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Energy Storage for Intermittent Renewable Energy Systems

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Abstract: The demand on various sources of energy especially renewable energy sources have significantly increased in the 21st century. However, such demand escalation and technology implementation is accompanied with some issues. The paper summarizes the energy storage systems and describes the most adequate ones to be used for the renewable energy sources i.e. wind, hydro, solar and geothermal.

Keywords: energy; storage; wind, hydro, solar; demand; renewable; efficient; flywheel; compressed; air; super-capacitor; super; conducting; magnetic; battery; flow; fuel; lifetime.

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1. Introduction

The demand on various sources of energy especially renewable energy sources have significantly increased in the 21st century. However, such demand of such escalation and technology implementation is accompanied with some issues. One of the main concerns renewable energy sources (RES) provide is intermittency in power generation; which acts as a major obstacle for their application. To overcome such problem, different energy storage systems (ESS) are practically viable to be used as an intermediate system between the generation side to possible commercialization and supply. Consequently, since the consumer demand is divided into three different periods [1] i.e. base, intermediate and peak load demands, energy storage systems acting in these intermediately stages need to meet the peak load demand stage since it requires the most energy requirement in the least possible time that ranges from a couple of seconds to a maximum of few hours. With such careful energy storage device usage, expanding the generation capacity by intensifying the power plant capacity is diminished as the supply and demand is met with surplus initially stored in these devices.

2. Results and Discussion

Electricity systems require the energy supply to match the fluctuating demand of energy on a second by second basis. Renewable energy systems usage is increasing worldwide, yet, power industries do not depend solely on them due to the intermittent supply. Renewable energy systems intermittency is mainly due to the unavailability of the natural phenomena that causes the generation of the energy throughout the day. Additionally, RES cannot be easily regulated or dispatched to the energy supply chains because they produce high energy generation when not needed. A main solution to this problem is to deploy energy storage systems (ESS) allowing the storage of the electrical energy. The main causes of intermittency for the RES are shown in Table 1.

Table 1. Intermittency causes for various RES

Renewable Energy Source	Cause of Intermittency
Wind	• Wind availability. • Wind current concentration. • Wind Speed. • Air temperature.
Hydro	• Water current. • Seasonal variations. • Precipitation levels.
Solar	• Amount of diffuse solar radiation. • Seasonal variations. • Weather conditions. • Sun’s energy concentration.
Geothermal	• Uncontrolled drop of temperature. • Steam and heat levels.

Energy Storage (ES) is defined as the conversion of electric energy into a form in which it can be stored until converted back to electrical energy [1]. Recently, several power utilities are leaning towards RES in addition to conventional power generation methods. According to [1-2], efficient energy storage has various benefits to power utilities:

- Efficient use of renewable energy.
- Voltage profile improvement.
- Distribution losses reduction.
- Renewable energy contribution is maximized.
- Improved demand and generation match.
- Transmission losses reduction.
- Reduction of greenhouse gases emissions.
- Top ancillary services supplier.

- Peak loads reduction.
- Cost in building new transmission assets is reduced.
- Reliability of the power system is improved.
- Usage of power systems in more efficient way.

Additionally, with its ability to be cost effective solution to solve the intermittency, several ESS have been developed where each of the currently available technologies is suitable for specific application criteria, yet, they share common role as to [1]:

- Reducing stress on the generating system to provide for peak loads.
- Providing system ancillary services (spinning reserve, black start, reactive power, etc.)
- Minimizing short- and medium-term variability of renewable energy sources when used with power quantity (PQuan) improvement units.
- Lessening distribution network power fluctuation when used with power quality (PQual) improvement units.
- Supporting the penetration of renewable energy sources through reducing the intermittency of the supply.

Furthermore, ESS energy discharge rate plays a major role in the embedment of the energy storage systems with the RES to current power grids. This leads into classifying ESS based on their different discharge rate as shown below [1]:

- Systems to supply energy for a fraction of a second to more than a second to address power quality (PQual) events.
- Systems to supply energy for more than one second to several minutes to address power quantity (PQuan) shortages.
- Systems to supply energy for more than a few minutes to several hours and days for load leveling and energy management.

3. Experimental Section

When selecting any ESS for renewable energy systems application, several characteristics must be considered:

- Power (MW) and Storage capacity (MWh).
- Discharging Time.
- Response Time.
- Efficiency.
- Lifetime.
- Cost i.e. $/kWh.

From the above, it can be concluded that ESS technology is divided based on its storage type and capability, hence, it is necessary to highlight the various available energy storage systems and classify them. The following sections focuses on these systems and present comparison to three main types classified as follows:

1) Mechanical Energy Storage (MES):
    a. Pumped Hydro-electric storage (PSH).
    b. Flywheel energy Storage (FES).
    c. Compressed air energy storage (CAES).

2) Electrical Energy Storage (EES):
    a. Super capacitor (SC).
    b. Super conducting magnetic energy storage (SMES).
3) Chemical Energy Storage (CES):
    a. Lead Acid Batteries
        i. Flooded Type (FTLAB).
        ii. Valve Regulated(VRLAB)
    b. Nickel Cadmium (NiCd).
    c. Sodium Sulphur (NaS).
    d. Flow batteries
        i. Regenerative fuel cell (PSBFB).
        ii. Vanadium Redox (VRBFB).
        iii. Zinc.(ZnFB)
    e. Fuel Cells (FC).

Tables 2, 3, 4 present a comparison of the different ESS mainly applicable to RES integration [1-6].

