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Prospects Of Energy Storage Applications In Vietnam

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Abstract: In Vietnam, the development of renewable power sources in general and solar power in particular has overheated recently, causing many difficulties in the operation of the national power system. The energy storage systems (ESSs) have several merits, such as transmission and distribution congestion relief, frequency and voltage regulation, smoothing of renewable energy power generation, demand shifting, peak reduction, spinning reserve, etc. The paper reviews the energy storage technologies in the world, their applications and prospects of their applications in Vietnam. Some characteristics of Vietnam's power system are discussed, especially the issues due to the deep integration of renewable energy into the power system. The paper also recommends potential energy storage technologies to be applied in Vietnam.
Keywords: Energy storage system, Li-ion battery, Vanadium redox flow battery, pumped storage hydroelectricity, renewable energy, Vietnam's power system.

I. INTRODUCTION

Renewable energy technology has grown rapidly in recent years due to price declines, innovation and policy support. The ongoing transformation of the energy sector presents new challenges that require a change in the way policymakers, regulators and services plan, manage and operate power systems.

In Vietnam, the development of renewable power sources in general and solar power in particular has overheated recently, causing many difficulties in the operation of the national power system. From 2015-2020, the share of generating capacity of renewable energy increased from 1% to 26%, of which solar power increased from 0% to 24%, wind power from 0% to 1%, biomass kept at 1% [1].

The rapid explosion of renewable electricity requires a more flexible energy system to ensure that the energy system with a large share of renewable energy can operate reliably and cost-effectively.

With its unique ability to absorb, store and generate electricity, electricity storage is seen as an outstanding solution to solve some of the technical and economic challenges of integrating renewable energy. Power storage can provide a range of services that enable the integration of wind and solar and address some of the challenges posed by the variability and uncertainty of wind and solar entering the system. Power storage could play a key role in the next energy transition, allowing for a higher share of renewables in the power system, accelerating electrification, and indirectly reducing carbon in the transportation sector.

For the above reasons, it is necessary to study and evaluate energy storage technologies and the applicability of each technology in Vietnamese conditions. The paper will focus on analyzing and comparing the characteristics of energy storage technologies in the world and evaluating the applicability of these technologies in Vietnam's conditions.

II. ENERGY STORAGE TECHNOLOGIES AND APPLICATIONS

The US Department of Energy 2019 research report shows that, as of 2018, the total installed capacity of global energy storage is about 178 GW. Also detailed data for the most basic and popular storage technologies currently installed worldwide are shown in Tables and Figures below. It shows that pumped-storage hydroelectricity (PSH) energy storage still accounts for the largest share of 170 GW, accounting for 98% of the total installed capacity of all types of global energy storage technologies. All other types of storage technologies have an installed capacity of 3,371 MW, accounting for only 2%, of which 1,629 MW is of Lithium - ion technology. Lithium-ion technology belongs to the group of electrochemical energy storage technologies. The remaining group of 2% of storage technology is very small compared to the total storage of pumped-storage hydroelectric technology. Regarding the role of energy storage, this group of remaining energy storage technologies and pumped hydroelectricity are the same, but the service function in the current energy system is 2% of the energy storage technology group. is different from PSH.

Technology	Deloyed (MW)
NaS Battery	189
Lithium-ion Battery	1,629
Lead acid Battery	75
Sodium metal halide Battery	19
Flow battery	72
Pumped storage hydroelectricity (PSH)	169,557
Compressed-air energy storage (CAES)	407
Flywheels	931
Electrochemical capacitor	49
Total	172.928

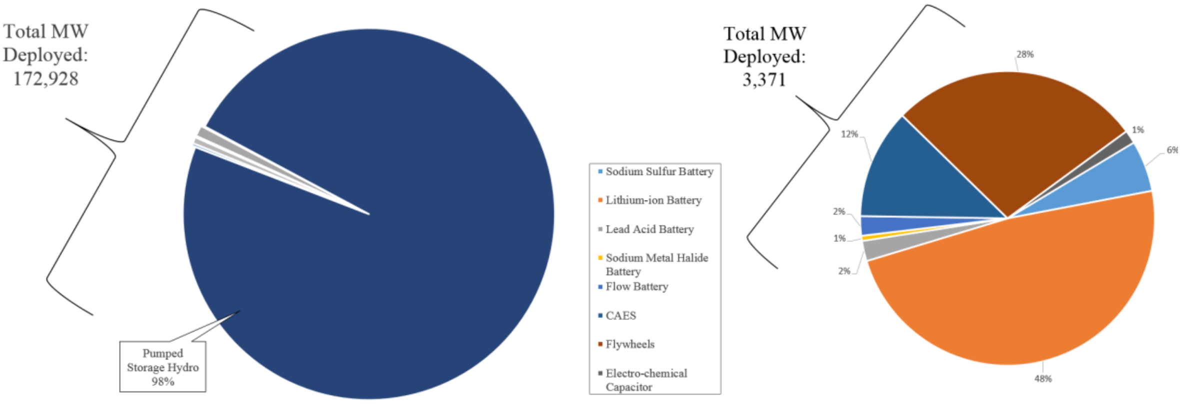

Figure 1. Share of energy storage sources in the world as of 2019 [2]

