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Multi-time Scale Scheduling Strategy for Power System with Large-scale Intermittent Energy

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Abstract. Large-scale integration of intermittent energy has brought many problems to active power dispatching of the power grid, which will not only increase the operation cost, but also increase the operation risk. This paper developed a multi-time scale scheduling strategy, integrated day-ahead scheduling, intra-day dispatching and automatic generation control (AGC) system, in order to ensure the safe and stable operation of power grid. The strategy aims to minimize the sum of operating costs of power system, and sets six constraints such as power flow constraint, to analyse and optimize the dispatching process of power systems. After simulation and analysis by Particle Swarm Optimization (PSO) algorithm, the results show that the strategy has a significant optimization on the power system with intermittent energy.

Keywords: Large-scale, Intermittent energy, Multi-time scale, Power system dispatching

1. Introduction

Since intermittent energy represented by wind power and PV power were connected to power grid, the power fluctuation caused by environmental factors has brought voltage and frequency stability problems to the system. To cope with the power fluctuation issue, the system should have greater capacity [1]. However, problems such as unreasonable structure of traditional power supply and difficult power consumption are the main reasons that have restricted China's development of intermittent energy [2-4]. Therefore, it is of great practical significance to research the scheduling strategy for power system with large-scale intermittent energy.

Many researches have been reported on the integration of large-scale intermittent energy. Reference [5] proposed that battery energy storage is an effective measure to enhance the grid-connected capacity of intermittent energy. Besides, the configuration of battery energy storage in power grid was emphatically analyzed.

Meanwhile, optimized dispatching of new energy has drawn more attention. Considering the specific situation, the new energy power generator set with the lowest marginal cost is preferred to meet the load demand with the lowest total production cost of the system [6-7]. The main method of achieving the balance of active power is to manage conventional units and new energy units reasonably [8]. Reference [9] constructed a multi-scale model including three different control modules, to analyze the optimal dispatching of PV power stations.

This paper constructs a multi-time scale scheduling model integrated day-ahead scheduling, intra-day dispatching and AGC system, from the perspective that the optimal model can improve the



dispatch of power system with large-scale intermittent energy. A compromise decision of stable operation and the integration of intermittent energy can be got, with both power balance and technical conditions of generator units taken as constraints.

2. Multi-time scale scheduling principle

Based on day-ahead scheduling data, intraday dispatching is used for adjustment, and short-term load response is conducted through AGC system [10-13]. Figure 1 is a multi-time scale scheduling principle diagram [14].

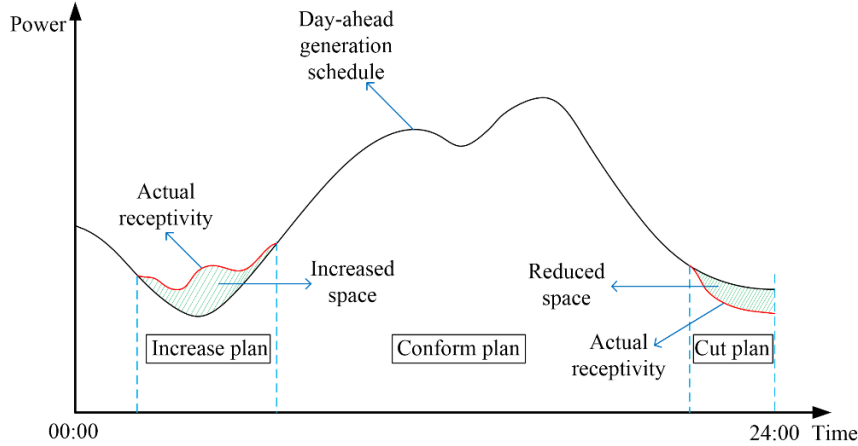


Figure 1. Multi-time scale scheduling principle diagram.

