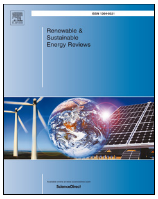
Renewable and Sustainable Energy Reviews 91 (2018) 109–125

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Battery energy storage system size determination in renewable energy systems: A review

Yuqing Yang[a,*], Stephen Bremner[a], Chris Menictas[b], Merlinde Kay[a]

[a] School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, New South Wales 2052, Australia
[b] School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, New South Wales 2052, Australia

ARTICLE INFO

Keywords:
Battery energy storage system
Battery sizing
Distributed renewable energy system
Microgrid
Standalone hybrid renewable energy system
Renewable energy power plant

ABSTRACT

Renewable energy, such as hydro power, photovoltaics and wind turbines, has become the most widely applied solutions for addressing issues associated with oil depletion, increasing energy demand and anthropogenic global warming. Solar and wind energy are strongly dependent on weather resources with intermittent and fluctuating features. To filter these variabilities, battery energy storage systems have been broadly accepted as one of the potential solutions, with advantages such as fast response capability, sustained power delivery, and geographical independence. During the implementation of battery energy storage systems, one of the most crucial issues is to optimally determine the size of the battery for balancing the trade-off between the technical improvements brought by the battery and the additional overall cost. Numerous studies have been performed to optimise battery sizing for different renewable energy systems using a range of criteria and methods. This paper provides a comprehensive review of battery sizing criteria, methods and its applications in various renewable energy systems. The applications for storage systems have been categorised based on the specific renewable energy system that the battery storage will be a part. This is in contrast to previous studies where the battery sizing approaches were either arranged as an optimised component in renewable systems or only accounted for one category of renewable system. By taking this approach, it becomes clear that the critical metrics for battery sizing, and by extension the most suitable method for determining battery size, are determined by the type of renewable energy system application, as well as its size. This has important implications for the design process as the renewable energy system application will drive the battery energy storage system sizing methodology chosen.

1. Introduction

Renewable energy (RE), especially solar and wind energy, has been widely regarded as one of the most effective and efficient solutions to address the increasingly important issues of oil depletion, carbon emissions and increasing energy consumption demand [1,2]. At the same time, numerous solar and wind energy projects have been developed, or are under construction, to meet renewable energy targets [3–5] and increase renewable penetration. Policies for renewable energy development strategies and incentives have also been launched by various governments [5]. Moreover, it is expected that by 2025, solar PV and onshore wind energy will experience a price reduction of 43% and 26%, respectively [6].

Despite the environmental advantages and sustainability of renewable energy, there remain two major issues when integrating it into the power grid. Firstly, it is well-known that renewable energy production strongly depends on local weather and climate conditions. The consequent intermittent and stochastic characteristics of non-dispatchable renewable energy can bring about instability into power systems [7]. These stability issues, due to the fluctuating features of the resources, can be exacerbated when a high penetration of RE is present. Secondly, as the penetration of renewable energy increases, it is more difficult for existing conventional power systems to accommodate the increase in renewable energy generation. For example, in recent studies [8,9], the

---

Abbreviations: BA, Bat algorithm; BESS, Battery energy storage system(s); CAES, Compressed air energy storage; CHP, Combined heat and power; CPLEX, IBM ILOG CPLEX optimisation studio; DE, Differential evolution; DG, Distributed generations; DOD, Depth of discharge; DP, Dynamic programming; ESS, Energy storage system(s); GA, Genetic algorithm; GAMS, General algebraic modelling system; GHI, Global horizontal irradiation; HESS, Hybrid energy storage system(s); HRES, Hybrid renewable energy system(s); LA, Lead-acid battery; LCC, Life Cycle Cost; LCOE, The levelised cost of electricity; LOLE, Loss of Load Expectation; NEM, National electricity market; NPV, Net Present Value; O&M, Operation and Maintenance; PCC, Point of common connection; PSO, Particle swarm optimisation; RE, Renewable energy; RES, Renewable energy system(s); SC, Super-capacitor; SOC, State of charge; TOU, Time of use; VRB, Vanadium redox flow battery; VRLA, Valve-regulated lead-acid battery

[*] Corresponding author.

E-mail address: yuqing.yang@unsw.edu.au (Y. Yang).

https://doi.org/10.1016/j.rser.2018.03.047
Received 15 June 2017; Received in revised form 31 January 2018; Accepted 17 March 2018

overgeneration of PV led to a very low net demand during midday in California, but the net demand in the morning and evening, when PV cannot deliver power, was still high. This net demand profile, when further PV is included, would see the net demand trough in the middle portion of the day deepen, leading to the so called “duck” curve. As a consequence, with a limited capability to accommodate this huge ramp, solar energy needs to be curtailed, thereby reducing the economic and environmental benefits of renewable energy integration.

