Research on renewable energy accommodation in Henan Province during the 13th five-year plan

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Abstract. As the government is promoting the development of distributed renewable energy (Renewable energy in this paper refers to wind power and solar power) in central and eastern China, the renewable energy generation in Henan Province will develop rapidly during the 13th Five-Year Plan period. In order to avoid the serious wind and solar power curtailment, this paper established an assessment model of renewable energy accommodation of Henan Province, and estimated renewable energy accommodation in Henan. Through time-sequential power system production simulation, this study drew the following conclusions: if the renewable energy installation capacity and distribution are as planned, the renewable energy curtailment rate of Henan would be 2.2% ~ 3.6% in 2020; if the distribution can be adjusted, more renewable energy will be consumed in Henan with no renewable energy curtailment.

1. Introduction
As a major coal consumption province in China, Henan is in urgent need of energy transformation. Non-fossil energy consumption in Henan Province accounted for 5.2% in 2016, 6.8% lower than the national average level. According to the 13th Five-Year Plan of Henan Electric Power Development, the reserve fossil energy resources are insufficient, while the water resources have almost been developed, so wind and solar energy development will be an important measure to improve energy structure and drive energy transformation in the future.

Compared with the scale of China's wind power and solar energy development, wind and solar energy development in Henan is small. As to the wind and solar power installed capacity, Henan province had installed 9370MW by the end of 2017, accounting for 11.8% of the total installed capacity, 4.8 percentage points lower than the national average level. Henan province and China's power structure at the end of 2017 was shown in Figure 1.

In view of the recent national support for the development of decentralized wind power and distributed photovoltaic in the eastern and central region, wind and solar energy power generation in the eastern and central region including Henan will increase massively during the 13th Five-Year period. More than 20000MW wind and solar power generation projects had been approved in Henan Province by the end of 2016. What's more, several UHV channels had been planned to supply power to Henan. Therefore, it's necessary to research whether the local wind and solar energy power generation in Henan can be consumed.
2. Research framework and model design

2.1. Research idea

Based on the simulation model of power system sequential production, this paper studies and quantifies the accommodation of renewable energy and the capacity to accommodate renewable energy in Henan province in 2020. The calculation of the renewable energy accommodation is to analyse the operation of wind and solar power generation in the system, and whether there is any curtailment under the condition of planning power structure, unit operating parameters, grid structure, and load level. The research on the capacity to accommodate renewable energy is to calculate the installed capacity of wind and solar power when there is no renewable energy curtailment. The boundary condition of the study adopts the 13th Five-Year Plan of Henan Electric Power Development Development. The load level of each city, fossil energy power and hydropower installation and layout, the operating parameters of the unit and the grid structure are given as the input parameters.

2.2. Research model

2.2.1. Objective function. The objective of the power system production simulation model is to minimize the system fuel cost. The objective function is expressed as:

$$\min \sum_{i=1}^{n} \sum_{t=1}^{8760} \left[ \alpha_i (P_i^t)^2 + \beta_i P_i^t + \gamma_i \right] H_i$$

In the formula, $\alpha_i$, $\beta_i$, $\gamma_i$ each represent the fuel cost coefficient of unit $i$. This paper assumes that the fuel cost of thermal power is subject to quadratic function, while the fuel cost of hydropower, wind power and solar power is 0. $P_i^t$ is for the power output of the unit $i$, $t=1,2,3...8760$, if the level year is a leap year, the $t$ maximum value is 8784), $H_i$ is for the unit $i$ power generation utilization hours, and $s$ for a partition or the whole system($s=0$ means the whole system).
2.2.2. Primary Constraints. System and partition power balance constraints

\[ \sum_{i \in s} P'_i + \sum_{l \in s} \Delta P'_l = L'_s \]  
(2)

\[ \sum_{s \neq 0} L'_s + \sum_{l \in s} \Delta P'_l = L'_t \]  
(3)

In the formula, \( L'_s \) stands for system or partition’s load at \( t \) hour, \( P'_i \) stands for the power of contact line \( l \) into the system or partition \( s \) at \( t \) hour.