Firstly, the day-ahead scheduling plan forecast the hourly power grid situation before the research day. Then, the intra-day dispatching do continuous adjustments every 15 min from 00:00 of the research day, which is based on ultra-short-term forecast of load, wind power and PV power. When obtaining the first 15 min of ultra-short-term forecast data, the day-ahead forecast results would be quickly corrected, and the correction amount would be added to obtain the latest data. The intra-day dispatching can be regarded as a kind of feedback, which will feed the latest ultra-short-term forecast data obtained back to the original basic calculation data.

The intra-day dispatching ensure the data remain roughly same as the impending actual conditions in a short time, but does not pursue precise regulation and optimization. After the intra-day dispatching, AGC system would adjust the power generation and stabilize the grid frequency.

3. Multi-time scale scheduling model

3.1. Objective function

To analyze the real-time intra-day dispatching process clearly, the conventional units are divided into base-load units and peak-load regulation units. Aiming at the minimum total operating cost of power system, set

$$\min F = \sum_{t=1}^T \sum_{i=1}^{N_g} [C_i(p_i^t)u_i^t + S_i^t] + \sum_{i=g+1}^{N_k} L_i(t) + A_{ex} \times E_{ex} \quad (1)$$

as the objective function. This function takes into account the generation cost $C_i(p_i^t)$, the start-up cost of base-load units S_i^t , the regulation cost of peak-load units $L_i(t)$, and the cost of abandoned intermittent energy.

Where i and t are respectively the index for conventional units' number and hours, T is the total number of hours divided in the study period, N_g and N_k are respectively the total number of base-load units and peak-load units in the system, p_i^t is the active power output of unit i at time t , u_i^t is the operation state of unit i at time t (1 means running, 0 means stopping).

$C_i(p_i^t)$ is the characteristic cost function of unit i that only related to the active power output of it.

$$C_i(p_i^t) = a_i p_i^{t2} + b_i p_i^t + c_i \quad (2)$$

a_i , b_i and c_i are constants which have been given.

S_i^t is the start-up cost function of unit i at time t, shown as:

$$S_i^t = [\psi_i + \zeta_i (1 - e^{-x_i^{t-1}/\tau_i})] u_i^t (1 - u_i^{t-1}) \quad (3)$$

Where ψ_i and ζ_i are respectively the fixed cost and cold start-up cost of units, τ_i is the thermal time constant of units, x_i^t is hours of running or stopping continuously of unit i at time t.

$L_i(t)$ is the peak-load regulation cost of peak-load regulation unit i. It is related to the intermittent energy size and scale which is connected to the power grid.

A_{ex} is the adjustment cost of the intermittent energy units. E_{ex} is the interactive energy of intermittent energy station and the power grid.

$$A_{ex} = \begin{cases} A_b, E_{ex} > 0 \\ A_d, E_{ex} < 0 \end{cases} \quad (4)$$

Where A_b is the penalty cost of abandoned intermittent energy, and A_d is the reward cost of expanded intermittent energy. They are all related to the electricity market.

$$E_{ex} = \int_0^T P_{ex}(t) dt \quad (5)$$

Where P_{ex} is real-time interactive energy of intermittent energy station and the power grid.

3.2. Constraint condition

On the basis of ensuring the safe and stable operation, there are some constraints need to be considered.

3.2.1. Constraint for power flow.

$$\begin{aligned} P_{Gi} + P_{Ki} + P_{Li} - P_{Di} &= U_i \sum_{j=1}^n U_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \\ Q_{Gi} + Q_{Ki} + Q_{Li} - Q_{Di} &= U_i \sum_{j=1}^n U_j (G_{ij} \sin \theta_{ij} + B_{ij} \cos \theta_{ij}) \end{aligned} \quad (6)$$

Where P_{Gi} and Q_{Gi} are respectively the active power and reactive power of the base-load units at the system bus bar i, P_{Ki} and Q_{Ki} are respectively the active power and reactive power of the peak-load regulation units at the system bus bar i, P_{Li} and Q_{Li} are respectively the adjustment amount of active power and reactive power at the system bus bar i, P_{Di} and Q_{Di} are respectively the active power and reactive power of the load at the system bus bar i.

