Assessing the Electricity Storage for Renewable Energy in Saudi Arabia

Gafar Elamin, Mohamed Shwehdi, Salih AlAwaji

***Abstract*—**The ministry of water and electricity of Saudi Arabia (MOWE) is undertaking research studies and assessments for the optimal selection of renewable energy storage systems to be used with power plants. A comprehensive survey of the renewable energy resources in Saudi Arabia is presented in this paper. A review of the global electricity storage systems has been conducted to select the best storage system to be implemented with the new establishment of many solar and wind plants in the Kingdom. The study aims to suggest the best storage systems that can be used to store the power generated from renewable energy resources in Saudi Arabia. Even though, the survey covered all the available energy storage technologies, only the mature well-developed storage technologies are presented in this paper. Recommendations were made for the best technologies to be used to store electricity produced from renewable energy in Saudi Arabia.

***Keywords*—** Electricity Cost**,** Emission Reduction, Energy Storage, Renewable Energy

I. INTRODUCTION

IN an effort to reduce the global carbon emissions, national and international policies are driving the increased penetration of renewable energy such as solar and wind energy onto the electricity networks. The increased penetration of renewable energy onto the electricity grid is driving a demand for greater capacity in the area of energy storage [1]. Currently, utilities effort to store energy is heavily increasing as the interaction of renewable resources with the main electricity grids grown. Energy storage is essential to balance supply and demand. Peaks and troughs in demand can often be anticipated and satisfied by increasing, or decreasing generation at fairly short notice. In a low-carbon system, intermittent renewable energy makes it more difficult to vary output, and rises in demand do not necessarily correspond to rises in renewable energy generation [2]. Energy storage are required for grid flexibility and grid stability and to cope with the increasing use of intermittent wind and solar electricity. The implementation of energy storage systems and methods does help utilities avoid many energy losses resulted from the difference of the supplying loads and demand at different times by smoothing out the load curves and make the them steady with no distinct peaks.

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As the largest oil exporter in the world, the Kingdom of Saudi Arabia (KSA) plans to rely on the promotion of renewable energy for the production capacity of 54 Giga Watt by the year 2032 [3]. The huge production of clean energy meets more than 30 percent of the Kingdom's needs of electricity. These plans fulfil the Kingdom international obligations towards the global emission reduction and are in line with the recommendations of the recent report of the United Nations on climate change that is long overdue and stresses the need to move away from the use of carbon-based fuels. In addition, these plans take advantage of the vast potential of the Kingdom of renewable energy sources, which can be generated in various ways, but the biggest obstacle lies in how to use them as one of the biggest disadvantages of renewable energy is its intermittency and unpredictability. Mostly the time marks the optimum production of electricity from renewable energy sources corresponds to lower demand for electricity, which requires the storage of surplus electricity to be use at the high demand for any electricity during peak hours.

In addition to the well-known challenge of the integration of renewable energy and storage systems in the national grid system, multiple challenges are facing the Kingdom of Saudi Arabia (KSA) plans to convert part of its economy to rely on renewable energy. The ministry of water and electricity (MOWE) of Saudi Arabia is facilitating the challenges to the use of renewable energy in Saudi Arabia. The most prominent of these challenges are; the lack of legislation to regulate the use of solar energy, and to convince the private sector to invest in renewable energy. Many regulatory organizations are working on to regulate and encourage renewable energy plants.

II. ELECTRICITY COST IN SAUDI ARABIA

During the past decade (2004 -2013), the number of subscribers to the service of the Saudi Electricity Company has increased by 59% and the amount of energy sold increased by 77%. The demand for peak load time has increased by as much as 93.3% [3]. The fuel elements used in 2013 for the production of electrical energy in the Kingdom are natural gas (46%), crude oil (29%), and diesel (15%), and the heavy fuel oil was used in the production of the rest of the needed energy [3]. In addition, the average cost of producing, transmitting, and distributing electricity in the year 2013 is about 15.2 halalas (4 cents) per kilowatt-hour, which is far below the world price [3]. The difference represents a part of the state aid to reduce the price of electricity. Without this support, which is valued in the fiscal year 2013 by about 150 billion Saudi riyals (equivalent to 40 billion US dollars), the average costs of production, transmission, and distribution of the electricity in Saudi Arabia for the year 2013 will be about 80 halalas (21 cents) per kilowatt hour. As presented in Ref. [3], Table (1) represents a comparison of the fuel price for producing one million British Thermal Unit (BTU) of energy in Saudi Arabia and the rest of the world.

