2.2. Constraints

2.2.1. Constraint on power balance

Power balance constraint requires the total output of unit meet total system load at any time, which can be described as:

$$\sum_{i=1}^{N} P_{i,t} + P_{w,t} + P_{g,t} = L_t + P_{p,t} \tag{5}$$

where $P_{w,t}$ is wind power output in period t; $P_{g,t}$ is generating power output of PHES in period t; $P_{p,t}$ is pumping power in period t;

When considered network loss, there would be an extra percentage of total power output. Here, the network loss is ignored as there will be less impacts to the result.

2.2.2. Constraint on spinning reserve

In order to ensure the reliability of power system, a certain amount of extra spinning generating capacity need to be reserved besides meeting system load requirement. The constraint can be described as:

$$\sum_{i=1}^{N} \overline{P_i} + P_{w,t} + P_{g,t} \ge L_t + P_{p,t} + R_t \tag{6}$$

where $\overline{P_i}$ is the upper limit of power output of unit i; R_t is the spinning reserve requirement in period t; High level of the spinning reserve capacity can leads to better reliability. But it also caused high cost of the operation of the system. A reasonable level of spinning reserve capacity should consider both reliability and efficiency. In [15], Reliability indices, like LOLP and LOLE, was introduced to evaluate the level of spinning reserve capacity. In this paper, we define R_t is 10% of the load.

$$R_t = 10\% \times L_t \tag{7}$$

2.2.3. Constraint on time of thermal unit start-up and shut-down

Thermal unit cannot be powered up and down continuously as limited by heat dissipation and technical regulation. To ensure safety utilization of thermal unit, minimum start-up and shut-down time is set as showed below:

$$(rr_{i,t-1} - T_{i,on})(u_{i,t-1} - u_{i,t}) \gg 0 \tag{8}$$

$$(zz_{i,t-1} - T_{i,down})(u_{i,t} - u_{i,t-1}) \gg 0 \tag{9}$$

where $rr_{i,t-1}$ is the continuous operating time of unit i in period $t-1$; $zz_{i,t-1}$ is the continuous shutdown time of unit i in period $t-1$; $T_{i,on}$ is the minimum start-up time and $T_{i,down}$ is the minimum shut-down time.

2.2.4. Constraint on technical power output

Thermal power output is limited by an adjustment range as described in Eq. (10). The regulating speed of thermal unit, which is constrained by speed controller, also has top and bottom limitation as showed in Eq. (11).

$$u_{i,t} \cdot \overline{P_i} \le P_{i,t} \le u_{i,t} \cdot \underline{P_i} \tag{10}$$

$$-P_{i,ramp} \leqslant P_{i,t} - P_{i,t-1} \leqslant P_{i,ramp} \tag{11}$$

where $\overline{P_i}$ and $\underline{P_i}$ power output of unit i; $P_{i,ramp}$ is ramp speed of unit i.