Analysis on the accommodation of renewable energy in northeast China

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Abstract. The accommodation and curtailment of renewable energy in northeast China have attracted much attention with the rapid growth of wind and solar power generation. Large amount of wind power has been curtailed or abandoned in northeast China due to several reasons, such as, the redundancy of power supplies, inadequate power demands, imperfect power structure with less flexibility and limited cross-regional transmission capacity. In this paper, we use multi-area production simulation to analyse the accommodation of renewable energy in northeast China by 2020. Furthermore, we suggest the measures that could be adopted in generation, grid and load side to reduce curtailment of renewables.

1. Introduction
Recently, wind power in northeast China has been largely curtailed with increasing installed capacity. National Energy Administration (NEA) has promulgated series of policies to improve the accommodation of wind power in northeast China, such as "Guidelines to promote the coordinated development of power sectors in northeast China". These policies aimed to control the growth rate and installed capacity of renewable energy in northeast China. However, the curtailment of wind power is even getting worse than ever before.

In the future, it is planned to construct more coal-fired power plants, nuclear plants, which might lead to greater challenge to the accommodation of renewable energies. How to mitigate the curtailment of renewables and enlarge the accommodation range and scale, is important to promote the revitalization of northeast industrial base [1].

2. Development status of renewables in Northeast China
At the end of 2015, the total power installed capacity is about 121GW in northeast China (including Eastern of Inner Mongolia), as shown in Figure 1. Power supply in northeast China mainly consist of coal-fired, wind and hydro, with installed capacity of 84.5GW, 24.7GW and 8GW, respectively, which account for 97% of total installed capacity. The installed capacity of solar power is about 0.8GW in northeast China. Meanwhile, peak load of northeast China power grids is about 54.4GW. There are two cross-regional transmission lines located in northeast China grid and connected with northern China grid. Total transmission capacity is about 5GW.
According to statistics, in 2015, total curtailment of wind power in northeast China is up to 8100GWh, accounting for 17.4% of theoretical wind generation. Wind curtailment ratio of Jilin, Heilongjiang, Liaoning and Inner East Mongolia reached 14.6%, 31.1%, 20.5% and 10.3%, respectively. Curtailment of solar power didn’t occur in northeast regions.

3. Reasons that lead to curtailment of renewables in northeast China

Main reasons that cause the serious curtailment of renewables in northeast China could be summarized as follows:

First reason is the serious redundancy of power supplies and inadequate power demands in northeast. The growth rate of power demands has been slowed down recently, which exacerbate curtailment of renewable energy. During 12th Five-Year period, total installed capacity of power supply in northeast increased by 37%, 20 percentage points higher than that of load growth. In 2015, the installed capacity is 2.2 times larger than maximum load. It indicates prominent redundancy electricity phenomenon. The utilization hours of coal-fired power plants in northeast China has been declined rapidly since 2006, which decreased from 5900 hours in 2006 to 4079 hours in 2015. At the same time, electricity demand growth slowed down in the northeast. The growth rate of electricity consumption became negative in 2015, which is 2% lower than that of last year. It leads to great difficulties to the accommodation of electricity (including renewables) in local regions.

Second reason is the imperfect power structure. The proportion of flexible power source to total installed capacity is relatively low in northeast China. 70% of the power is supplied by coal-fired power plant, while over 60% of coal-fired plants are combined heat plants (CHPs) in each province of northeast China, especially in Jilin province with a percentage of 75%. In winter, most CHPs didn’t participate in deep peaking with mere flexibility, ranges from 15%-20%. However, windy days and hours coincide with heating periods in northeast. As a result, there are great contradictions between heat demands and power balance, the accommodation of renewable energy and minimum operating level of CHPs. In addition, the installed capacity of captive coal-fired power plants (most of them are CHPs, as well) accounted for more than 10%. Load of these captive power plants is relatively fixed and merely participate in peaking load, which gives rise to the decline of power output level of public plant and renewable energy.