System and partition electricity balance constraints

\[ \sum_{i \in s} E'_i + \sum_{i \in s} E'_i = E'_s \]  
(4)

\[ \sum_{s \neq 0} E'_s + \sum_{l \in s} E'_l = E'_0 \]

In the formula, \( E'_i \) represents the system or partition’s expect electricity at \( t \) hour, \( E'_l \) represents the power generation of unit \( i \) at \( t \) hour; \( E'_l \) represents the electricity of contact line \( l \) into the system or partition \( s \) at \( t \) hour.

System and partition peak regulation equilibrium constraints

\[ \sum_{i \in s} \Delta P'_i + \sum_{l \in s} \Delta P'_l \geq \Delta L'_s + R'_s \]  
(5)

In the formula, \( \Delta P'_i \), \( \Delta P'_l \) each represent the peak shaving capacity of unit \( i \) and contact line \( l \) at \( t \) hour, \( \Delta L'_s \) represents system or partition’s load peak-to-valley difference at \( t \) hour, and \( R'_s \) represents system or partition's rotational standby capacity and standby capacity for downtime.

Maximum transmission capacity constraints for contact lines

\[ \bar{Q}'_{s,l} \leq P'_l \leq Q'_s \]  
(6)

In the formula, \( \bar{Q}'_{s,l} \), \( Q'_s \) each represent the maximum transmission capacity of the contact line.

2.3. Partition settings

![Subarea and main power network in 2020 of Henan province.](image)

According to geographical location, Henan Province is divided into four regions: North Henan, Middle East Henan, West Henan and South Henan. The main network between each region is shown in Figure 2. North Henan includes Anyang, Hebi, Puyang, Xinxiang and Jiaozuo five prefecture-level
cities; Middle East Henan includes Zhengzhou, Kaifeng and Shangqiu three prefecture-level cities; West Henan includes Sanmenxia, Luoyang and Jiyuan three prefecture-level cities; South Henan includes Xuchang, Luohe, Zhoukou, Pingdingshan, Nanyang, Zhumadian and Xinyang seven prefecture-level cities. This paper establishes regional models for each prefecture-level cities.

3. Analysis of renewable energy accommodation in Henan Province

3.1. Main boundary conditions

3.1.1. Load and Electricity consumption. According to the 13th Five-Year Plan of Henan Electric Power Development, it is estimated that by 2020 the total social electricity consumption will be 376000GWh to 390000GWh and the maximum power load will be 73800MW to 76500MW. In this paper, high demand scenario and low demand scenario are constructed based on the upper and lower limit of the power consumption and the maximum power load to estimate the renewable energy accommodation in Henan Province. The load and electricity for different scenarios in 2020 are shown in Table 1.

| area               | Load and electricity for different scenarios in 2020 of Henan province. |
|--------------------|------------------------------------------------------------------------|
|                    | Low Demand Scenario                                               | High Demand Scenario                               |
|                    | Max Load (MW) | Electricity consumption(GWh) | Max Load (MW) | Electricity consumption(GWh) |
| North Henan        | 17470         | 90600                       | 18120         | 104400                      |
| Middle East Henan  | 19400         | 120700                      | 20110         | 95900                       |
| West Henan         | 11800         | 64000                       | 12220         | 73700                       |
| South Henan        | 25130         | 100700                      | 26050         | 116000                      |
| Sum                | 73800         | 376000                      | 76500         | 390000                      |

3.1.2. Power structure. According to the 13th Five-Year Plan of Henan Electric Power Development, in order to implement the requirements of the national ecological protection plan and achieve the goal of reducing the total coal consumption by 10%, Henan Province need to speed up the adjustment of power supply structure. It is expected that by 2020 the scale of coal power installed capacity will be slightly increased, the scale of hydropower will be basically unchanged due to the limit of water resources, the scale of gas power will be increased to 2960MW, the scale of wind power will be increased to 10250MW, and the scale of solar power will be increased to 14030MW. The specific power supply structure of each region is shown in Table 2.

