Storage strategies for renewable energy

Abstract: **Renewables are sustainable energy, but these energies come from nature and subject to natural factors, storage strategies have been introduced to solve this problem. This essay compared the characteristics of storing electricity as electrochemical, thermal and mechanical forms. Also, four progresses including operating with alternative generation ways, improving the storage performance itself, using data and IoT and make use of waste energy will be elaborated.**

I. INTRODUCTION

Renewables generate power intermittently and constrained by weather. The imbalance of generation and demand led to the "duck curve problem" in California in 2013, as figure 1 shows [1]. Besides, shading problem and variations in tidal or wind range will cause unstable output. So feasible ways such as storage need to be adapted to deal with these problems. In this essay, the necessity of storage will be introduced first. Then, storage strategies that popularly used for now will be compared, and better solutions that may potentially promote will also be discussed.

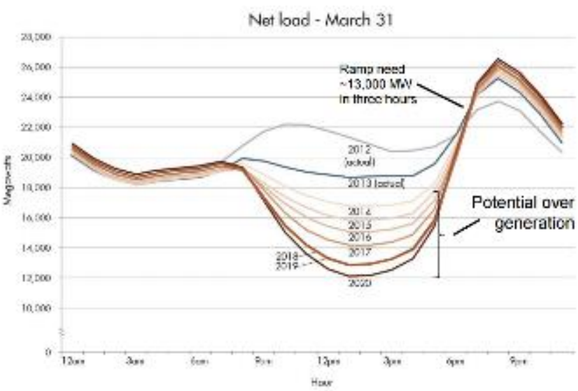

Figure 1: "Duck Curve". Source: Stanford University

II. FUNCTIONS OF RENEWABLES ENERGY STORAGE

Renewable energy storage is not only used as power bank, but also have two purposes in operation. One is to smooth the voltage and improve quality. The intermittency and variability problem can result in voltage fluctuations, even beyond limits [2],[3]. By storage method, fluctuations can be reduced. The other one is to manage the network and balance the generation and demand. So that it can shift load and manage the "duck curve" problem.

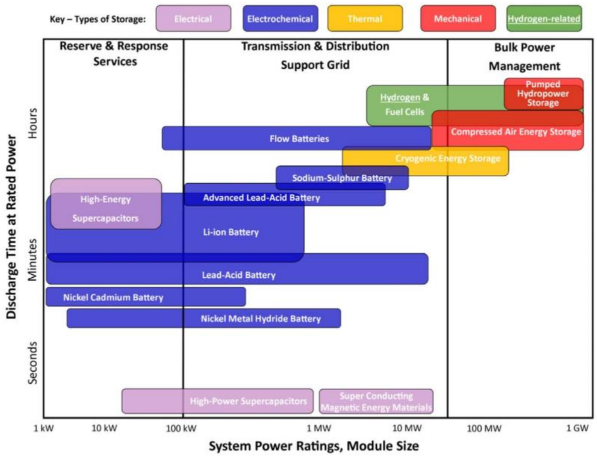

Figure 2, Comparison of key-type energy storage technologies [4]

Energy storage can applicate to different operating requirements. As figure 2 shown, they have different energy density, capacity, discharge time and so on, so the applicable situations are different, and usually be used together. Those with small capacity and short dis/charge time's storages can be used to improve power quality. Medium-scale storages can be used as buffer or emergency storages [5]. Large and long-term storage can applicate to network management like peak shaving [5].

III. STORAGE STRATEGIES BEING USED NOW

There are several ways to store energy. As electricity cannot be stored directly, storing it means to convert it to other forms by storage media, including five classes as table1 shows [6]. Some popular storages will be discussed below, and the comparison of them is shown in the picture 3.

Table 1 storage media

storage media	examples
electrochemical	batteries
thermal	Heat storage, cold storage etc
mechanical	pumped-hydro technologies, flywheel, Compressed Air Energy Storage (CAES)
electrical	supercapacitor and superconducting system
chemical energy storage	use of hydrogen or synthetic natural gas as a carrier

	Max Power Rating (MW)	Discharge time	*Max cycles* or lifetime	Energy density (watt-hour per liter)	Efficiency
Pumped hydro	3,000	4h – 16h	30 – 60 years	0.2 – 2	70 – 85%
Compressed air	1,000	2h – 30h	20 – 40 years	2 – 6	40 – 70%
Molten salt (thermal)	150	hours	30 years	70 – 210	80 – 90%
Li-ion battery	100	1 min – 8h	*1,000 – 10,000*	200 – 400	85 – 95%
Lead-acid battery	100	1 min – 8h	6 – 40 years	50 – 80	80 – 90%
Flow battery	100	hours	*12,000 – 14,000*	20 – 70	60 – 85%
Hydrogen	100	mins – week	5 – 30 years	600 (at 200bar)	25 – 45%
Flywheel	20	secs - mins	*20,000 – 100,000*	20 – 80	70 – 95%

Figure 3 Comparison of different storage methods. Source: https://www.eesi.org/papers/view/energy-storage-2019

1). Electrochemical energy

Electricity can be stored in batteries as electrochemical energy. Batteries are easy to install, no geographical limitations. As figure 4 shown, in comparison with other batteries, Lithium-ion batteries can be a preferable choice due to its high energy density, long life, short charging time and have relatively low toxicity. But it requires an external management system to control and expensive. Besides, raw materials such as nickel and cobalt are poisonous. Mining cobalt is harmful to the local environment, causing negative effects on citizens' health and killing many animals [7].

