Energy xxx (2016) 1–10

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Case study of the constraints and potential contributions regarding wind curtailment in Northeast China

Weiming Xiong [a], Yu Wang [a], Brian Vad Mathiesen [b], Xiliang Zhang [a, *]

[a] Institute of Energy, Environment and Economy, Tsinghua University, Sino-Italian Energy and Environment Building, Beijing, 100084, China
[b] Department of Development and Planning, Aalborg University, A.C. Meyers Vænge 15, DK-2450, Copenhagen SV, Denmark

ARTICLE INFO

Article history:
Received 2 October 2015
Received in revised form
5 March 2016
Accepted 20 March 2016
Available online xxx

Keywords:
Wind power integration
Wind curtailment
Renewable energy
Heat storage
Heat pump

ABSTRACT

The wind power industry in China is faced with the obstacle of ineffective use due to severe wind curtailment recently. With detailed representation of the electricity and heat sectors in an energy-system-modeling tool, we evaluated the potential of technical improvements that could be implemented to increase wind integration in Northeast China. First, different regulation modes are compared and analyzed. Then, sector integration between the heat and electricity sectors is simulated assuming heat storage and large-scale heat pump utilization. While current regulation rules hamper wind integration, there are no apparent technical barriers to ramp up/down more flexible for wind power generation in Northeast China. The results also indicate that the implementation of heat storage and heat pump could enhance the flexibility of an energy system, making it able to accommodate an increase of wind penetration. Thus, more flexible dispatch rules and integration between the electricity and heating sectors are believed as mature technical solution to increase wind integration in Northeast China.

1. Introduction

Wind power is regarded as the most mature renewable energy technology to mitigate carbon emission and air pollution in China. Therefore, wind industry has received strong support from Chinese central government through series of policies. Consequently, the total installed capacity of wind power has reached 91.4 GW in 2013 [1], which makes China the largest wind market in the world. In the 12th-Five year plan released by National Energy Administration, China had set the ambitious target of 200 GW for wind power capacity by 2020 [2]. Especially, the NCG (Northeast China Grid zone), known a s an autonomous electricity grid zone comprising Liaoning, Jilin, Heilongjiang and eastern part of the Inner Mongolia, is one of the five main grid zones in China. As the one of the most significant seven large-scale wind basements, wind capacity in NCG accounted for 30.1% of the national total [3]. With rich wind potential and limited hydropower resource, wind power is becoming the second largest generation source behind coal-fired power in NCG. In 2012, the share of wind power in total electricity generation and installed capacity in NCG are 17.5% and 13.8%, respectively [4].

Although wind industry has achieved a rapid growth since the beginning of this century, wind power curtailment has occurred in recent years, especially in the NCG. The wind curtailment means the available wind power is refused by grid and the wind turbines have to be closed due to safety, technology, grid congestion and other reason. In 2012, the total wind curtailment has exceeded 20 GWh, meaning that 17% of available wind power is wasted [5]. It is reported that NCG is critically affected by the inefficient utilization of wind power, where is the home for 45.4% of wind curtailment in the country [6]. The issue has imposed obvious impact to the incomes of wind farms, which would weaken the enthusiasms of wind investors. In order to improve the utilization level of large-scale wind power development, it is important to implement potential solutions to decrease wind curtailment in NCG.

A few existing studies have attempted to analyze the causes of wind curtailment in China. Cong has pointed out the optimal generation mix of wind, solar and biomass would increase the maximum utilization of renewable energy from system perspective [7]. Luo's analysis indicates that the planning methods and grid management in China are the main obstacles for effective wind utilization [8]. With the combined system of CHP (combined heat and power) and electric boilers, the curtailed wind power could be decreased through the integration of electricity system and heating system in Chinese existing energy sector [9]. Particularly, due to the

* Corresponding author. Room 325, Sino-Italian Energy Saving Building, Tsinghua University, Beijing, 100084, China. Tel.: +86 10 62796166; fax: +86 10 62772759.
E-mail address: zhang_xl@tsinghua.edu.cn (X. Zhang).

http://dx.doi.org/10.1016/j.energy.2016.03.093
0360-5442/

lack of market-based pricing signals, wind power is abandoned by dispatch center NCG in some circumstances if annual contracts for coal-fired power must be guaranteed [10]. The technical limitation from electricity grid led to some serious power grid accidents related with wind power but China has already improved grid codes for wind power [11]. As the coldest region in China, the high penetration of CHP in NCG to supply district heating in winter has also constrained the wind power integration according to high utilization level of on-line CHP units [12]. In summary, the lack of flexible regulation at policy side and conflicts between heat and power in winter are believed as the key limitation for wind curtailment in cold regions in China such as NCG, while the pure technical issues do not play important role in this.

