Journal of Energy Storage 11 (2017) 25–54

Contents lists available at ScienceDirect

Journal of Energy Storage

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

Review article

Evaluation of Electrical Energy Storage (EES) technologies for renewable energy: A case from the US Pacific Northwest

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ARTICLE INFO

Article history:
Received 8 August 2016
Received in revised form 12 January 2017
Accepted 16 January 2017
Available online 26 April 2017

Keywords:
Technology evaluation
Multiple criteria decision making
Review

ABSTRACT

Increase in use of renewable energy such as solar and wind has created challenges in balancing load. Renewable energy intermittency can be addressed with different solutions and technologies. Using Electric Energy Storage (EES) has been an approach which has been studied extensively in the recent years. This paper reviews the storage technologies leveraging both technical papers on technologies as well as other reviews of such technologies done by other researchers. The contribution of this paper is in two areas. First the use of a case study demonstrates how different approaches can address different challenges. Second contribution is the review of evaluation factors and methods of such technologies resulting in a proposed framework.

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http://dx.doi.org/10.1016/j.est.2017.01.003
2352-152X/

1. Introduction

1.1. Research background

Energy is essential for sustainable economic development and prosperity of a society. The literature agrees that there are options for supplying bulk low-carbon electricity: fossil with carbon capture and sequestration (CCS), nuclear, and renewable sources [1].

Each option has challenges such as waste disposal with CCS and nuclear. Fossil fuels draw on finite resources and they are becoming too costly from both economic and expensive or too environmental perspectives. Renewable sources, particularly wind and solar are challenged by the intermittency of the resource. Therefore, it is crucial for the decision makers in electricity industry to formulate a diverse and comprehensive energy policy and increase the share of renewable technologies [2].

1.1.1. Challenges in renewable energy electricity

In most scenarios, the problem on the demand growth is generally addressed by using the low cost conservation and energy efficiency resources. However, renewable energy sources are getting more attention to address the issue of demand growth due to several reasons [3].

Strong political support for renewable energy per se, which is due to the attendant environmental advantages, associated the absence of greenhouse gas emissions, as well as national energy security advantages in the US avoiding reliance on imported fossil fuels is one of the driving reasons behind this growth. Renewable Portfolio Standard (RPS) – also known as Renewable Energy Target (RET) – laws require the States' power producers to generate a significant percentage of their electricity from specifically designated, low-impact renewable energy sources by a specific date. RPS generally require utilities to produce a certain portion of their electricity from renewable energy. This is 20% by 2020 for European Union [4].

The United States has a region wide RPS of 20% by 2030, with different targets and years depending on the state [5]. For example, in Oregon, 25% of generation should be from approved renewable energy sources by 2025 [6] [7]

Government policy has been the key driver for renewable energy expansion globally, including in EU. U.S. and Canada resulting in over 50% of (non-hydro) renewable capacity additions in the US from the late 1990s through 2007 [8]. Federal, provincial and state tax incentives, renewable energy investment funds, economic competitiveness, voluntary green power markets, public support, and hedging against fuel price increases and carbon regulation have been other positive influencing factors [8–10].

Rate payer selected willingness to pay a premium for "green power" as a personal means to advance renewable energy is another strong reason behind the growth [11,12]. In the U.S. as of the end of 2014 [13], more than 500 utilities, including cooperatives, in 34 States offer green pricing programs. Altogether, more than 418,000 customers participate in utility green pricing programs

Improved renewable sources–such as wind power another major driver. Despite the increasing interest as mentioned above, renewable energy sources are facing something of a challenge in term of their power output. The variability of power output showed by numerous renewable energy sources represents something of a challenge to keeping up secure supplies in the incorporated electricity systems of industrialized countries – particularly if, as broadly foreseen, the commitment of renewable energy sources to national grids rises to exceptionally considerable levels [14].

Electricity produced from sustainable energy resources have demonstrated astounding development worldwide. However the availability for variable resources often does not positively correlate with the power demand [8,9]. Thus, the development implies greater network load stability problems. In particular the United Kingdom, Ireland and Denmark possess favorable wind conditions. In comparison Eastern Mediterranean countries seem to be less favorable for the use of onshore wind energy [15].

Intermittent renewable generators (mainly wind, solar photovoltaic without storage) are not like traditional ones [1]. The yield of renewable electricity is portrayed by steep "slope/ramp" rather than the controlled, progressive "slope" up or down experienced with electricity demand and the yield of traditional generation [8–10,14,16]. Dealing with these slopes can be challenging for network operators, especially if "down" slope happen as demand increases and the other way around. Inadequate ramping and dispatchable capability on the remainder of the bulk power system can increase these challenges [8,14].

The penetration of renewable sources (especially wind, solar, and wave power plants) into the power system network has been increasing in the recent years [5,17]. The United States ranked third in annual wind additions in 2014, but was well behind the market leaders in wind energy penetration [17]. Several countries have much higher levels of wind energy penetration in their electricity grids ranging from 20% to 40% while about 5% in the US [17].

1.1.2. Renewable energy intermittency

The above facts have led into a discussion over reliable and satisfactory operation of the power grid systems. In United States, the limits of wind and solar are not resource based. Wind and solar resource are fundamentally more prominent than the total electric demand [10,16]. The major technical challenge is resource intermittency, or the fact that the supply of variable renewable generation does not equal the demand for electricity during all hours of the year [1].

The difficulty associated with integrating renewable sources of electricity stems from the fact that the power grid was designed around the concept of large, controllable electric generators, while intermittency is an inherent characteristics of renewable energy-based electricity generation systems [18].

Intermittent renewable sources disrupt the traditional methods for planning the daily operation of the electric grid. Their power fluctuates over multiple time horizons, forcing the grid operator to change its day-ahead, hour-ahead, and real-time operating procedures [19]. Reliably integrating high levels of intermittent resources into the North American bulk power system will require significant changes to traditional methods [8].

Power balancing requirements resulting from the intermittency of renewable sources suggest using intermittency support