One of the possible solutions for the above issues is to use Hybrid Renewable Energy Systems (HRES), integrating various renewable energy resources in an optimal combination [8]. In this regard, the periods with low generation of one resource could naturally be compensated by other resources with high generation [10]. A good example is the complementary nature of solar and wind energy [11]. Thus, the potential system efficiency and supply reliability can be enhanced [12–15]. There are some detailed reviews on the optimal sizing of generation units [16–19], energy management and control [20–22] in such HRES. However, in most hybrid systems, a conventional generator or connection to the main grid is still required to guarantee reliability and stability. The use of Energy Storage Systems (ESS) to facilitate the increasing penetration of renewable energy by absorbing and releasing power in different time horizons has been extensively studied [23–26]. Of the various types of ESS technology available, Battery Energy Storage Systems (BESS) have attracted considerable attention with clear advantages like fast response, controllability, and geographical independence [5,27]. Besides the advantages mentioned, BESS also have a wide scope of applications ranging from short-time power quality enhancement to long-term energy management, as well as reliability enhancement, uninterrupted power supply and transmission upgrade deferral [28–31].

Although certain battery storage technologies may be mature and reliable from a technological perspective [27], with further cost reductions expected [32], the economic concern of battery systems is still a major barrier to be overcome before BESS can be fully utilised as a mainstream storage solution in the energy sector. Therefore, the trade-off between using BESS to improve renewable energy system performance and to achieve profitable investment is a critical decision to make for project developers. In this regard, the optimisation of BESS sizing is a vital issue to balance this trade-off, by attaining the best solution for multiple, or even contradictive, requirements.

It is noted that considering the variability of renewable resources, numerous studies have attempted to solve BESS size determination in different Renewable Energy Systems (RES). However, to the authors’ knowledge, there has not been a thorough review on battery sizing issues in various RES, although there have been comprehensive reviews done for battery applications in power systems [33,34], battery sizing in standalone systems [35,36], storage sizing for solar and wind power plants [37] and HRES sizing reviews where the battery is included as a component [10,38,39]. Therefore, this overview focuses on the state-of-art battery sizing studies providing researchers with a fast reference of work done on this important problem. The review also has the added benefit of informing project investors and designers of more detailed factors to consider during the BESS sizing procedure. Research papers using energy storage to enable renewable systems are also included in this review if the specific type of ESS was not clarified and its characteristics were regarded to be compatible with BESS.

The paper is organised as follows. Numerous BESS sizing studies in terms of sizing criteria and solution techniques are summarised in Sections 2 and 3. BESS's applications and related sizing studies in different renewable energy systems are overviewed in Section 4 to show the spectrum of BESS's functions. The justification of the classification of RES and the range of battery sizing outcomes are discussed in Section 5. By categorising BESS's applications based on specific RES, it becomes clear that critical metrics for battery sizing are associated with the type of RES application, as well as its size. This implies that the battery size determination process in specific RES will influence the BESS sizing methods and criteria chosen. Finally, some conclusions are presented in Section 6.

2. Battery energy storage system sizing criteria

There are a range of performance indicators for determining the size of BESS, which can be used either individually or combined to optimise the system. Studies on sizing BESS in terms of optimisation criteria can be divided into three classifications: financial, technical and hybrid criteria.

2.1. Financial indicators

One key driver for determining the size of a BESS, and indeed the overall design of a RES, is the financial return for the operation of the system. A key attraction of financial indicators is that there is a common unit for making decisions, namely the local currency, enabling the comparison of different alternatives. Even with the benefit of a common unit for comparison, there are several different indicators that can be used as optimisable parameters for designs. Many studies have looked at the overall costs and benefits of the battery system in RES over the operational lifetime of the system. These approaches used the time value of money, via a discount rate, to determine overall costs on a lifetime basis, including levelised upfront capital costs, annual/daily operation and maintenance (O&M) costs, as well as fuel costs if the corresponding generators were applied. The indicator to be optimised can then be the Net Present Value (NPV) of the system [40], which should be maximised, or the levelised cost of electricity (LCOE) on an annual basis [41] or daily basis [42,43], which should be minimised. The NPV in [40] was formulated as the difference of levelised daily operation costs with and without ESS, whereas the LCOE in [41] took the annualised investment cost, annual operation cost and fuel cost into account directly. During the formulation, the modelling of a BESS's cost is a key issue. Therefore, it is worthwhile to mention the study of [44], where a detailed explanation of the methodology for calculating and analysing a BESS's total cost and annualised life cycle cost (LCC) can be found. However, the modelling of BESS costs in most studies associated with BESS sizing used neither the total cost nor LCC. They generally included the capital cost of BESS, which was then converted into an annual/daily cost by taking into account the interest rate [45], and the annual/daily O&M cost of BESS. The replacement cost of BESS was included in the formulations in [40] and [41], but the disposal and recycling costs of BESS were rarely considered.

Another financial indicator approach is to look at maximising the market benefit of the inclusion of a battery system in a RES. One significant case is microgrids, where the total benefits in grid-connected mode are maximised and the total costs associated with being in islanded mode are minimised [46,47]. The total costs of microgrids include the levelised operating costs from BESS and other running components, whereas the total benefits were calculated through the difference between the benefits from selling electricity and the total operating costs. More details about these formulations can be found in [46,47]. Other examples looked at partial financial values, rather than the total costs/benefits, for instance, maximising the difference between the sale of electricity to the grid and purchase from the grid for a grid-connected system [48]. A more extreme example was to examine only the day to day operating profitability of the RES, namely a 24-h optimisation horizon, by exploiting time shifting of energy output to match profitably against the electricity spot price with no regard for lifetime running cost [49]. A contrasting example looking at operating profits was to minimise the overall investment cost, which included the capital cost of BESS and other components, for determining the power and energy rating of the battery system [50].