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Techno-economic and social analysis of energy storage for commercial buildings

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ABSTRACT

Techno-economical and social evaluation methodologies for energy storage systems applied for commercial buildings are presented in this paper. The demand analysis methodology is used to determine power rating and capacity. The technical and economical evaluations are described to analyze the techno-economic feasibility by the financial indices: net present value, internal rate of return, and initial investment payback period. Other benefits, including improved power quality/reliability, improved utilization of grid assets, and reduced greenhouse gas and air pollutant emissions, are estimated in a social evaluation. Finally, an illustrative example combining the measured load data and the current economic parameters is analyzed for three scenarios: 6.5 kW/12.7 kW h lead–acid battery, 5.4 kW/12.4kW h sodium–sulfur battery and 5.15 kW/10.4kW h lithium ion battery for the same peak shaving demand 4.9 kW and a two-hour discharge. The results and discussion of the abovementioned examples show that all three typical battery energy storage technologies are technically feasible, however, investment in sodium–sulfur and lithium ion battery for commercial buildings energy storage should be done with caution, as lead–acid battery systems are the more economic choice at this time. However, systems with lithium ion batteries provide the maximum social benefits due to their high cycle efficiency. Lastly, the standard discount rate with the largest absolute value of sensitivity coefficient has the biggest influence on the net present value through the sensitivity analysis.

1. Introduction

Global primary energy demand is expected to rise by an average annual rate of 1.5% between 2007 and 2030, reaching 16.8 billion tons of oil equivalent—an overall increase of 40% [1]. China's primary energy demand almost doubles between 2007 and 2030 to 3.8 billion tons, accounting for 39% of the global increase; in the electricity industry, global electricity generation will rise from 19,756 TW h in 2007 to 34,290 TW h by 2030 with China's addition of 1326 GW capacity [1]. However, building energy usage is one of the main drivers of China's energy demand growth [2]. Public buildings account for 13.6% of the national total buildings by area, but account for 21.7% by energy consumption [3]. Commercial buildings, as typical public buildings, contribute to most of the above energy consumption, but their demand fluctuates hourly and seasonally. Meanwhile, the stability of a grid relies on the equilibrium between supply and demand. The operation of commercial buildings increases the difficulty of stabilizing the local grid, and even the national grid (the imbalance between peak and valley can be clearly seen in Fig. 1), which also highlights the need for supply and demand regulation, which electrical energy storage systems should solve [4–6].

Electrical energy storage (EES) refers to a process of converting electricity from a power network into a form that can be stored for converting back to electricity when needed [5–7], which has numerous applications including portable devices, transport vehicles and stationary energy resources [7–16] and can provide benefits by reducing on-peak energy and load leveling [5,17–30]. It is therefore necessary for a commercial building to store the electricity with an appropriate electrical energy storage system (EESS).

This paper concentrates on EES systems (EESSs) for commercial buildings as one kind of stationary energy resource. Although Refs. [5,31–38] present EESSs for building, most of them are thermal energy storage (TES) systems, which are often recommended when the available energy surplus is heat. Furthermore, alternative adiabatic requirements or the stability of the phase change material under thermal cycling may limit TES. Other EESSs such as battery energy storage system (BESS) are more and more attractive. In addition to EES technology, the optimal size of EESS is significant. Oversized EESS may bring instability to the local grid, and also lead to the waste of investment and device resources [39]. Undersized EESS cannot satisfy the peak shaving demand and bring enough benefits—an uneconomic investment [39]. Thus Refs. [39–42]

