Journal of Energy Storage 17 (2018) 299–310

Contents lists available at ScienceDirect

Journal of Energy Storage

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

The role that battery and water storage play in Saudi Arabia's transition to an integrated 100% renewable energy power system

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ARTICLE INFO

Article history:
Received 3 October 2017
Received in revised form 28 December 2017
Accepted 18 March 2018
Available online xxx

Keywords:
100% renewable energy
Saudi Arabia
Energy transition
Battery
Water storage
Flexibility

ABSTRACT

Saudi Arabia can transition to a 100% renewable energy system by 2040 including the integration of the power, desalination and non-energetic industrial gas sectors. Single-axis tracking PV and battery storage contribute the highest to the final LCOE of the system. By 2050, single-axis tracking PV accounts for 79% of the total electricity generation. Battery storage accounts for 30% of the total electricity demand. Battery storage and desalination plants provide additional flexibility to the energy system. Through sensitivity analysis, it is found that decreasing the capex of desalination plants results in lower full load hours (FLH) and a decrease in battery storage output. This results in lower energy system costs. However, the SWRO capex has to be reduced by 50% to achieve a reduction of 1% in SWRO FLH and a 2.1% in the annualised energy system costs. This is because it is preferable to run the expensive SWRO plants in baseload operation for total energy system cost reasons. Flexibility to the energy system can be provided at a lower cost by solar PV and battery storage than by SWRO plants and water storage. Decreasing battery capex reduces the flexibility of desalination plants further, increases single-axis tracking PV capacities, decreases wind and CCGT capacities, and ultimately results in lower LCOE. These insights enable to establish the least cost pathway for Saudi Arabia to achieve net zero emissions by mid-century.

1. Introduction

Energy storage is seen as a cornerstone of the green energy revolution [1,2]. The intermittent nature of solar and wind resources can be overcome with different types of flexibility (supply side management, demand side management, grids, sector coupling, storage), thereof energy storage is regarded as one of the most important, enabling a faster transition towards a 100% renewable energy system [3–5]. With the increase in global installed capacities of renewable energy power plants, there is a surge in demand for energy storage capacities. The Bloomberg New Energy Finances (BNEF) New Energy Outlook 2016 report forecasts the storage capacity to increase to 25 GW by 2028 from the 1 GW installed today [6].

Luo et al. [2] provides an overview of the current storage technologies and explains that pumped hydro storage (PHS) accounts for 99% of the global storage capacities. However, with improved power to energy ratios, Lithium-ion batteries are currently experiencing by far the fastest growth of all storage options and being used in small and utility-scale applications [2]. Consequently, there has been a sharp decline in the capex of batteries as presented by Liebreich from BNEF [7]. The price of the electric vehicle (EV) lithium ion battery price is estimated to have fallen from 770 €/kWh in 2010 to 243 €/kWh in 2015 [7]. The report forecasts the cost to plunge even more sharply to 162 €/kWh by 2018, a 77% fall in cost between 2010 and 2018. Based on the discussed learning curve rate of 14% - 19%, the capital cost of electric vehicles is expected to arrive at parity with internal combustion engine cars by 2022 [7]. Tesla is reported to project even steeper cost reductions with cost of electric vehicle battery packs dropping to 100 USD/kWh by 2020 [8]. These projections are further supported by Kittner et al. [9], who based on their model, expect electric vehicles to be cost competitive with combustion engine vehicles as early as 2017 and no later than 2020. The core technology of Li-ion batteries does not differ substantially between mobile and stationary applications. Thus, cost reductions in one type of battery storage also translates to cost reductions in other applications. Schmidt et al. [10] analyses future cost projections for electrical energy storage, based on learning curves. The learning rate for lithium ion battery storage in electric vehicles is estimated to be 16%. Meanwhile, lithium ion battery storage in electronics has the steepest learning rate with 30%. Utility and residential scale applications had a lower learning rate of 12% in the past. Breyer

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https://doi.org/10.1016/j.est.2018.03.009
2352-152X/

et al. [11] have assessed the impact of learning rates for lithium ion battery storage on battery system cost and base their analysis on a learning rate of 15–20%.

In a recent study, we investigated the least cost pathway for Saudi Arabia to transition from the current fossil-based power sector to a 100% renewable energy based system by 2050, whilst integrating the increasing desalination sector with the power sector [12]. This study was motivated by the Saudi government's new vision to embrace the country's renewable energy resources and build a future without reliance on oil. Salam and Khan [13] explain that in order to achieve energy security and minimise energy costs, Saudi Arabia has to adopt higher shares of renewable energy. In addition, Saudi Arabia has consented to achieving 'net zero emissions' by mid-21st century at the Conference of the Parties (COP21) in Paris [14]. A pathway towards achieving this vision, agreed upon by almost all nations on the planet, is what we present. The energy transition pathway discussed aims to fulfill three main criteria: i) only existing technology is used; (ii) no conflict to the Paris Agreement; (iii) low cost pathway.

