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Design and thermodynamic analysis of a hybrid energy storage system based on A-CAES (adiabatic compressed air energy storage) and FESS (flywheel energy storage system) for wind power application

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ABSTRACT

Electricity generated from renewable wind sources is highly erratic due to the intermittent nature of wind. This uncertainty of wind power can lead to challenges regarding power system operation and dispatch. Energy storage system in conjunction with wind energy system can offset these effects, making the wind power controllable. Moreover, the power spectrum of wind power exhibits that the fluctuations of wind power include various components with different frequencies and amplitudes. Thus, the hybrid energy storage system is more suitable for smoothing out the wind power fluctuations effectively rather than the independent energy storage system. A hybrid energy storage system consisting of adiabatic compressed air energy storage (A-CAES) system and flywheel energy storage system (FESS) is proposed for wind energy application. The design of the proposed system is laid out firstly. The A-CAES system operates in variable cavern pressure, constant turbine inlet pressure mode, whereas the FESS is controlled by constant power strategy. Then, the off-design analysis of the proposed system is carried out. Meanwhile, a parametric analysis is also performed to investigate the effects of several parameters on the system performance, including the ambient conditions, inlet temperature of compressor, storage cavern temperature, maximum and minimum pressures of storage cavern.

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1. Introduction

Owing to the depletion of fossil fuel resources and global environmental pollution, the fast growing wind energy has been recognized as one of the promising renewable power sources throughout the world. Electricity generated from wind power is highly erratic due to the intermittent nature of wind, making the wind energy uncontrollable and dispatchable. Thus, the uncertainty of wind energy can lead to a challenge on balancing the power production and consumption with a high level wind power penetration, which is related to the power system operation and dispatch [1].

In this scenario, energy storage system (ESS) used in conjunction with wind farm can help mitigate the negative effects of wind energy penetrated in power system. The ESS can be divided into four main categories in terms of the mechanisms of energy storage process, which are mechanical energy storage, electromagnetic energy storage, electrochemical energy storage and phase change energy storage. Each category has several technologies with different technical indicators, such as the energy rating, power rating, round trip efficiency, capital cost, response time, cycle life, etc. Some publications regarding the review of ESS technology can be found in literature [1–3].

In recent years, lots of works regarding hybrid system based on wind-energy storage system have been carried out for improving the wind energy penetration level and power quality. The related energy storage technologies in hybrid system include pumped hydro storage (PHS) [4,5], compressed air energy storage (CAES) [6,7], flywheel energy storage system (FESS) [8], battery energy storage system (BESS) [9,10], hydrogen-based energy storage system (HESS) [11,12], superconducting magnetic energy storage (SMES) [13] and supercapacitor energy storage system (SCESS) [14]. These studies are mainly focused on the problems of performance investigation, control strategy, economic analysis and capacity allocation.

It can be seen that the energy storage systems in wind-energy storage hybrid system described above are independent energy storage system. The independent energy storage system means

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Nomenclature

a_1	total pressure recovery coefficient of air filter
C_p	constant pressure specific heat (J/kg K)
E	energy (kJ)
h	enthalpy (kJ/kg)
J	rotational inertia (kg m^2)
m	mass flow rate (kg/s)
p	pressure (MPa)
P	power (kW)
Q	heat exchange capacity (kJ)
R_g	gas constant (J/kg K)
T	temperature (K)
v	wind speed (m/s)
V	volume (m^3)

Greek letters

α	depth of discharge
γ	diffluence factor of splitter
η	efficiency
ξ	pressure loss coefficient
ρ	density (kg/m^3)
π	pressure ratio
ω	angular speed (rad/s)

Subscripts and superscripts

air	air
amb	ambient
c	compressor
cav	cavern
ch	charge
cold	cold
disch	discharge
fw	flywheel
hot	hot
HX	heat exchanger
in	inlet, cut in speed
max	maximum
min	minimum
out	outlet, cut out speed
r	rated
t	turbine
wind	wind farm

Abbreviations

BESS	battery energy storage system
CAES	compressed air energy storage
FESS	flywheel energy storage system
HESS	hydrogen-based energy storage system
Lead-Acid	lead-acid battery
Li-ion	lithium-ion battery
NaS	sodium–sulphur battery
Ni–Cd	nickel–cadmium battery
PHS	pumped hydro storage
SCESS	supercapacitor energy storage system
SMES	superconducting magnetic energy storage system
VRB	vanadium redox battery
ZBB	zinc–bromine flow battery

using only one energy storage technology. However, the power spectrum density of wind power shows that the fluctuations of wind power contain various components with different periods and amplitudes [15]. Moreover, each energy storage system has different characters, and thus is suitable for smoothing out the specific wind power fluctuation. The bulk energy storage system such as PHS and CAES has higher energy rating, higher power rating but slower ramp rate. On the contrary, the small energy storage

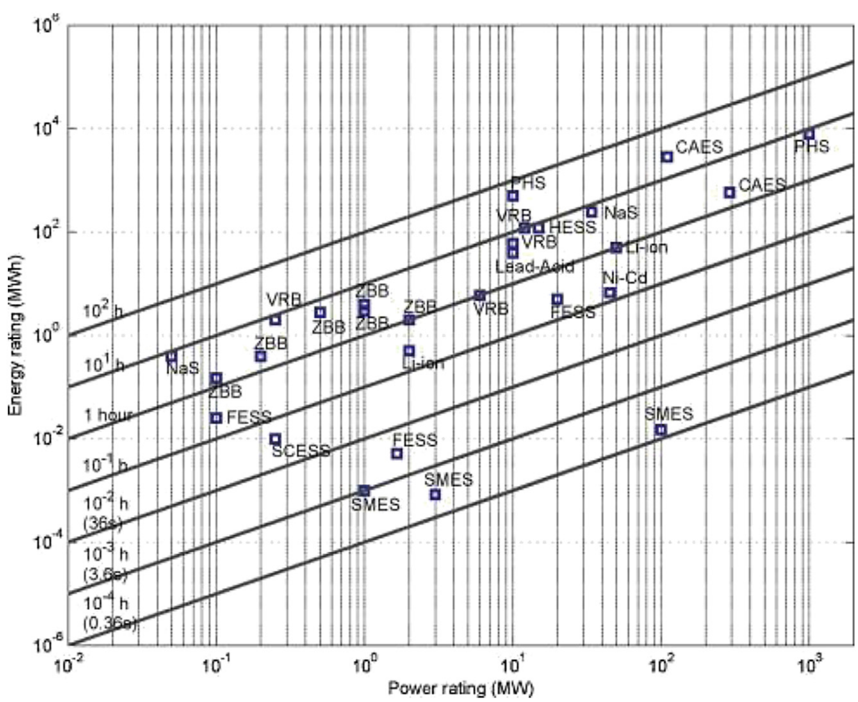

Fig. 1. The duration time at rated power of different energy storage technologies [1].

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