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Techno-economic analysis of the lithium-ion and lead-acid battery in microgrid systems

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ABSTRACT

Microgrids are a beneficial alternative to the conventional generation system that can provide greener, reliable and high quality power with reduced losses, and lower network congestion. However, the performance of renewable energy resource (RER) based generators in a microgrid is hindered by their intermittent nature. The energy storage system plays a key role in overcoming the intermittency of renewable sources by balancing the power demand against variable generation. Energy storage using batteries is accepted as one of the most important and efficient ways for retaining reliable energy supply whilst incorporating RERs into the electricity grid. Lead-acid (LA) batteries have been the most commonly used electrochemical energy storage technology for grid-based applications till date, but many other competing technologies are also being used such as lithium-ion (Li-ion), Sodium-Sulphur and flow batteries. This paper carries out the techno-economic analysis of the battery storage system under different configurations of the microgrid system. The design of an optimal model of standalone as well as grid-connected microgrid systems having PV-wind-diesel and biodiesel energy resources in the presence of Li-ion ($LiFeSO_4$ type) and LA batteries have been studied. The performance of the two types of batteries has been compared in the proposed microgrid systems considering realistic load profiles, real resource data, and real prices of the components. Load profiles of two rural villages, a business organization and an urban residential building have been used. On the basis of these load profiles and available resources, different microgrid configurations with generation from PV, wind turbine, diesel and biodiesel generators have been considered to study the performances of the batteries. The results include the cost of optimal system configuration under the given scenarios, electricity generation by various generating sources, detail comparison between various components, emissions, and various batteries performance assessment parameters. The study reveals that Li-ion batteries as energy storage are techno-economically more viable compared to LA batteries and they are expected to play a significant role in various applications of future electric power systems.

1. Introduction

Renewable energy in the electricity sector cannot only help in meeting the globally growing energy demand, but also can support the transformation of the existing grid into a smart grid. Wind and solar photovoltaic (PV) based renewable energy systems (RESs) have had substantial growth in the past decade above other renewable energy technologies. They can make electricity available to isolated and energy deficient regions [1]. Intermittent nature and increased levels of penetration of PV and wind power pose greater technical challenges to maintain the supply and demand balance of electricity in an electric power system [2]. These challenges motivate researchers across the globe to investigate and develop reliable energy storage systems (ESSs) that can offset this intermittency by storing the generated energy and making it available during times of demand [3]. In the last decade, the role of ESSs has increased in a variety of power system applications, such as grid stability enrichment, energy system efficiency enhancement, voltage-frequency regulation services, virtual inertia support, and in reducing the environmental impact from fossil fuel use [4,5].

Electrochemical energy storage technologies such as batteries are recognised as one of the most effective means of stabilising electrical networks with high levels of variable renewable energy (VRE). A range of battery chemistries can be used for energy storage in power system applications including load following, regulation, and energy management by adding or absorbing power from the grid [6]. Among different batteries, lead-acid (LA) type are the most commonly used ESS for electric power system applications. These batteries are well recognized for both automotive and industrial applications, and have been

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effectively implemented for utility storage [7]. The flooded lead–acid battery is a 150-year-old, matured and economical energy storage device, but has a short lifespan. This battery generally needs replacement every 4–5 years, which constitutes a major fraction of the system lifetime cost. Also, the future cost reductions of LA battery in commercial application can be anticipated to be small [8]. However, there are now rival electrochemical storage technologies including lithium-ion, sodium-sulphur and flow batteries that are effectively employed in energy storage applications.

Nowadays Lithium-ion (Li-ion) batteries are being used more in the power systems applications due to their lower maintenance, superior safety, volumetric and gravimetric energy densities characteristics. These features allow them to have less weight and size than that of LA batteries. In addition, the price of Li-ion battery technology is declining at 8–16% annually, and the cost advantage on Li-ion batteries is anticipated to improve considerably in the next few years [8].

Lithium-ion battery technology was developed commercially in the early 90s and it has empowered the portable electronics revolution. Currently this technology is increasingly being used in electric vehicles and grid storage applications [8]. The various Li-ion battery variants are further classified on the basis of employed chemistries such as energy density, cell voltage, cycle life, cost and rate capability (peukert factor), etc. The seven renowned Li-ion battery chemistries are LMO (lithium manganese oxide), NCA (lithium nickel-cobalt aluminium oxide), NMC (lithium nickel-manganese-cobalt oxide), LFP (lithium iron phosphate), LMO/LTO (lithium manganese-oxide cathode), NMC/LTO (lithium nickel-manganese-cobalt oxide cathode) and LFP/LTO (lithium iron-phosphate cathode). LFP/LTO includes the safety features of both LFP and LTO that make it safest among the seven chemistries. This chemistry has long cycle life with minimal degradation rates and has good performance under extreme temperature conditions. However, low cell voltage and high cost of LTO results in low energy density and high cost for the chemistry [8].

