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Theoretical analysis of a wind heating conversion and long distance transmission system

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ABSTRACT

As a clean and renewable energy, wind power gets a rapid growth in recent years. With the increasing proportion of wind power generation, the fluctuation and intermittency of wind energy impedes the safe and stable operation of national power grids, which causes wind curtailment and energy waste, hindering further development of wind power industry in China. To solve this problem, wind heating conversion was proposed. However, long distance transmission between wind fields and residential areas for thermal energy is an urgent issue for wind heating. This paper presents a novel wind heating conversion and long distance transmission system. A simple device was utilized for wind heating conversion in the present system, then thermal energy was transported to heat demand site through latent heat transmission of the working fluids. A model of the novel system was built and thermodynamics analysis showed that maximum transmission distance of the novel system could extended to 240 km, 9.6 times of that of typical hot water transmission system. And the novel system also could cut down the cost by greatly reducing pump work and pipe diameter. In addition, efficiency and circulation ratio was almost unchanged while wind power density increased from 350 W/m^2 to 650 W/m^2.

1. Introduction

Due to fuel prises rising, carbon dioxide emissions, global warming and energy source security, a number of countries have been committed to the development of renewable energy. Wind power shows huge potential for its rich resources and mature technology [1]. Wind power has developed dramatically in the present decades, for example, the total installed capacity for wind turbines in China exceeded 40,000 MW in 2010 [2,3]. However, the increasing proportion of wind power generation also brings a lot of new challenges and difficulties [4–8]:

(1) When incorporated into the main electricity grid, the fluctuation and intermittency nature of wind energy would bring about a series of problems such as peak regulation and frequency modulation.
(2) The fluctuation characteristic of wind energy and inadequate grid infrastructure would cause large area blackout.
(3) The difficulties in the real-time balancing process of wind power generation and consumption.
(4) Different from the scattered distribution and local accommodation mode of Germany, Denmark, Spain and the other countries, China's wind power is developed in a large-scale concentrated way, mainly in North China, Northwest China and Northeast China which are rich in wind resources and account for 83.4% of the total installed capacity of wind power.

The reverse distribution of wind power resources and load and large-scale concentrated develop mode make China the country with the highest input voltage, and wind power generation is normally transmitted to a long distance through the high-voltage channel [8]. Therefore, "Abandoned Wind Power Rationing" appeared gradually in China, which refers to the phenomenon that wind power generation is not put on grid and the wind turbines have to be shut down because of safety control, grid access management and other reasons [9,10]. Gu [9] proposed "Non Grid Connected Wind Power theory" to this issue, which directly applies wind power into a series of high energy consumption industries without power grid. Wind curtailment first appeared in wind power development in 2010 in China [8]. In 2011, the curtailed wind power in total exceeded 10 billion kW/h, equaling to losses of 3.3 million tons of standard coal [10]. Gansu, Inner Mongolia, Jilin and Heilongjiang accounted for 80% of the total curtailed wind

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Nomenclature

Variables

A	swept area of wind turbine blade, m^2
C_p	wind energy utilization coefficient
C_{pmax}	maximum wind energy utilization coefficient
D_h	actual discharge capacity of oil hydraulic pump, m^3/rad
D_r	wind turbine blade diameter, m
d	pipe diameter, mm
E	efficiency of wind power utilization
F	concentrated solution circulation ratio, kg/kg
h	specific enthalpy of working fluids, kJ/kg
K	resistance coefficient of damping throttle orifice
l	heating transmission distance, km
m	mass flow rate, kg/s
P_f	wind energy caught by wind turbine, W
P_h	thermal energy of the hydraulic oil, W
P_k	the kinetic energy of the hydraulic oil, W
P_0	wind energy through the swept area of wind turbine blade, W
P_p	pressure energy of the hydraulic pump, W
Q_P	energy losses of the working fluids, W
Q_t	thermal energy, W
q	heat dissipating capacity per unit area, W/m^2
R	wind turbine blade radius, m
Re	Reynolds number
u	average velocity of working fluids, m/s
v	wind velocity, m/s
W_l	heat loss of three pipelines, W
W_p	friction resistance loss of the working fluids, W
w	wind power density, W/m^2
x	concentration of ammonia solution, kg/kg