3.2.2. Constraints for unit technical output.

$$\begin{aligned} u_i^t p_i^{\min} &\leq p_i^t \leq u_i^t p_i^{\max} \\ u_i^t q_i^{\min} &\leq q_i^t \leq u_i^t q_i^{\max} \end{aligned} \quad (7)$$

Where p_i^t and q_i^t are respectively the active power technical output and reactive power technical output of the conventional unit i, p_i^{\min} , p_i^{\max} , q_i^{\min} and q_i^{\max} are respectively the lower limit and upper limit of the active technical output and reactive technical output of unit i.

3.2.3. Constraints for unit climbing rate.

$$-u_i^t \cdot D_r^i \cdot \Delta t \leq p_i^{t+1} - p_i^t \leq u_i^t \cdot U_r^i \cdot \Delta t \quad (8)$$

Where U_r^i and D_r^i are respectively the allowed output rising and falling limit rates of the active power of unit i per unit time. Δt is the time interval, which is one unit time.

3.2.4. Constraints of unit minimum running time or downtime.

$$u_i^t = \begin{cases} 1, & 1 \leq x_i^{t-1} < T_i^{on} \\ 0, & -1 \geq x_i^{t-1} > -T_i^{off} \end{cases} \quad (9)$$

Where T_i^{on} and T_i^{off} are respectively the minimum running time and minimum downtime of unit i .

3.2.5. Constraints for power transmission of intermittent energy station and the power grid.

$$|P_{ex}(t)| \leq P_{ex}^{\max} \quad (10)$$

Where P_{ex}^{\max} is the power limit of the transmission line.

3.2.6. Constraints for the output power of intermittent energy station.

$$\begin{aligned} 0 \leq p_{i,w}^t &\leq p_{i,w}^{\max} \\ 0 \leq p_{i,s}^t &\leq p_{i,s}^{\max} \end{aligned} \quad (11)$$

Where $p_{i,w}^{\max}$ and $p_{i,s}^{\max}$ are respectively the output power upper limit of wind power and PV power stations.

4. Simulation analysis of multi-time scale scheduling

4.1. Case description

This paper designs an experimental power system that meets the actual situation, including six types of power sources: thermal power, gas power, nuclear power, pumped storage power, wind power, and PV power. The load forecast data on the calculation date is also set. Among them, the total installed capacity of wind power and PV power is 1000MW, accounting for 19.2% of the total installed capacity of the system. Therefore, the experimental system is a typical power system with large-scale intermittent energy, and the installed capacity of all power sources and their proportions are shown in Table 1.

Table 1. The installed capacity and proportions of all power sources in the system.

| Source type | Thermal power | Gas power | Nuclear power | Pumped storage | Wind power | PV power | Total |
|--------------|---------------|-----------|---------------|----------------|------------|----------|-------|
| Capacity /MW | 2450 | 520 | 800 | 400 | 700 | 300 | 5170 |
| Proportions | 47.4% | 10.1% | 15.5% | 7.7% | 13.5% | 5.8% | 100% |

The number of various power supply units is specifically like 9 thermal power units, 4 gas power units, 2 nuclear power units, 2 pumped storage power units, 4 wind power plants and 5 PV power plants.

4.2. Simulation result

4.2.1. Scheduling result. The practicality of the multi-time scale scheduling model is verified by comparing with the day-ahead scheduling model mentioned in Reference [15]. Use PSO algorithm with inertia weight to solve the two models, and obtain two calculation results. The compared results with the actual load data on the calculation day are shown in Figure 2.