TABLE I
COMPARISON BETWEEN THE ENERGY COST IN KSA AND THE REST OF THE WORLD

Fuel Type	Cost in KSA ($)*	International Cost ($)*
Heavy Fuel Oil	0.43	15.43
Natural gas	0.75	9.04
Diesel	0.67	21.67
Crude Oil	0.73	19.26

*Cost is per one million BTU

III. RENEWABLE ENERGY RESOURCES IN KSA

In addition to the fact that KSA is the largest producer and exporter of oil in the world, KSA has huge resources of renewable energy. On another hand, the domestic power consumption per capita in Saudi Arabia is higher than in many other countries, and is projected to increase per capita. With these factors, some commentators are of the view that, if Saudi oil consumption grows to match the growth in domestic power demand, within 20 years, Saudi Arabia could become a net importer of oil [5]. To mitigate these scenarios and save the oil for next generation, KSA established King Abdullah City for Atomic and Renewable Energy (K.A. CARE) by a Royal Order on April 17th, 2010 with a mandate to contribute to sustainable development in Saudi Arabia. From the first day of its establishment, K.A. CARE work precisely to fulfil its mission. Currently, K.A. CARE's target is to procure 54 GW of renewable energy by 2032 [5] distributed as in Fig. 1.

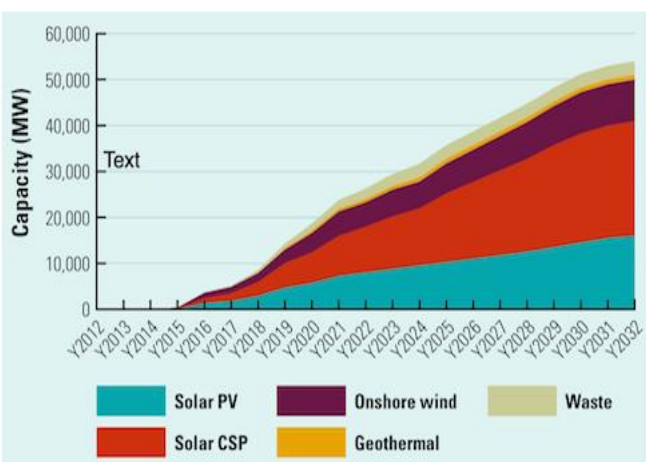

Fig. 1 Targeted Renewable Energy Capacity in KSA

A. Solar Energy

KSA is considered one of the fortunate countries in terms of solar energy as a natural resource. The average annual solar irradiation is estimated as 2000 kWh/m^2 [4]. This important source of energy is available across the country and can be utilized to the development of the rural areas in KSA. Moreover, there are many small-scattered villages and complexes in KSA, and it may not be possible for technical or economic reasons to supply these villages with power from the main electricity grid. Therefore, the logical solution in this case is the exploitation of solar energy in these remote complexes. Due to these convincing reasons, a large part of the proposal of K.A. CARE is based on the development of new technologies and the gradual production of a total of 41 GW from solar energy until the year 2032 [4]. Fig. 2 depicts the average solar irradiation across KSA.

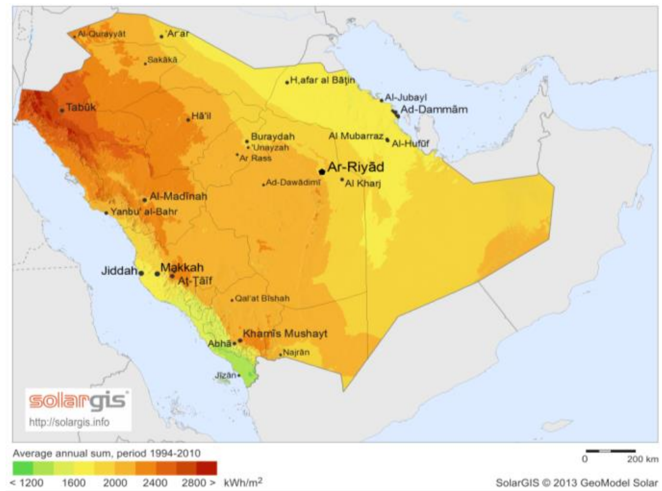

Fig. 2 Solar Irradiation in KSA

B. Wind Energy

Based on recent researches, Saudi Arabia has various suitable sites for large-scale onshore wind generation. As in Fig.3, The most attractive sites for wind power generation are located along the two coastlines, for example, Yanbu in the West and Juaymah and Dammam in the East [6]. Part of K.A.CARE's renewable energy program is the installation of 9 GW of wind power capacity by 2032.

