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A wind-hydrogen energy storage system model for massive wind energy curtailment

Guotao Zhang, Xinhua Wan*

New Technology Department, R&D Center, Goldwind Science & Technology Co., Ltd., No. 8, Bo Xing 1st Road, Beijing Economic & Technological Development Zone, Beijing 100176, China

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ABSTRACT

With wind energy penetration rate increasing, wind energy curtailment turns severe in some wind farms nowadays and new wind farm construction trends to aggregate this situation. Therefore the need for massive energy storage technology such as "Power to gas" is growing. In this study, a model of integrating curtailed wind energy with hydrogen energy storage is established based on real time data in term of 10 min avg. throughout a whole year in a wind farm. Two wind/hydrogen production scenarios via water electrolysis are given and the influence exerted on payback period by electrolyser power and hydrogen price is talked in tandem as well as the model validity is specified in the conclusion section. Our results further stress the importance of hydrogen energy storage technology on addressing wind energy curtailment and disclose some regularities from an economical perspective.

1. Introduction

The total installed capacity of wind turbines of 2012 all over in China has been up to 75.3 GWs with a growth rate of 20.8% comparing to that of 2011 while the annual net growth rate has been declining every year since 2010 [1]. However, the average equivalent full load hours of wind turbine climbed down from 1920 H in 2011 to 1890 H in 2012. A total estimated electricity loss in 2012 is 20 billion kWh and the situation trends to worsen with more and more wind turbine installed. The reasons of such severely curtailed wind energy phenomenon lie mainly on: 1) the outputs of wind farms are intermittent and fluctuating on the time terms of seconds, minutes, hours, days and seasons [2] and the wind power peaks do not overlap well with the local electric demand peaks; 2) the wind farms are geographically distant away from power load centers, esp. in north of China from northwest to northeast, and the transmission capacity of power grids cannot meet the real needs as its construction falls far short of the wind farm development.

Large-capacity energy storage technologies, namely pump hydro energy storage, compressed air energy storage and hydrogen-based energy storage, are taken as effective methods to address the problem of massive wind energy curtailment and improve renewable energy penetration [3,4]. As the applications of the former two are geologically limited, hydrogen-based energy storage technology via water electrolysis is considered as a flexible way by virtue of its broad energy storage period length, fast response time and geographical convenience, even though its roundtrip efficiency is not very high when the stored energy is converted back to the term of electricity [5]. As an energy carrier, hydrogen is utilised in several main applications such as

* *Corresponding author*. Tel.: +86 (0) 10 67511888x1827; fax: +86 (0) 10 67511888x1983.
E-mail addresses: guotao.jun@163.com (G. Zhang), wanhua@gmail.com (X. Wan).
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Nomenclature

Acronyms

PMDD	permanent magnet direct drive
SCADA	supervisory control and data acquisition
t	transient 10 min avg. time
$v_{n,t}$	Wind speed of *n*th wind turbine at time t
$P_{n,t}$	*n*th wind turbine real power at time t
$\overline{v_t}$	average wind speed at time *t*
$\overline{P_t}$	theoretical average wind turbine power at time t
$P_{t,g}$	wind power transmitted to grid
$\Delta P_{t,c}$	wind farm curtailed power at time *t*
$E_{n,t}$	*n*th wind turbine real wind energy in 10 min at time *t*
$\overline{E_t}$	theoretical average wind turbine energy in 10 min at time *t*
$\Delta E_{t,c}$	wind farm curtailed wind energy in 10 min at time *t*
Q_{H_2}	hydrogen production
E_{H_2}	wind energy used for electrolyser system
μ	electrolyser average energy consumption
E_C	curtailed wind energy used for electrolyser system
E_{grid}	grid electricity used for electrolyser system
P_e	electrolyser rated power
$T_{\Delta Pt,c \geq Pe}$	total time when $\Delta P_{t,c} \geq P_e$
$T_{\Delta Pt,c < 25\%Pe}$	total time when $\Delta P_{t,c} < 25\%P_e$
PP	payback period
H	equivalent full load hours
ρ	hydrogen price

directly fuelling for fuel cells, powering internal-combustion engines, blending with natural gas in pipelines, and recycling CO_2 into fossil fuels [6]. What's more, both hydrogen and oxygen are important raw materials for chemical plants such as oil fineries and so on [7].

A recent review article provides information about numerous hydrogen-based energy storage experimental/pilot plants, realized or being planned worldwide, which is also called power to gas [8]. This review article shows the total installation at operation or planning stage, mainly utilised for wind energy storage, has dramatically increased since 2010, most of which are below 1 MW. With water electrolyser efficiency, reliability, lifetime and cost improving, the power of a single installation trends larger and larger as the electrolyser modularisation is very flexible in its system sizing [9] and thus technical problems for large scale applications can be overcome. But it is necessary to make a precise model close to the real wind farms in addressing massive wind energy curtailment for large real wind farms by means of hydrogen energy storage before any large wind/hydrogen installation.

Beccali M et al. [10] modelled wind energy deployment for an assumed grid-connected wind farm in central Sicily and described an optimisation method for power systems in which possibly curtailed wind energy is used to produce hydrogen by water electrolysis. They discussed four scenarios of different wind penetration rates in the electrical systems for transportation and stationary use. But in their models there were several disadvantages as follows:

1) The wind speed was processed with hour as minimum time unit, which is not enough for a precise calculation for wind turbine output throughout a whole year as the accuracy of this method depends intensely upon the accuracy and reliability of the initial wind farm data.
2) Two fractions of surplus wind energy could not be used to produce hydrogen-higher than the electrolyser rated power and lower than its idling threshold (20% of rated power).
3) If keeping the electrolyser a stable rated power without extra power from grid, it would work intermittently, which exerts negative influence on electrolyser efficiency, lifetime and hydrogen purity [11–13]. Actually operating electrolyser part time can only reduce the average hydrogen production cost to a limited extent [14].

In this study, a new model of integrating wind energy with hydrogen production was established which was based on utilising curtailed wind energy and thereafter evaluating loss offsetting for a severely curtailed grid-connected wind farm in North of China. The original data of both wind speed and real-time output for every wind turbines in the wind farm were collected throughout a full year in term of 10 min as minimum time unit and therefore there were totally 52560 numbers for each item, which could ensure the model simulation's accuracy. And the electrolyser sizing in this model was handled by means of unit modularisation and all the unit electrolysers were set to work with its real-time power varying from 25% to 100% of its rated power. We discussed two scenarios of how electrolyser worked:

1) Continuous operation with power grid's extra electricity when curtailed wind power could not meet 25% of the rated electrolyser power or when the speed came to wind turbine's cut-out speed;
2) Intermittent operation without any other power source supply when curtailed wind power was not enough for starting electrolyser.

2. System description

2.1. Wind farm data

The wind farm is located in central north of Inner Mongolia and consists of 66 Goldwind's GW77/1500 PMDD wind

Table 1 – Goldwind's GW77/1500 PMDD wind turbine specification.

Rated power kW	Cut-in wind speed m/s	Rated wind speed(static) m/s	Cut-out wind speed m/s in 10 min avg.	Rotor diameter m	Swept area m^2
1500	3	11	22	77	4649