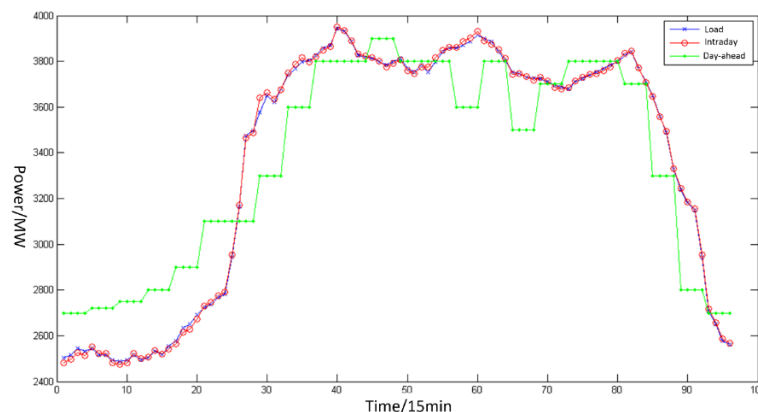


Figure 2. Scheduling results.

The blue curve with “×” mark is the actual load data of the system on the calculation day. The green curve with “•” mark is the obtained day-ahead scheduling plan. The red curve with “○” mark is the dispatching plan data using the multi-time scale scheduling model of this paper.

Through the method of multi-time scale scheduling, the data are corrected every 15 minutes to track the reality, which means to decrease the difference between the day-ahead scheduling plan and the actual output. And this little difference can ensure the security requirements of power system after adjusting power generation by AGC system. These results shows that the multi-time scale scheduling model has a remarkable effect on the optimal dispatching of unstable power systems after connected to the intermittent energy.

4.2.2. Output data of conventional units. During the intra-day dispatching process, the output data of thermal power, gas power, nuclear power and pumped storage power conventional units which is divided to 96 parts by every 15-minute periods of the day is shown in Figure 3.

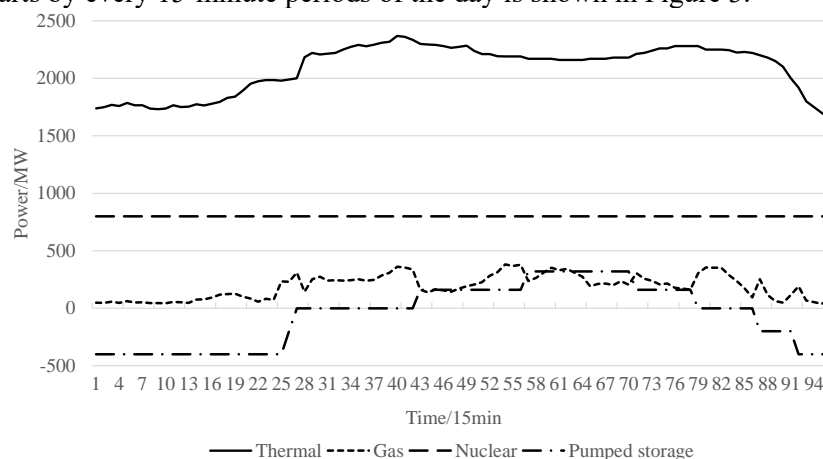


Figure 3. Output curve of different conventional units.

Thermal power and nuclear power are mainly responsible for the basic load. The output of thermal power units is basically kept between 1700 MW to 2400 MW. It's impossible at the technical level to regulate the peak load by starting or stopping a large number of thermal power units. Meanwhile, the switching action needs a great cost, which doesn't meet the optimal conditions of the objective function. As for nuclear power units, they keep full-time operation, and the total output power of the two units remains 800MW unchanged.

While gas power and pumped storage power are responsible for peak-load regulation. The adjustment speed of gas power units is fast, so it can cope with sudden power change. For pumped storage power, the power is negative at night, which means the units are working as load, and the power is positive during the day, which means the units are working as the hydropower station.

5. Conclusions

In order to ensure the safety and stability of the power grid, this paper presents a multi-time scale scheduling model with day-ahead scheduling, intra-day dispatching and AGC system. A practical example is designed and the simulation results are presented in the form of comparison diagram. The results show that this model has a significant practicability on the optimization of the power system with intermittent energy. As well, this paper analyses the output data of conventional units, and studies the different roles played by thermal power, gas power, nuclear power and pumped storage power in the dispatching process.

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