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Energy regulating and fluctuation stabilizing by air source heat pump and battery energy storage system in microgrid

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ABSTRACT

The energy consumption statistics of buildings have shown that in China, 50%–70% of the annual energy consumption is consumed by cooling and heating systems, the majorities are air conditions and hot water supply. To cut down the investment of BESS, this paper studies the application of Air Source Heat Pump (ASHP) in a photovoltaic/Battery Energy Storage System (PV/BESS) microgrid. Energy dispatching strategy is proposed to take advantage of the thermal storage, and fluctuation stabilization strategy is proposed based on the decouple characteristics between Heat Pumps (HPs) and terminal devices. As the characteristics of fluctuation and the inputted capacity of ASHP should be considered during the stabilization, there are too many input variables for traditional fuzzy logic algorithm. According to this, this paper proposes an improved fuzzy logic algorithm, Double Fuzzy Logic (DFL) algorithm, to involve in all the necessary variables. At last, a case is simulated to verify the feasibility of the energy dispatching and fluctuation stabilization strategy. The results have verified that ASHP can decrease the capacities of PV/BESS and stabilize the fluctuation effectively.

1. Introduction

Photovoltaic (PV) technology has been regarded as a solution to produce electrical energy. In recent years, PV technology has been improved greatly to achieve high energy efficiency with high durability [1–5]. While in the past the price of the PV modules was the major contribution to the cost of the systems, a downward tendency is now seen thanks to the development of silicon technologies such as Thin Film technologies, an increasing competition among manufacturers and a massive enlargement in the production capacity of PV modules [6]. However, similarly to other renewable energy sources, solar energy tends to be unsteady because it is influenced by natural and meteorological conditions [7]. Moreover, high penetration of intermittent renewable resources can bring up technical challenges including grid interconnection, power quality, reliability, protection, generation dispatch, and control [8]. The issue of how power fluctuation in PV is to be smoothed has attracted widespread interest and attention. As the levels of penetration of renewable energy rise, the technical impact of PV on grid operation has led to the application of energy storage for renewables [9].

Recent papers proposed this application include a simple scheme to charge and discharge the Energy Storage System (ESS), such as storing excess power when the solar power output exceeds a threshold and discharge it back to the grid when the load demand is high [10]. In Refs. [11], a State of Charge (SOC) based smoothing control strategy was adopted to smooth out short-term power fluctuations of wind/PV hybrid system. In Refs. [12], a generalized double-shell framework for the optimal design of renewable energy systems was developed. Optimal sizing of distributed energy resources with storage systems was studied based on the yearly Joule losses, the yearly costs (capital and management), and the yearly CO_2 emissions. In Refs. [13], a bidirectional converter and control system were designed for Renewable Energy Sources (RESs) and ESSs to take part in the voltage regulation and the frequency transient regulation. Ref [14] studied the economically feasibility of installing medium-scale distributed storage devices in the power system designed to lower the electricity cost for a customer-side application, assuming flexible electricity tariffs. In addition to the capability of enabling the integration of more RESs into the network, ESSs can provide many other benefits that can be summarized as: benefits related to load/generation shifting, benefits

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Nomenclature

C	specific heat capacity of water
f	output power of PV
g_1, g_2	load curves
h, h'	annual cost functions
K,K_1,K_2	correction factors
P_{ASHP}	power consumption of ASHP
P_{BESS_low}	output of BESS for stabilization
P_{high}	high frequency component
P_{HP}	capacity of HPs
P_{HPmax}	extremely capacity design of HPs
P_{hump}	operating power of ASHP
P_{low}	low frequency component
P_N	rated power of ASHP
P_{Stotal}	stabilization command
Q_1 , Q_2, Q_3	electric quality differences between generators and load demands
S_{BESS}	State of Charge of BESS
$S_{BESSmin}$	allowed minimum state of BESS
T	time constant
T_f	time constant of filter
$X(s)$	reference value
X_1,X_2,X_3,X_4	inputs of fuzzy logic modules
$Y(s)$	power consumption

Greek symbols

w	flow of water
ΔT	temperature difference
τ_2, τ_3	time period
ΔQ_{loss}	heating loss
ΔQ_{COP}	decreased power consumption
Δf	frequency deviation
$\Delta f/\Delta t$	frequency changing rate
α, β	are the normalized coefficients
μ_{1i},μ_{2j}	membership values
Δh	increased investment of HPs
ΔP_{HP}	increased capacity of HPs
ΔQ_{BESS}	decreased capacity of BESS
$\Delta h'$	decreased investment function
ΔP_{ASHP_low}	power increment of ASHP

Superscript/subscripts

ASHP	Air Source Heat Pump
ASHP_low	Low frequency stabilization of ASHP
BESS	Battery Energy Storage System
BESS_low	Low frequency stabilization of BESS
COP	Coefficient of Performance
f	filter
high	high component
HP	Heat pump
hump	hump value
loss	energy losses
low	low component
N	nominal rating
max	maximum
min	minimum
Q_{ASHP}	heating volume
$S_{BESSmax}$	allowed maximum state of BESS
Stotal	total values of stabilization
t	time

Acronyms

ASHP	Air Source Heat Pump
BESS	Battery Energy Storage System
COP	Coefficient of Performance
DFL	Double Fuzzy Logic
ESS	Energy Storage System
HP	Heat Pump
LCC	Life Cycle Cost
MPPT	Maximum Power Point Tracking
PCC	Point of Common Coupling
PV	Photovoltaic
RES	Renewable Energy Source
SOC	State of Charge

related to ancillary services and benefits related to grid system applications. In Refs. [15], the operating and maintenance cost of ESS was studied, and an ESS management was proposed based on the power forecasting module of PV. Similarly in Refs. [16,17], a cost-benefit analysis method was proposed for battery energy storage system (BESS) when BESS was applied to microgrid with PV systems. It is preferable to keep installed ESSs as small as possible, since ESSs are generally expensive. Table 1 shows an example of several ESSs' costs per output power (kW) and costs per energy(kWh) [18]. Table 1 shows that most ESSs' costs are still quite high.

Thus far, various BESS-based methods of smoothing power fluctuations in renewable power generation systems have been proposed, but economic cost of BESS has not been substantially reduced. As an effective way of reducing the capacity of BESS, controlling electrical appliances on the demand side was considered in Ref. [19]. In Refs. [20], the manageable loads were studied and a new formulation of shiftable loads was employed for a new load modeling method. Manageable loads are loads for which can be modified during the operating cycle without damage and degradation to the quality of the consumer. They can either be adjustable or shiftable. The ideal manageable loads should meet several requirements:

Table 1
Example of ESSs' cost.

ESS	Cost per kW [1000$/kW]	Cost per kWh [1000$/kWh]
NaS battery	7.6	0.4
Li-Ion battery	6–15	1–4
NiMH battery		
High speed flywheel	0.5–1	120–240
Electric double layer capacitor	2	50~
Pumped hydro	1.5–2	0.2