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1] Cobalt	Li-ion[1] Manganese	Li-ion[1] Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 149°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

Figure 4 comparison of different kinds of batteries. Source: batteryuniversity.com

2). Thermal energy

Electricity can also be stored as thermal energy. Thermal energy storage (TES) not only decreases the discrepancy between supply and demand but also improves the reliability of the system [8]. For example, as shown in figure 5, concentrating solar power plant is using molten salt as media, and it can be stored in the thermal tank for later use.

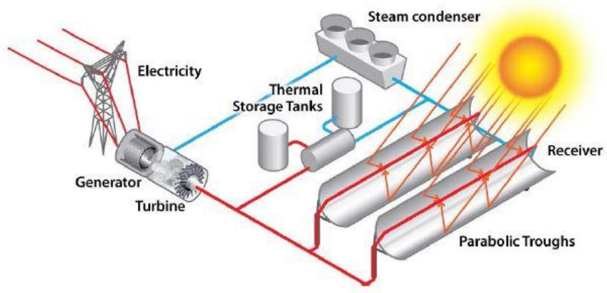

Figure 5 concentrating solar power plant. Source: US Department of Energy

3). Mechanical energy

Another way is to store energy in mechanical form. Storage concepts are shown below.

Table 2 storage concepts of convert electricity to mechanical energy

	Pumped-hydro technologies [9]	***Flywheel [10],[11].***	***Compressed Air Energy Storage (CAES)***
Type	Potential (gravity)	Kinetic	Potential (elastic)
Absorb energy (uses exceed electricity)	Pump water to a high place	(rotation) Speed up	Compress air (stored underground)
Release energy (generates electricity)	Water flows down and pushes the turbine	Rotate the generator (speed down)	Combust with gas fuel, propel the turbine

Pumped-hydro technologies can store massive scale of power (GW), and it can provide electricity in a relatively short time (seconds to minutes). Instead of using water, a new research of Mountain Gravity Energy Storage uses sand and gravel, which can reduce the impact of environment and no evaporation [12], [13]. Flywheel can provide electricity fast (millisecond), but last time short (seconds to minutes) [6]. Consequently, it can be used on improving power quality. CAES costs low and especially good for wind plants since the machinal power of the wind turbine can be directly used by the compressor (no energy conversion) [6]. But the total efficiency is not high (less than 50%), because the released heat cannot be utilized when compressing the air whereas when being used, it needs heat to expand [6].

IV. RECENT RESEARCHES REGARDING RENEWABLE ENERGY STORAGE

Recent researches give alternative ways to make storage more cost-effective. Several ways are introduced below.

1). Decrease the required storage size

The system proposed in [14] is to integrate spatially diverged PV plants with the same power ratings, as shown in figure 6. Integrating these plants can make fluctuations small, and the battery storage system can further (smooth the output power) remove the PV power variability, thus the power can be dispatch to the grid directly and a smaller scale of batteries is needed [14].

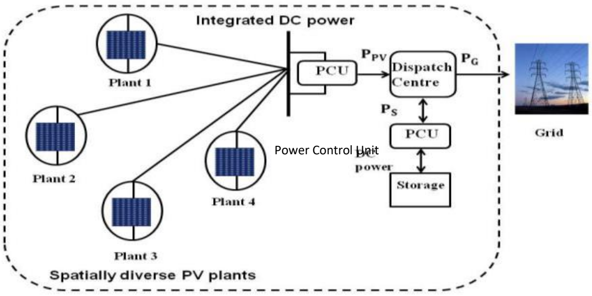

Figure 6 integrated PV plants [14]

2). Virtual storage

Virtual storage is the concept of demand dispatch by using software to distribute surplus energy to other demanded equipment so that the power can be used effectively [15]. It can coordinate with the availability of solar power without compromise the comfort and add no cost for running the equipment [15]. Besides, with Internet of Things, the equipment (e.g. air-conditioner) can run as a low-energy mode when the sensor detects the room is unoccupied thus save energy easily. However, the risk of being hacked cannot be ignored.

3). Boost capacity of li-ion battery

Li-ion batteries use redox reaction to make the li-ion flow thus generate current. So, more li-ion can be used means more electricity it can store. Scientists are researching a li-ion silicon battery ($Li_{15}Si_4$). A small amount of anode material can store more electricity because of its 15-to-4 ratio [16]. This can increase the capacity by 20% to 40% and improve safety. The drawback is it would disintegrate thus damage the battery if repeatedly dis/charged [16].

4). Improve overall efficiency

Research [17] coordinates liquefied air energy storage (LAES) with low-carbon refrigeration to improve overall efficiency. It uses exceed electricity to liquefy air which will be stored in the insulated low-pressure tanks [17]. Not like CAES, it does not need cavern to store air, thus no geographical restrictions. When needed, the liquid can be expanded to gas and propel the turbine, at the same time, it will absorb heat when expanding, thus cools the food [17].

V. CONCLUSION

Storage strategies for renewables were discussed above. Every method has its characteristic, so making use of its advantage and improve efficiency is important. The last part has introduced four types of research in recent years. The point is to combine with different ways such as new operation method, IoT, waste energy usage etc. to achieve sustainability better.

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