| Capacity(MW) | Conventional coal | Thermal coal | Gas power | Hydro power | Pumped storage | Wind power | Solar power |
|--------------|-------------------|--------------|-----------|-------------|----------------|------------|------------|
| North Henan  | 20300             | 2480         | 0         | 0           | 1200           | 2910       | 4760       |
| Middle East Henan | 14420         | 2370         | 780       | 0           | 0              | 570        | 910        |
| West Henan   | 9900              | 3290         | 700       | 2350        | 0              | 3400       | 1560       |
| South Henan  | 14200             | 2160         | 1480      | 320         | 120            | 3370       | 6800       |
| Sum          | 58820             | 10300        | 2960      | 2670        | 1320           | 10250      | 14030      |

3.1.3. Minimum technical power output. According to the research data, the minimum technical power output of the conventional public coal power unit is considered as 50% of its capacity, the self-owned coal power unit is considered as 90%, the coal-fired thermoelectric unit is considered as 60% in
heating period, the gas power unit and the conventional hydropower unit are considered as 0, and the pumped-storage station is considered as -100%.

3.2. Results analysis

3.2.1. Renewable energy accommodation. The simulation results show that on the premise of lowest fuel cost, the system can achieve power and electricity balance and no load-loss occurs. However, due to such factors as the large scale installation of renewable energy, the weak capacity of system regulation, the large scale of external power and cross-sectional constraints, renewable energy curtailment has occurred in the system and some partitions. Under the low demand scenario, the renewable energy curtailment rate will be 3.6% in 2020, 1.4 percentage points higher than that under the high demand scenario. Specifically, there will be 15 cities occurring wind power curtailment under the low demand scenario, as is shown in Figure 3. The areas with high wind power curtailment mainly include Puyang, Anyang, Xuchang, Nanyang and Xinxiang, with wind power curtailment above 100 million kilowatt-hours; the areas with high wind power curtailment rate mainly include Xinxiang, Jiaozuo, Puyang, Xuchang, Kaifeng, with wind power curtailment rate above 5%. As to solar power curtailment, there will be 7 cities occurring solar power curtailment under the low demand scenario, which is shown in Figure 4. Solar power accommodation seems a little better than wind power, because wind power has the characteristics of anti-peak regulation and solar power has the characteristics of positive peak regulation. According to statistics, there will be more than 75% of the wind power curtailment in Henan province occurring in the low-load period, and more than 60% of the wind power curtailment in North Henan occurring in winter heating period when the regulation capacity of the system is low.

![Figure 3. Wind power curtailment situation in different cities under low demand scenario.](image3)

![Figure 4. Solar power curtailment situation in different cities under low demand scenario.](image4)
3.2.2. The capacity of renewable energy accommodation. As is shown in the above, renewable energy curtailment will mainly focus on North Henan. If the renewable energy layout can be adjusted, wind power can be slightly transferred to West Henan because of better wind energy resources in West Henan. According to the simulation results, on the condition that there is no renewable energy curtailment of the system, the capacity of wind and solar energy power accommodation will be respectively about 9000MW and 17000MW under the low demand scenario through adjusting the renewable energy distribution.

3.2.3. Sensitivity analysis of renewable energy curtailment. The available literature indicates that improving the regulation ability of power supply and transmission capacity of contact line, and implementing electricity replacement are effective to reduce the renewable energy curtailment [6]. If the flexibility transformation of thermal power’s capacity reaches 10000MW, the renewable energy curtailment will reduce 120GWh, as is shown in Figure 5. If the transmission capacity of inter-regional contact line rises by 50%, the renewable energy curtailment will reduce 428GWh, as is shown in Figure 6. If the scale of electricity replacement reaches 2000MW, the renewable energy curtailment will reduce 746GWh, as is shown in Figure 7.

![Figure 5. Schematic analysis of the sensitivity of thermal power flexibility transformation.](image1)

![Figure 6. Schematic analysis of the sensitivity of contact line transmission capacity.](image2)

![Figure 7. Schematic analysis of the sensitivity of electricity replacement.](image3)
4. Conclusions

This paper constructs a model of all-voltage level power system of Henan Province and simulates the power system operation. The simulation results show that if the renewable energy develops as planned, there will be renewable energy curtailment in Henan; but if the renewable energy layout can be adjusted, the power system will consume a little more renewable energy with no renewable energy curtailment. Measures such as flexibility transformation of thermal power, improvement of transmission capacity of inter-regional contact line and electricity replacement can also be taken to reduce renewable energy curtailment. Relatively speaking, the latter two measures have more obvious effect.

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