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Nomenclature

P	active power (kW)
P_1	inactive power (kV A)
P_2	apparent power (kW)
W	electricity consumption (J)
P_{avrT}	average load (kW)
P_{avrd}	average daily load (kW)
P_{maxd}	maximum daily load (kW)
P_{mind}	minimum daily load (kW)
γ_T	load factor for time duration (T)
γ_d	daily load factor
β	minimum daily load factor
θ	peak to valley ratio
δ	peak shaving rate (%)
P_{desb}	desired power rating (kW)
η_{BESS}	battery energy storage system cycle efficiency (%)
P_{BESS}	actual power rating (kW)
P_{ps}	maximun power rating after BESS installation (kW)
E_{BESS}	desired capacity (kW h)
P_{load}	hourly power load (kW)
E_{BESS}	actual capacity (kW h)
DOD_{max}	maximum depth of discharge (%)
κ	self-discharge rate (%)
h_1	percentage of the private capital out of the initial cost (%)
h_2	percentage of the subsidization out of the initial cost (%)
IC_0	initial cost ($)
C_b	battery capacity (kW h)
$Cost_b$	cost of battery ($/kW h)
$Cost_{PCS}$	cost of power conversion system ($/kW h)
P_{PCS}	power rating of power convsersion system (kW)
IC_{BOP}	initial cost of balance of plant ($)
$Cost_{BOP}$	cost of balance of plant ($/kW h)
P_{BOP}	power rating of balance of plant (kW)
$Cost_w$	grid connection and internal cabling cost ($/m)
L_w	length of wire used (m)
$IC_{install}$	installation cost ($)
P_{HVAC}	HVAC system power rating (kW)
$Cost_{HVAC}$	cost of HVAC system ($/kW)
j	annual value
E_{SB_0}	total amounts of electricity produced by BESS (kW h)
E_{PB_0}	total amounts of electricity stored by BESS (kW h)
EP	electricity price ($/kW h)
EP_{S_0}	electricity price during the peak time ($/kW h)
EP_{P_0}	electricity price during the off-peak time ($/kW h)
e	EP_{S_0} annual escalation (%)
i	standard discount rate (%)
e_1	EP_{P_0} annual escalation (%)
r_k	replacement cost coefficient (%)
g_k	annual change of price level for the kth major part of BESS (%)
ρ_k	technological improvement level for the kth major part of BESS (%)
n	life time of BESS (year)
n_k	replacement period of the kth major part of BESS (year)
h_3	percentage of the operation and management cost out of IC_0 (%)
g_m	annual increase of the cost of the BESS devices (%)
m	ratio of RVI_n out of IC_0 (%)
RVI_n	residual value of investment after n-year operation ($)
NPV	net present value ($)
NPV_n	net present value over n-year operation ($)
IRR	internal rate of return (%)
IPP	initial investment payback period (year)
TPQP	total improved power quality & reliability benefits ($)
TDB	total T&D deferral benefits ($)
CS	coal saving (kg)
RE_{CO_2}	reduced CO_2 emissions (kg)
RE_{CO}	reduced CO emissions (kg)
S_{ar}	rate of sulfur in coal without desulfurization (%)
t_s	percentage of SO2 emissions out of sulfur in coal (%)
η_s	desulfurization rate (%)
RE_{SO_2}	reduced SO_2 emissions (kg)
N_N	mass fraction of nitrogen in coal (%)
η_n	efficiency of the nitrogen to be converted into NO_x (%)
η_N	nitrogen removal efficiency (%)
λ	percentage of NO_x from the fuel out of the total amounts of NO_x emissions (%)
RE_{NO_x}	reduced NO_x emissions (kg)
S_{IF}	sensitivity coefficient

emphasize the importance of sizing analysis of EESS installed in commercial buildings and provide various models to determine the optimal size through techno-economic evaluations. But these models are incomplete and more factors should be taken into account. Social benefits are often ignored or only limited to environmental benefits, usually only reduced greenhouse gas emissions in most papers [43–45]. Thus, benefits brought by EESS are not comprehensively considered and the corresponding evaluation methods need to be improved.

This paper presents an EESS with lead–acid battery (flooded), sodium–sulfur (NaS) battery, and lithium ion battery applied for a commercial building, i.e. the official building of the Institute of Engineering Thermophysics, Chinese Academy of Sciences (IET, CAS). In addition to a more detailed demand and techno-economic evaluation in which more factors such as the self-discharge rate of the battery, the future and present value of economic parameters are considered, a complete social benefits evaluation encompasses not only improved power quality/reliability and utilization of grid assets but also coal saving and reduced air pollutants emissions like sulfur dioxide SO_2, nitrous oxides NO_x, carbon monoxide CO, and greenhouse gasses, mainly carbon dioxide CO_2. Finally, the sensitivity analysis is undertaken to reveal the financial parameters influence level on the financial indices.

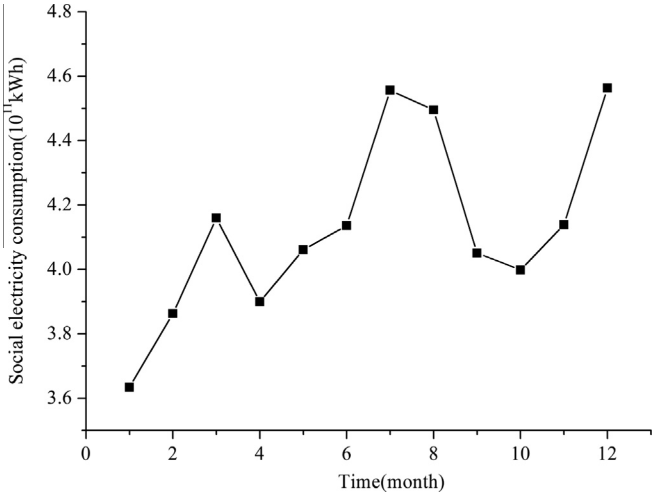

Fig. 1. Chinese national social electricity consumption in 2012.