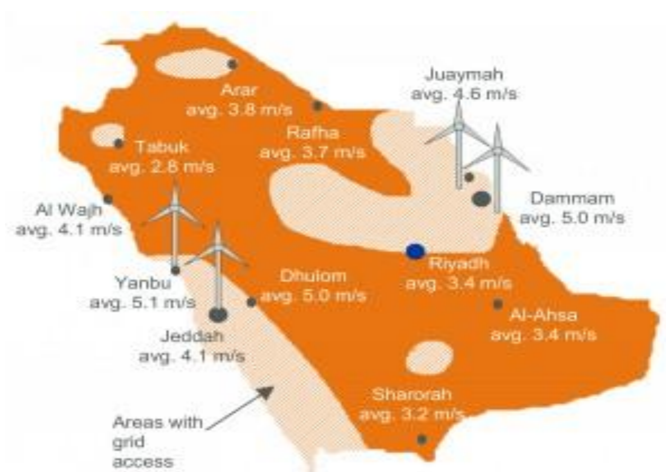

Fig. 3 Regional Suitability for Wind Power Generation in KSA

C. *Waste-to-Energy*

Preliminary studies of waste-to-energy potential in Saudi Arabia by researchers at King Saud University in Riyadh [7] indicate immense potential despite limited data availability. Municipal solid waste (MSW) generation was estimated to be 1.75 kg per capita per day in 2012, and growing rapidly. Populations are relatively concentrated, with more than 75% of the population of approximately 29 million people concentrated in urban areas. Fig. 4 shows the approximate composition of MSW in Saudi Arabia. K.A. CARE is planning to generate 3 GW from waste-to energy by the year 2032.

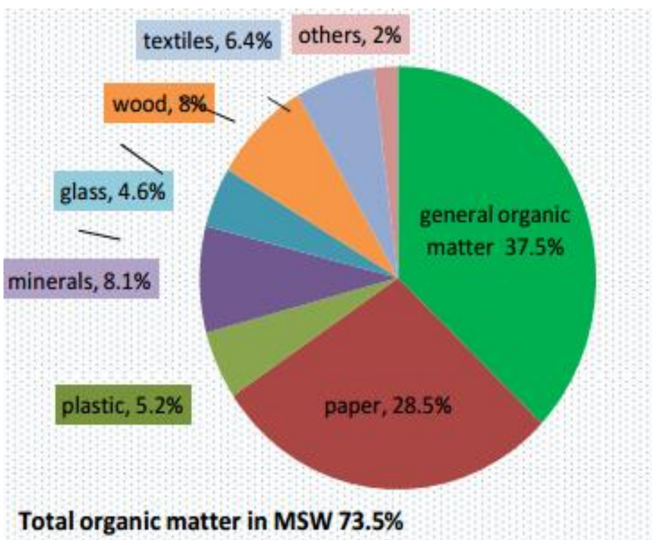

Fig. 4 Components of MSW in KSA

D. Geothermal Energy

Due to the lack of detailed studies and its inability to compete with other energy sources, geothermal energy is not currently considered a major source of electricity generation or heating in Saudi Arabia. However, preliminary studies indicate that there promising possibility for Saudi Arabia to take advantage of the use of geothermal energy associated with shallow ground as a heat source for the development of more efficient cooling system in buildings. The planned contribution of geothermal energy in the K. A. CARE's renewable energy mix is one GW by the year 2032.

IV. Energy Storage Systems

Since the discovery of electric power, people tried to find successful ways to store it for use when they needed it later. In the last century, the effort continues to develop an efficient energy storage technology that match the changes in the methods of production of electrical energy. Currently, there are many technologies to store electric energy. Some of these technologies are mature and deployed others are still in the demonstration and testing phase. Pumped Hydroelectric Energy Storage (PHES), Compressed air energy storage (CAES), flywheels, rechargeable batteries, and molten salt-based thermal storage are considered mature storage technologies. Electrochemical capacitors and superconducting magnet energy storage (SMES) are promising technologies in the demonstration or advanced research phase [8]. Since the scope of this paper is to select a mature storage technology, the focus will be of the deployed technologies specially the ones applicable to the store the electricity generated from renewable energy sources. The next paragraphs provide the description, functions, and applications of these technologies.

A. Pumped hydroelectric energy storage (PHES) System

Pumped hydroelectric energy storage (PHES) systems operate by transporting water between two reservoirs at different elevations, thereby converting between electrical, kinetic, and potential energy to store and deliver electricity. Pumped hydro is best suited for bulk power management applications since it can operate at high power ratings. Pumped hydro, however, suffers from constraints arising from its dependence on suitable geographical settings as well as from constraints related to licensing requirements, environmental regulations, and uncertainty in long-term electric markets [9].

