Available online at www.sciencedirect.com
SCIENCE DIRECT®
Renewable Energy 31 (2006) 1355–1370
RENEWABLE ENERGY
www.elsevier.com/locate/renene

Improving the technical, environmental and social performance of wind energy systems using biomass-based energy storage

Paul Denholm*

National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401-3393, USA

Received 27 November 2004; accepted 1 July 2005
Available online 24 August 2005

Abstract

A completely renewable baseload electricity generation system is proposed by combining wind energy, compressed air energy storage, and biomass gasification. This system can eliminate problems associated with wind intermittency and provide a source of electrical energy functionally equivalent to a large fossil or nuclear power plant. Compressed air energy storage (CAES) can be economically deployed in the Midwestern US, an area with significant low-cost wind resources. CAES systems require a combustible fuel, typically natural gas, which results in fuel price risk and greenhouse gas emissions. Replacing natural gas with synfuel derived from biomass gasification eliminates the use of fossil fuels, virtually eliminating net CO_2 emissions from the system. In addition, by deriving energy completely from farm sources, this type of system may reduce some opposition to long distance transmission lines in rural areas, which may be an obstacle to large-scale wind deployment.

Keywords: Wind; Compressed air energy storage; Biomass gasification; Transmission

1. Introduction

Greatly expanded use of wind energy has been proposed to reduce dependence on fossil and nuclear fuels for electricity generation. The large-scale deployment of wind energy is

* Tel.: +1 303 384 7488; fax: +1 303 384 7449.
E-mail address: paul_denholm@nrel.gov.

0960-1481/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2005.07.001

limited by its intermittent output and the remote location of high value wind resources, particularly in the US.

Wind energy systems that combine wind turbine generation with energy storage and long distance transmission may overcome these obstacles and provide a source of power that is functionally equivalent to a conventional baseload electric power plant. A 'baseload wind' system can produce a stable, reliable output that can replace a conventional fossil or nuclear baseload plant, instead of merely supplementing its output. This type of system could provide a large fraction of a region's electricity demand, far beyond the 10–20% often suggested as an economic upper limit for conventional wind generation deployed without storage [1]. (It should be noted that the maximum penetration of wind into systems without storage is an area of considerable ongoing research [2].)

While energy storage and long distance transmission greatly increase the technical performance of wind energy these 'enabling' technologies may reduce its environmental benefits and social acceptability. The majority of existing utility-scale energy storage in the US and worldwide is pumped hydro storage (PHS), which requires two large bodies of water separated by a large difference in height [3]. In the Midwestern US, which contains a large percentage of the nation's low-cost wind resources, flat terrain, and lack of water makes compressed air energy storage (CAES) more suitable for new wind energy storage projects [4–6]. CAES is a hybrid storage/generation technology that requires combustible fuel (typically natural gas). This dependence on fossil fuels will compromise some of the environmental advantages of a baseload wind system. In addition, the need for new, high capacity, long distance transmission systems will decrease the social acceptability of this energy source, presenting barriers to its implementation.

A more socially and environmentally acceptable alternative is a baseload wind system that uses biomass fuel in the storage system instead of natural gas. This completely renewable energy system will decrease the system's dependence on fossil fuels, and may increase the acceptability of long distance transmission systems in agricultural regions by using farm-derived fuel sources.

2. Description of the standard baseload wind system

The basic components of a baseload wind system include a large amount of wind generation, a large-scale energy storage system, and long distance transmission. Cavallo [7–9] has performed a number of analyses that describe the basic technical characteristics and economic viability of baseload wind energy systems. More recent studies include economic analysis by DeCarolis and Keith [10] and Greenblatt [11], as well as an environmental assessment by Denholm et al. [12]. These previous studies assume that the wind/CAES system acts as a 'baseload' plant with nearly constant output. Actual power plant operation, however, will likely use the energy storage system to reduce low-value output during off-peak periods and increase high-value output during on-peak periods, improving the economics of the system [6]. This method of operation has been suggested for a proposed wind/CAES plant in Iowa [13], which will be the first plant built that incorporates the basic features of baseload wind systems described here.