In the study in [12] it was found that Saudi Arabia can achieve a 100% renewable energy power system by 2040 with a power sector dominated by PV single-axis tracking and battery storage. Single-axis tracking PV contributed 210 GW out of the total 403 GW by 2040. The contribution increased to 369 GW out of a total of 520 GW by 2050. Battery storage contributed up to 30% of the total electricity demand in 2040 and the contribution increases to 48% by 2050. The combination of PV and battery storage provided the least cost option to meet Saudi Arabia's power and desalination sector demands. This was mainly due to the sharp anticipated decrease in PV and battery storage.

In addition, the integration of the power and water desalination sector provided the least cost transition pathway as opposed to the independent transition of the two sectors. The desalination plants and water storage provide additional flexibility to the system, enabling better utilization of the renewable energy generated. This leads to a reduction in the demand for battery and power-to-gas (PtG) storage in the transition. The study [12] highlights the relationship between water and battery storage in the energy transition pathway for Saudi Arabia. Al-Nory and El-Beltagy [15] have modelled the role of water storage when high shares of renewable energy capacities are integrated into the Saudi Arabian electricity grid. The model was simulated for 7 days, on a daily resolution. A 12% reduction in total costs was determined, compared to the integration of renewable energy capacities without water storage. This study further contributes to the understanding of the role that seawater desalination and water storage can play in a 100% renewable energy power system. Similarly, Bognar et al. [16] found that the integration of SWRO plants in a hybrid wind and diesel energy system, for Cape Verde, resulted in the least electricity and water costs. These views are further supported by Lopes et al. [17]. Strang [18] discusses the benefits of storing excess electricity in water and presents an example of tidal power plant design in Australia utilising desalination plants and water storage.

Located between the Persian Gulf and the Red Sea, Saudi Arabia is one of the largest arid countries without any permanent rivers or lakes. Whilst the global average renewable water resource per capita per year is 6000 m^3, Saudi Arabia has only 84.8 $m^3/(capita \cdot a)$ [19]. In spite of the water scarcity, Saudi Arabia has the third highest water consumption per capita at 250 liters/(capita·d). This is only behind the United States and Canada. The country's water demand is expected to increase by 56% by 2035. Meanwhile, at the current rate of water withdrawal, ground water aquifers are expected to provide potable water only for the next 10–30 years [20].

To augment the fresh water resources, Saudi Arabia relies on seawater desalination, particularly to meet the municipal and industrial water demands. In 2010, 58% of the country's total water demand was met through non-renewable ground water resources, 33.5% by surface water and renewable ground water, 6% by desalinated water and 2.2% by waste water reuse [21]. In 2014, desalinated water is estimated to have met 60% of KSA's municipal water demand [22]. By the end of 2015, Saudi Arabia accounted for 15% of the global installed desalination capacity [21]. With the diminishing of fresh water resources, seawater desalination is expected to play a pivotal role in meeting Saudi Arabia's future water demands.

The Saudi Vision 2030 document, released in April 2016, illustrates the Saudi government's road map to ensure the country's development and security [23]. The document, together with the more detailed National Transformation Program 2020 document [23], highlights the government's urgency to secure the country's water resources. In addition to better management of existing renewable water resources and more water from desalination, one of the objectives is to increase the strategic water storage from 0.4 days at present to 3 days by 2020 [23]. However, this is much lower than the water storage capacities planned for by other countries in the Gulf region. The United Arab Emirates (UAE) have recently completed an underground water reservoir that can provide 180 liters of water per person per day for 90 days [24,25]. Similarly, the Water Security Mega Reservoirs Project in Qatar is expected to provide 7 days of water storage. After the final phase of construction, the reservoirs are expected to store 14,384,520 m^3 of water [26], as opposed to the current water storage capacity of 1,097,766 m^3. Research on food and water security in Saudi Arabia by Future Directions International highlight the importance of long term water storage in water-scarce Saudi Arabia [27].

Saudi Arabia's increasing demand for water storage, and the results in [12], which suggest an interplay between battery and water storage, provide the motivation for the current study: How do the technical and financial parameters of battery and water storage influence the least cost transition path to a 100% RE based power system? The research answers will demonstrate if it is cost-effective for Saudi Arabia to harness the increasing desalination and water storage demand to reduce the requirements for battery storage in the energy transition. Or, will battery storage remain the lower cost storage option for the Saudi energy transition? Existing literature discuss the potential role of desalination and water storage in hybrid energy systems on a smaller scale. In this manuscript, a more detailed study of the role of desalination plants and water storage in a full energy system is conducted.

In the sections that follow, a cost-optimised energy transition pathway for Saudi Arabia to achieve a 100% RE based power sector, seawater desalination and industrial gas sector, by 2050, is presented. A sensitivity analysis is then carried out on the pathway to understand the interplay between battery and water storage. This will enable to further optimise the energy transition pathway for Saudi Arabia.

2. Methodology

2.1. Overview

The objective of our work is to understand the features of battery and water storage that will allow for the optimal transition of Saudi Arabia's 2015 power, seawater desalination and industrial gas sector to a 100% renewable energy based system by 2050.

The approach taken to answer the research question is similar to that in [12] and additionally accounts for KSA's multiple effect distillation (MED) desalination plants and the industrial gas sector. In addition, the water storage plants are now located at the