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Dynamic performance of the standalone wind power driven heat pump

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Abstract

Reducing energy consumption and increasing use of renewable energy in the building sector are crucial to the mitigation of climate change. Wind power driven heat pumps have been considered as a sustainable measure to supply heat for detached houses, especially those that even don't have access to the grid. This work is to investigate the dynamic performance of a heat pump system directly driven by a wind turbine. The heat demand of a detached single family house was simulated in details. According to the simulations, the wind turbine is not able to provide the electricity demanded by the heat pump all the time due to the intermittent characteristic of wind power. To solve it, an electric energy storage system was included. Obviously, increasing the size of battery can always reduce the probability of load loss. However, different from the energy storage system, increasing the capacity of wind turbines is not necessary to reduce the probability of load loss instead, due to the different start-up speeds for different capacities of wind turbines. In order to maximize the system benefit, it is of great importance to optimize the capacity of the wind turbine and the size of the energy storage system simultaneously based on dynamic simulations.

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Keywords: wind power, heat pump, dynamic performance, space heating, standalone system, probability of load loss

1 Introduction

Today, the building sector has consumed more energy than the industry sector, the transport sector, the agriculture and non-energy use sector, accounting for more than one third of the world's energy

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consumption [1]; and more than 50% is used for space heating and cooling [2]. In Sweden, the energy consumption for space heating and domestic hot water (DHW) production reached 100TWh in 2014 [3]. Sweden has already set a target to reduce it by 20% by 2020 and 50% by 2050 comparing to the level in 1995 [4]. In order to achieve a sustainable development, reducing energy consumption in the building sector is playing an important role.

In Sweden, there are different ways to supply heat, such as district heating (DH), and using heat pumps (HP), electrical radiator, and biomass/oil/gas boilers. Even though, DH is the most common way to supply heat, accounting for more than 50% of the total heat demand, there are still many single family houses that are not connected the DH network. Heat pumps represent an energy efficiency technology for heat production; however, the share of HP in the Swedish heat market is not very high unfortunately, only covering a little more than 20% of the heat demand [5]. Meanwhile, although there is a tiny share of power from fossil fuel in Sweden, nuclear power accounts for a big proportion, more than 40% [6]. Nevertheless, nuclear power will be phased out in Sweden, therefore, more power should be explored from other renewable resources, such as wind power. Wind power has experienced a fast growth in the past 10 years. The installed capacity in 2014 was 10 times of that in 2004, reaching 5.5 GW. In such a context, developing wind power driven heat pumps (WP-HP) is of significance to achieve the Swedish energy target in 2020 and 2050. In addition, wind potential is usually high during winter, in which the heat demand is high; therefore, combining wind power and heat pumps is a win-win technical solution. Moreover, there are also some detached houses that even don't have access to the electricity grid. For such houses, WP-HP is more attractive.

There have been some studies about WP-HP. Jwo et al. have experimentally investigated the performance of a WP-HP system. A method to improve the energy efficiency was proposed [7]. Hedegaard et al. studied the potential of wind power integrating using individual heat pumps and thermal energy storage [8]. According to the brief literature review, there has been little information about the dynamic operation about the WP-HP. No detailed energy demand of detached houses was considered. In addition, due to the intermittent characteristic of WP, even though an energy storage is considered, there is no guarantee of a satisfying indoor thermal comfort. However, there has been no available study about it. To bridge the identified knowledge gaps, this paper is to evaluate the dynamic performance of the standalone wind power driven heat pump. Both the power output of wind and heat demand are modelled in details dynamically. The probability of load loss is used as a key performance indicator. The results will provide insights and guidelines concerning the development of the standalone wind power driven heat pump.

2 Methodology

2.1 System description

As shown in Fig 1, a heat pump system driven by a standalone wind turbine is used to supply heat to a detached house. To handle the intermittent characteristic of wind power, an electric energy storage system was included. In this work, it was assumed that heat is only supplied during October and March.

1.1. House model

A typical Swedish house model was built in IDA ICE [9] to simulate the dynamic heat demand. The house is located in Stockholm and is South-facing. It composes of two floors, including one living room, one kitchen, one laundry, two bathrooms, one office, two kid's rooms, one double bedroom, one hall way and one relax room, and has a total area of 153 m^2. Some general information about the house is listed in Table 1. The mean door of the house has a size of 2.2m x 1.5m and the back door that is in the opposite side of the main one is 2.1m x 1m. Lights with a power of 50W are chosen for each room, and it is assumed there are 3 lights in the kitchen and the living room, 5 lights in the relax room, 1 light in the laundry and 2