To the best of our knowledge, few studies have attempted to quantify the potential impact of decreasing wind curtailment in China. Specifically, interaction between the electricity and heat sectors has been largely overlooked in China, whereas previous work has proposed the merging of energy sectors to be the main solution for the integration of renewable energy [13]. In addition, in the next generation of district heating system, the integration of renewable energy is defined as the key part of implementation of sustainable heating system [14]. Thus, our goal is to fill in this gap in the research taking NCG as a case study. Based on energy system modeling, the aim of this paper is to discuss and quantify the technical solutions available for optimizing the effective use of fluctuating wind power in the Northeast region, which could promote further development of wind power energy in China.

The remainder of this article is organized as follows. First, an overview of the existing energy system in the NCG is presented. Then, the method used to simulate the energy system in the study area is described with technical details. Following this, the potential improvements in regulatory modes and interaction with the heat sector are identified based on several scenarios. Finally, discussion and the conclusion are provided.

2. Materials and methods

2.1. Overview of NCG energy system

NCG region encompasses an area of 1.2 million km^2 with a population of 109 million, accounting for 10.7% of the national GDP (growth domestic product) in 2012 [15]. As one of the six main electricity grid regions in China, NCG's generation capacity in 2012 was 106 GW, in which coal-fired power and wind power provided 78.4 GW and 18.4 GW respectively [3]. In 2012, annual electricity demand in NCG was 378 TWh and the net export to neighboring regions was only 10.9 TWh [4]. Thus, here we simulate NCG as a single isolated grid zones from the perspective of energy balance when limited export is included in total consumption.

With abundant rich resource, the wind power development in NCG has accelerated since 2006 for the purpose of carbon emission mitigation [16], which reached the annual generation of 17.1 TWh in 2012 accounting for 13.9% of total [17]. The demand for space heating in NCG is 275 TWh, of which 57% is supplied by co-generation plants and the rest is from coal-fired heat-only boilers [4]. A large number of coal-fired extraction-mode CHP units are required to be on-line during the long-term heating period (roughly October to April), which limits the ability of CHP to participate in the load following as heat demand must be met first.

2.2. Energy system modeling tool

In order to simulate large-scale wind integration in a region with high heat demand for CHP such as NCG, an energy-modeling tool capable to represent the fluctuations of the renewable energy and interaction between heat and electricity is required. Previous studies have already developed modeling frameworks to evaluate the renewable energy integration combined with heating system. For instance, heat production management to facilitate wind integration with CHP and electric heat pumps has been investigated using a unit-commitment model for Beijing, China [18]. Kiviluoma and Meibom used a linear programming model to find the cost-least capacity expansion of renewable energy capacity from the perspective on both electricity and district heating sectors [19]. EnergyPRO was used to simulate and optimize the output of heat production and power production for CHP unit with high-penetration of wind energy in Western Denmark [20]. In summary, to determine the hourly wind output in high heat demand grid region is generally described as a mixed integer linear program optimization problem which accounts for both technical constraints and economic criteria. Unit commitment and economic dispatch models are widely used to simulate wind integration evaluation from the perspective of overall energy system including the variation characters of wind energy, CHP, heat storage and power demand [21]. However, data access of unit-level technical details in China is not available. Furthermore, mixed linear program to capture the suitable technology details for wind integration in NCG will require expensive computation sources to deal with thousands of variables and parameters at generation-unit level.

To address these issues, we use an hourly dispatch model, EnergyPLAN to simplify the calculation of utilization of renewable energy through hourly optimization of least-fuel consumption. The model is based on analytical programming process which is opposed to iteration, linear programming or other advanced mathematical tools. Different with unit commitment or economic dispatch models, EnergyPLAN can be used to seek for the hourly simulation over one year of renewable energy production, heating production, hydrogen use as aggregated data through “generation layers”. The model is a deterministic input/output model for energy-system simulation and analysis in hourly time-steps, which can be applied to analyze different regulation strategies with regard to heat and power supply, import/export, ancillary services, grid stability, and excess electricity production, see in Fig 1. Various thermal, renewable, storage/conversion, and transportation technologies are included in the model to allow the reconstruction of energy systems in order to increase system flexibility with high penetrations of intermittent renewable energy sources and CHP plants [22].

Particularly, curtailed renewable energy is modeled in terms of production, conversion and demand on both electricity and heat sectors where categories of technologies are aggregated to represent one “unit”, which is capable of identifying the energy balance in both the electricity and the heat sectors in NCG region. Typical studies based on EnergyPLAN have been used to evaluate different regulation strategies for the management of the integration of fluctuations in electricity production from renewable energy sources in Scandinavia countries, which are similar with NCG in terms of high heat demand and rich wind resource [13,23]. In addition, this model is applied to reveal the benefit of integration between heat and electricity system to absorb renewable energy in both Europe and China, which is the main scope of this paper [24,25]. As the aim of this study was to analyze the potential of large-scale integration of fluctuating wind power in electricity-heat integrated energy system, EnergyPLAN is applied to simulate the wind integration in case study of NCG due to its unique advantage of detailed description of heat demand and heat production technologies.

Please cite this article in press as: Xiong W, et al., Case study of the constraints and potential contributions regarding wind curtailment in Northeast China, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.03.093