Third reason is the cross-regional transmission capacity could not meet the requirement of renewable energy accommodation in large spatial range. At present, the northeast power grids are connected with northern China power grids only by Gaoling back to back DC transmission project and Suizhong power plant grafting project. Suizhong power plant grafting project operated as “point to grid” mode with the capacity of 2GW and mainly deliver coal-fired power generation. It means that actual delivery capacity of northeast China is around 3GW, while the electricity surplus of northeast is more than 20GW.
4. Accommodation of renewables in Northeast China during “13th Five-Year” period

4.1. Development planning of power in northeast during “13th Five-Year” period

Based on power demand and power source structure forecast of “13th Five-Year” period in northeast China, we established a development scenario of renewable energy. Power demand of northeast China will be 450 TWh and the maximum load will reach 70GW at the end of 2020. Zarud-Qingzhou UHVDC (ultra-high voltage DC) transmission lines and Yuanbaoshan power plant grafting project will be put into operation by 2020. Total installed capacity of northeast will be around 150GW at the end of 2020. Each type of power generation is listed as Table 1.

| Generation   | 2020 |
|--------------|------|
| Coal-fired   | 95   |
| Gas-fired    | 0.3  |
| Hydro        | 7.9  |
| Pumped Hydro | 3.5  |
| Nuclear      | 6.7  |
| Wind         | 30   |
| Solar        | 5    |
| Biomass      | 2    |

4.2. Multi-area production simulation model

Aiming to analyse the accommodation of renewable energy in northeast China by 2020, we established a multi-area production simulation model. Production simulation of power system involves the unit maintenance or unit commitment and economic load distribution, power system balance and system peak load balance, etc. Multi-area power production simulation model will take technical and economic characteristics of various types of generation units into consideration, to ensure safe and stable operation of power systems and the continuous power supply.

Objective function:

Main objective function of multi-area production simulation is to optimize the operation cost or pollutant emission of power systems and mitigate the curtailment of renewable energy, listed as following [2-5]:

\[
\text{LeastCost} = \min(E_{\text{wind}}) \cap \min(E_{\text{solar}}) \cap \min(E_{\text{hydro}}) \cap \max(\overline{P}_{\text{hydro}} + R_{\text{hydro}}) \cap \max(\overline{P}_{\text{wind}} + R_{\text{wind}}) \\
\cap \max(\overline{P}_{\text{solar}} + R_{\text{solar}}) \cap \max(\min(\Delta P_{\text{wind}})) \cap \min(F(P_T)) \cap \max(\min(\Delta P_{\text{coal}})) \cap \min(\Delta E_s)
\]  

(1)

Where, \( E_{\text{wind}} \), \( E_{\text{solar}} \) and \( E_{\text{hydro}} \) represents curtailment of wind, solar and hydro respectively. \( \overline{P}_{\text{hydro}}, \overline{P}_{\text{wind}}, \overline{P}_{\text{solar}} \) mean that Hydro, pumped hydro and nuclear power plant should generate as much as possible under the consideration of reserve capacity \( \overline{R}_{\text{hydro}}, \overline{R}_{\text{wind}}, \overline{R}_{\text{solar}} \). \( \Delta E_s \), \( \Delta P_{\text{coal}} \) are defined as electricity shortage and power surplus. \( P_T \) is the power output of coal-fired power plant. As to coal-fired power plant, the operation cost should be least to minimize the abundancy or insufficient of power supply month by month.

Main constrains [6-7]:

1. power balance: the output power of plants in local area and transmission power delivered into this area should meet with the load.
2. electricity balance: the generation of local power plants and electricity delivered into this area should meet with the electricity demands.
(3) reserve: load, rotating and failure reserve are the sum of reserve capacity that each power plant could provide, and larger than the minimum requirements of system or areas.

(4) peaking: peaking load capacity should larger than the sum of failure reserve and load peak-valley difference.