Because of the above discussed features and merits of Li-ion battery over LA battery, it is significant to compare the performances of both batteries as an energy storage unit in microgrid systems.

1.1. Literature review

Hybrid power systems based on renewable energy resources (RERs) can comprise a cost-effective substitute to fulfil the growing power demand. Because of the importance and benefits of HRES (Hybrid Renewable Energy Sources), numerous hybrid energy optimizations studies have been performed through Hybrid Optimization Model for Multiple Energy Resources (HOMER) and other software in the literature [9–31]. A detailed survey of various RES configurations, battery types, cost of energy (COE), grid connectivity status, location and type of software, which were implemented by various researchers for renewable energy generation based application, have been shown in Table 1.1 and Table 1.2. The detailed techno-economic feasibility of the stand-alone as well as grid connected hybrid power generation systems across the globe is presented in these studies. Renewable energy sources such as solar PV, wind turbine generator (WTG), biogas and biomass generator, and small-scale hydropower are commonly used at various locations to generate electricity.

1.2. Novelty and contributions

It can be inferred from the literature that various studies have been carried out in order to estimate the optimal configuration of various HRES based power systems, in terms of economics and reliability. The studies also indicate that the battery as an energy storage device has played a major role in the renewable generation based power system. However, from the analysis (Table 1), it can be seen that LA batteries have most commonly been used in these applications. Therefore, it is significant to perform economic investigations on the Li-ion battery for

Table 1.1
Critical review summary of various RESs configurations, battery types, cost of energy (COE), grid connectivity status, location and types of software used in power system.

Authors Name/Year	Location	System Type	Battery Type/Model	COE	On/Off Grid Status	Load type/ application	Software	Ref.
C. Phuralatpam, et al., 2018	Palari, Chhattisgarh & Hyderabad India	Photovolaic (PV) array, Wind turbine generator (WTG)	Lead acid (L.A)battery	0.163 $/kWh	both	Small village load , residential building and IT business building load	HOMER	[9]
Y. Sawle, et al., 2018	Barwani, MP, India	PV/WTG/Bio/Diesel Generator (DG)	Flooded L.A battery	0.289 $/kWh	Off-grid	Residential / Village	HOMER and PSO	[10]
V. Tomar, et al., 2017	New Delhi, India	Grid connected PV	Flooded L.A (Hoppecke 12)	–	both	Slab wise and time of day (ToD) tariff structure	HOMER	[11]
M. Usman, et al., 2017	New Delhi, India	PV/WTG/DG	Flooded L.A Battery (Surrette 6CS25P)	8.84 Rs/kWh	both	Electrical load of faculty of Engineering and Tech., Jamia Millia Islamia, New Delhi	HOMER	[12]
H. Maammeur, et al., 2017	Chlef district, Algeria	PV	Without battery	0.6 $/kWh	On-grid	Family farms	HOMER	[13]
S. Rehman, et al., 2017	Bisha, Saudi Arabia	PV	With and without battery	–	On-grid	Grid	RET-Screen	[14]
B. K. Das, et al., 2017	Bangladesh	Biogas generator (BG)-PV-DG	L.A batteries (Trojan L16P)	0.28 $/kWh	Off-grid	Village	HOMER	[15]
M. K Shahzad, et al., 2017	Layyah in the Punjab, Pakistan	PV/Biomass	Li-ion batteries	5.51 PKR/kWh	Off-grid	Agriculture and residential load	HOMER	[16]
P. Peerapong, et al., 2017	Kohmak island, Thailand	PV/DG	Flooded L.A (Surrette 6CS25P)	0.374 $/kWh	Off-grid	Hotel, residential etc.	HOMER	[17]
R. Rajbongshi, et al., 2017	Jhawani village, Tezpur, India	PV/DG/BG	LA battery (Surrtte 6CS25P)	0.145–0.064 $/kWh	both	Jhawani village	HOMER	[18]
L.M. Halabi et al., 2017	Sabah, Malaysia	PV/DG	Fiamm type Battery	1.22-1.36 $/kWh	Off-grid	Remote areas of two island (Pulau Banggi and Tanjung Labian)	HOMER	[19]
A. H. Mamaghani, et al., 2016	Puerto Estrella, Colombia	PV/DG/WTG	L.A Batteries (4KS25P), Batteries (H3000)	0.414–0.868 $/kWh	Off-grid	Off-grid villages in Colombia	HOMER	[20]