Table 2. Summary of the main MES with the specifications needed for RES.

	Power (MW)	Storage Capacity (MWh)	Discharge Time	Response Time (ms)	Efficiency (%)	Lifetime	Cost ($/kWh)
PSH	**250-1400**	**1680-14000**	**10h**	**na**	**70-82**	**>30 yrs**	**100-430**
FES	**0.005-10**	**0.005-1.5**	**15 sec -20 min**	**2 -5 ms**	**85-94**	**20 yrs**	**1000-5000**
CAES	**135**	**1080 - 2700**	**8 -20h**	**na**	**68-75**	**na**	**60-125**

Table 3. Summary of the main EES with the specifications needed for RES.

	Power (MW)	Storage Capacity (MWh)	Discharge Time	Response Time (ms)	Efficiency (%)	Lifetime	Cost ($/kWh)
SC	**0.001-1**	**0.0003-0.003**	**1 sec -1 min**	**0.5**	95	**20 yrs**	**2400-6000**
SMES	**0.01-5**	**0.001-1.5**	**1 sec-20 min**	**0.5-5**	95	**20 yrs**	**na**

Table 4. Summary of the main CES with the specifications needed for RES.

	Power (MW)	Storage Capacity (MWh)	Discharge Time	Response Time (ms)	Efficiency (%)	Lifetime	Cost ($/kWh)
FTLAB	**200-400**	**20-100**	**4-5 hrs**	**na**	**72-85**	**1000-2000 cycles**	**425-675**
VRLAB	**0.3**	**0.58**	**na**	**na**	**72-78**	**200-300 cycles**	**na**
NiCd	**27**	**6.75**	**na**	**na**	**72-78**	**3000 cycles**	**na**
NaS	**300**	**50**	**6hr**	**na**	**75**	**6 hrs**	**520-550**
PSBFB	**15**	**120**	**na**	**na**	**75**	**na**	**na**
VRBFB	**250**	**50**	**5hr**	**na**	**65-75**	**100000 cycles**	**620-740**
ZnFB	**250**	**50**	**5hr**	**na**	**60**	**Na**	**290-350**
FC	**0.005-10**	**1-700**	**Min-hours**	**20**	**50-60**	**10 yrs**	**na**

With the vast availability of ESS technologies, RES would be easily integrated into the current power industries, yet, when comparing that ESS against each other, it is clear that most of these technologies have low efficiencies i.e. <90% and for power industries, hence directly neglected resulting in huge losses. Based on the comparison, it is noted that super capacitor, super conducting magnetic energy storage and flywheel energy storage are branded with best efficiencies, in addition, to faster response time, an important aspect for the rapidly changing intermittence in the RES. Finally, their lifetime is of an adequate lifespan to convince power industries to accept the RES penetration into their power grids. Since these ESS technologies are unrelated to the geothermal energy storage mechanism, the geothermal energy storage is not suitable for RES.

When comparing the integration of ESS into wind power generation, it is vital to consider the power system's most sensitive wind frequency, specifically medium frequency i.e. 0.01Hz to 1 Hz as studies show. This implies that short term ESS would provide the maximal benefit for the wind farm SC, SMES and FES are all best used for short term storage, yet, it is better to use dual energy storage technologies at the same time. FES has been used for wind power generation due to its power quality and stability enhancement. Additionally, SCES and SC are similar in their effect while being used in wind energy storage such reducing voltage flickering, eliminating current harmonics, pulsating load and uninterrupted power supply. However SC stacks with less auxiliary equipment's, more stable and convenient than SCES [7].

Hydroelectricity represents about 94% of the renewable energy production and 20% of the worldwide power, thus, the integration of ESS to the current intermittent systems is vital to enhance the power output and reduce the losses that results from the intermittency where micro-hydro power generation has a huge potential to be expanded worldwide in appropriate locations. Study of grid connected hybrid wind/micro hydropower systems embedded with a SC ESS has resulted in smoothing and enhanced power output. [8]

Several studies have been conducted on the deployment of SC, SMEC and FES ESS for photovoltaic (PV) distributed power generation grids and have shown that Flywheel energy system is the most abundant energy storage system used for the following advantages especially when compared to lead-acid batteries:

- Higher charging and discharging rate.
- Durability resulting in lower overall cost for a 20 year lifetime.
- Environmentally friendly, especially at disposal time.
- Temperature independent storage capacity.

Additionally, other studies have suggested the usage of Super Capacitors as they compensate for uncertainties in the PV source production in both steady & transient states. Moreover, the study described in [10] showed that SC can advance the load, following the characteristics of the main sources, by providing a stronger power response to changes in the system load. Adding energy storage to the distributed power systems improves power quality and efficiency.

In general, the penetration of energy storage systems into current power grids is mainly affected by the cost of the storage systems. The huge initial cost of such RES defer them from being used on the short term yet, on the long term, the initial investment would result in more saving in a 20 years lifetime especially the grids that depend on batteries rather than a better, yet expensive alternative ESS. Additionally, the usage of fuel and the reduction in carbon footprints are of great help to the environment.

4. Conclusions

In conclusion, the 191 parties that have ratified the Kyoto Protocol to reduce the greenhouse gases have intensively adopted RES into their power grids, yet, the intermittency concern of these RES have played a drawback to their expansion due to the unpredictable nature of power generation. Energy storage systems has been proved to solve these issues in the RES, and several ESSs have been studied to enhance the power generation from the potent RES that are likely to be used and expanded more in the world of power generation in the near future.

Conflict of Interest

The authors declare no conflict of interest.

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