(5) transmission capacity: forward or backward delivering power should not exceed the transmission capacity.

(6) maintenance: simultaneous maintenance unit should be under the maintenance field constraint.

(7) emission: air emissions, such as CO$_2$, SO$_2$, NO$_x$ and dust, should be within the given limitations.

**Optimization flowchart:**

First of all, optimal power and electricity exchange between different areas are obtained under the delivery capacity constraints of cross-regional transmission lines, by promoting technical and economic characteristics of each power plants. And then, unit commitment of coal-fired power plants in each area are calculated and optimized according to power and electricity balance. Finally, the location and capacity of each power plant to fulfil load requirements will be determined. The curtailment of renewable energy is obtained, as well [8-9].

### 4.3. Accommodation of renewables in northeast by 2020

Considering all kinds of unit maintenance, congestion, reserve, the results of multi-area production simulation indicates that electricity surplus amounted to 26GW-28GW of northeast China by 2020 and the curtailment of renewables is about 15.1%. Based on this development scenario, maximal accommodation capacity of northeast China might be around 10GW as the curtailment is limited under 5%. Furthermore, when we mitigate the curtailment under 10%, maximal accommodation scale could be improved to 18GW.

### 4.4. Measures to mitigate the curtailment of renewables

In the generation side, the minimum technical output rate of the CHPs in heating period could be reduced to release more flexibility and accommodate more renewables. If costly technical retrofitting measures are not carried out in northeast, the minimum technical output rate of CHPs could be adjusted from 80% currently to 70%. As a result, the curtailment of renewable can be reduced to 6% in northeast region by 2020. Meanwhile, operating costs of coal-fired power plant decreased by nearly 1.7%, and carbon emissions decreased by 1.9%, as shown in Figure 2.

![Figure 2](image-url)

**Figure 2.** Simulation results of the generation side measures in mitigating renewable curtailment

In the grid side, it is an effective way to mitigate curtailment by increasing cross transmission power. It could release more flexibility of transmission lines during the valley load period, such as nighttime. Simulation results showed that the curtailment of renewables could be mitigated 6 percentage points by increasing delivery power of Gaoling back to back DC transmission project and Zarud-Qinzhou UHVDC transmission lines at nighttime from 50% to 70%, as given in Figure 3. Utilization hours of coal-fired power plants in northeast grids increased from 3994 hours to 4057.
hours, while that of Shandong province (receiving side of Zarud-Qingzhou UHVDC transmission lines) might reduce by 98 hours.

![Figure 3](image1.png)

**Figure 3.** Simulation results of the grid side measures in mitigating renewable curtailment

At the load side, it is important to increase the load level in windy period. There are several ways to increase load level, such as, wind heating, demand side response, TOU (time of use) electricity price mechanisms, etc. It is assumed that 2GW load would be released at load valley period by 2020. As a result, the curtailment of renewables in northeast might be mitigated by 3 percentage points, as shown in Figure 4.

![Figure 4](image2.png)

**Figure 4.** Simulation results of the load side measures in mitigating renewable curtailment

5. **Conclusions**

According to production simulation on the accommodation of renewable energy in northeast China by 2020, the way to mitigate curtailment could be concluded. In short-term, by promoting the construction of market structure and incentive policies for renewable energy accommodation in northeast regions, under the premise of not significantly increasing power system operation cost to release flexibility of generation, grid and load, the curtailment of renewable could be largely reduced. The measures include moderately reducing minimum output level of CHPs in heating period, adjusting operation curves of cross-regional transmission lines. In the long-term, it is realistic to simultaneously strengthen mitigation measures in generation, grid and load, such as flexibility retrofitting of coal-fired power plants, demand side response, encouraging active loads by incentive policy and beneficial mechanisms. Meanwhile, the inner power grids structure should be planned, optimized and strengthened in northeast China.

5. **References**

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