B. Flywheel Energy storage System

Flywheel energy storage system stores rotational kinetic energy via a spinning rotor-disk in a vacuum chamber. Flywheel energy storage system has a very fast response time (less than a second), therefore is suitable for applications that require very fast response times and shorter discharge durations such as frequency regulations. However, the flywheel storage systems has very high cost compared to other storage systems. Also, it suffers from high self-discharge rate of the loss of energy due to the high friction which can be up to 100 % of the energy stored in during the day [10].

C. Compressed Air Energy Storage (CAES) System

When energy production is over demand or when the availability of energy is in the non-needed time, such as solar energy or wind power this energy can be used to compress air. The pressurized air then can be stored in caves underground or into well-designed vessels. Then the saved air is used to drive a gas turbine to generate electricity at the high demand for power. This is the working principle of compressed air energy storage (CAES) system. CAES system is featured as a rapid response system, which makes it suitable for the storage of renewable energy, especially wind power. However, this system requires a location geographically suitable to host the underground caves or special design vessel. In addition, its round trip efficiency is considered low as compared to others energy storing systems [11].

D. Batteries

Batteries are considered the most versatile technologies to store energy. Their applications span from frequency regulation to transmission and distribution of energy. Batteries can be used to store renewable energy or conventional energy. Of the numerous battery chemistries and configurations that have been developed, lithium-ion (Li-ion), sodium sulfur (NaS), and lead-acid batteries are considered mature while technologies such as advanced lead-carbon and flow batteries are still in the demonstration phase [8].

Li-ion batteries has high power density, high roundtrip efficiency, and rapid response time. These features make the Li-ion batteries suitable for frequency regulation and power support. Currently, the main problem of the Li-ion batteries are the high prices, and the safety and restrictions on their life cycle. Any increase in the charging and discharging time or the temperature over the allowable limits leads to decrease the battery life dramatically. So the Li-ion batteries storage must integrate control techniques to control the charging and discharging process in a timely manner which increases operating costs. However, there are some recent improvements in the manufacturing process of these batteries, which is expected to play a key role in reducing costs in the future [12].

Sodium sulfur (NaS) batteries operate at high temperatures (310°C –350°C) [13]. While high efficiency (up to 90%) and abundant, low-cost active materials make this technology attractive, thermal management, reliability, and system safety are challenges [8].

Lead-acid batteries employ a lead oxide positive electrode and a lead metal negative electrode in a sulfuric acid electrolyte. The most important characteristic of lead acid batteries is the low price and reliability and relatively affordable for the various operating conditions of the charging currents and high temperatures as well as the lack of vulnerability to increase the depth of discharge and is to be stored for an indefinite period before bottling the solution electrolytic. Nevertheless, the most important disadvantages is the weight of the weight and low energy density and the length of time shipped and the short life cycle [13].

E. Thermal Storage (Molten Salt)

In thermal storage system, solar energy is employed to heat high-temperature liquefied salts (450°C–600°C) to store thermal energy. Then the molten salt is stored in an insulated chamber until electricity is required, at which time the molten salt is used to generate steam to drive a turbine. Often the salt used for energy storage consists of a mixture of potassium nitrite, sodium nitrite, and sodium nitride, and calcium nitrite, nitrite and lithium. Molten salt technology has advantages of high efficiency, low cost compare to other storage technologies, and abundant storing materials (salts). However, among all energy generated from renewable sources types, this system is only suitable for the storage of concentrated solar power (CSP) [14].

V. Conclusions and Recommendations

Through the extensive research that has been conducted and after gathering the necessary information about the KSA's plans of the deployment of renewable energy and based on the through comparison of all the well-developed energy storage technologies and the latest international experiences for the storage of energy generated from renewable energy sources we can draw the following conclusions and recommendations:

- Thermal storage system (Molten-salt) storage technology is the best storage to be used to store the energy produced from solar energy since the Kingdom's plan is to produce 41 GW from solar energy and 25 GW of this production will utilize the concentrated solar power (CSP) technology.
- The pumped hydraulic storage system is not the best option to store energy in Saudi Arabia. The Kingdom is a desert country with no rivers or lakes. Moreover, the suitable geographical site might not be closed to the available water resources in KSA.
- The compressed air energy storage (CAES) technology is recommended only when there is a suitable geographical site very close to the renewable energy production plants.
- For electricity produced from solar (PV technology), wind energy, waste-to-energy, or the geothermal, batteries (Li-ion, NaS, or Lead-acid) can be used. Further technical and economical evaluation is needed to select the best suitable type for application in KSA among these batteries

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