Greek letters

ρ_{air}	air density, kg/m^3
ρ_f	working fluids density, kg/m^3
λ_{tip}	tip speed ratio
Ω	angular velocity of hydraulic pump shaft, rad/s
η_w	wind turbine efficiency
η_e	wind heating conversion efficiency
η_g	gear transmission efficiency
η_p	delivery pump efficiency
η_{ep}	power generation efficiency
ΔW	system energy loss, W
ΔP	pressure loss, MPa
λ	coefficient of friction resistance
ε	relative pipe roughness, mm/mm

Subscripts

abs	absorber
am	ambient temperature
as	ammonia-strong solution
aw	ammonia-weak solution
con	condenser
eva	evaporator
gen	generator
hr	hot water return pipe
hs	hot water supply pipe
rec	rectification tower
ref	refrigerant ammonia

power of China. The curtailment of wind installed capacity always maintains at a high level, and in Jilin province the average ratio of abandoned wind power generation reached 32% in 2014 [11,12].

Wind energy resource is abundant in North China. However, wind curtailment in corresponding areas has been a new challenge. Those areas are very cold in winter, and the heating period in some districts last for 6 months per year, thus heat demand is very large. The existing heating methods in those areas are coal-fired heating, natural gas heating and electric heating, which bring energy consumption and environmental problems such as oppressive haze, greenhouse gas effect and serious pollution [13–15].

On the one hand, the difficulties in wind power integration caused wind curtailment phenomenon and low investment return of wind farms; on the other hand, the existing heating method in North China caused the energy consumption and serious environmental problems. Therefore, developing wind heating conversion technologies not only can solve the problem of wind curtailment, but also can reduce energy consumption. As a complement of wind energy utilization, wind heating conversion has aroused widespread concern under the circumstances.

Wind power generation should not be the independent energy supplier for the heat users because of the fluctuation and intermittency characteristics of wind energy [14]. And in the existing heating method in China, wind generation and heating system are typically the combination of wind power generation and thermal energy plant [14,15]. And the existing heating method does not meet the requirements of the principle of energy cascade utilization.

Considering heater cost, electric converter cost and operation duration and flexible wind speed range, wind heating conversion has advantages over the combination of wind power generation and thermal plant system [16]. Current research of wind energy utilization mainly focused on two aspects: wind power generation and wind heating [17–19]. The wind power generation technique often produces large energy losses during mechanical energy to electrical energy conversion [19,20].

Wind heating conversion method is divided into two categories. One is wind direct heating, including solid friction heating, fluid agitated heating, and hydraulic damping heating; the other is indirect heating system in which wind energy is firstly converted into electricity (or other energy type) and then converted into thermal energy, such as thermal resistance heating, eddy current heating, electrolytic water heating, compressed air heating [21]. For wind direct heating system, it is usually assumed that all produced mechanical energy is transform into thermal energy. For example, the experimental device of hydraulic damping wind heating system has high reliability and long-life-expectancy, matching with wind turbine better, thermal dissipation problem can be easily solved consequently [22].

In general, wind field always locates at remote open areas, far away from heat demand site. Therefore, how to implement the long distance transmission of thermal energy is a challenge [23]. Kang et al. [24,25] proposed an absorption system called STA for thermal energy transportation. Jiang et al. [26] proposed a long distance energy transportation method utilizing an absorber for heating at the heat demand site. Ma et al. [27–30] set up an experimental prototype to verify the feasibility of the circulation.

Wind heating conversion is of great significance in avoiding the instable operation of power grids, reducing energy consumption and being environmental friendly. However, the development of wind heating conversion must solve the problem of long distance transmission of thermal energy.