A. Energy storage technologies

Energy storage uses technologies ranging from pumped hydraulic storage, flywheels, supercapacitors, compressed air, thermal energy storage, and batteries. Advanced energy storage technologies are capable of delivering electricity within seconds and can provide backup power from minutes to hours. Each type of energy storage system has its own properties. These factors need to be considered in order to select the right technology for a particular purpose. Table 1 provides a comparison of the different specifications of different energy storage technologies.

Table 1. Operational characteristics of energy storage technologies [3] [4]

Parameters	Lead acid	Li-ion	NaS	Flow battery	Flywheels	CAES	PSH
Round trip energy efficiency (DC-DC)	70-85%	85-95%	70-80%	60-75%	60-80%	50-65%	70-80%
Discharge duration	2-6h	0,25-4+ h	6-8h	4-12h	0.25-4h	4-10h	6-20h
C Rate	C/6-C/2	C/6-4C	C/8-C/6	C/12-C/4	C/4-4C	-	-
Cost (USD/kWh)	100-300	250-800	400-600	400-1000	1000-4000	>150	50-150
Construction period	6 month - 1 year	6 month -1 year	6 month - 1,5 year	6 month - 1,5 year	1-2 year	3-10 year	5-15 year
Operating cost	High	Low	Moderate	Moderate	Low	High	Low
Space required	Large	Small	Moderate	Moderate	Small	Moderate	Large
Cycle life: number of discharge	500-2.000	2.000-10.000	3.000-5.000	12.000-14.000	100.000	10.000+	100.000
Maturity of technology	Mature	Commercial	Commercial	Moderate	Moderate	Moderate	Mature

B. Energy storage applications

Energy storage is a versatile asset type with the wide range of benefits it can offer, with variety of installable locations, and with a large number of potential technologies suited for providing value to the grid. Essentially, energy storage transfers energy from one time period to another. However, the value of the stored energy varies widely according to the ability to control, transport, and use that energy.

In the past, the power system has operated on a "just-in-time" basis – power production is based on the real-time demand and the readiness of the transmission system. Therefore, power and load must always be in perfect balance to ensure the high quality and reliability of the electricity for the end customer. At the very high penetration of wind and solar energy, the energy storages can store the excess energy at certain times and transfer it to other times, improving reliability and bring both economic and environmental benefits.

The storage's physical characteristics allow it to perform many functions on the grid, at the customer level, and in the transmission sector. The ability to store energy when there is no demand and deploy it when it is needed can be applied to all aspects of the energy system. In addition, the storage system can act like a power plant, generating electricity. When renewable resources such as solar, wind or hydroelectricity generate excess energy, the ES can store it for later use, reducing energy waste.

The value of energy storage technologies lies in the services they provide in different parts of the energy system. These technologies can be used in power grids, heating and cooling networks, distribution systems and off-grid standalone applications. Furthermore, they provide services that support the supply, transmission, and distribution infrastructure and portions of the energy system. Broadly speaking, they can be valuable tools for system operator with the ability to change supply and/or demand.

The main applications of energy storage are defined:

– Seasonal storage: The ability to store energy for days, weeks, or months to offset long-term energy supply interruptions or seasonal fluctuations from both the demand and supply sides of the power system.

– Arbitrage: store low-priced electricity during low-demand times and resell it during peak times.

– Frequency regulation: automatically balance the continuously changing supply and demand within a control area, in a time frame of minutes or less.

– Load following: the second balancing mechanism following frequency regulation is load following, with time frames from 15 minutes to 24 hours, automatically or manually.

– Voltage support: inject or absorb the reactive power to maintain voltage levels on transmission and distribution systems.

– Black start: In a bad situation, the electrical system fails, and all other ancillary mechanisms fail, the black start allows the power generation to restart without power from the grid

– T&D congestion relief and infrastructure investment deferral: energy storages temporally and/or geographically shift the energy supply or demand in order to relieve congestion points in transmission and distribution networks or to delay the need for large investments in transmission and distribution systems.

– Demand shifting and peak reduction: Energy demand can be shifted in order to match with supply and to help the integration of variable supply resources (like renewable energy). This shifting is accomplished by varying the timing of some operations (e.g. heating, electric car charging).

– Off-grid: Off-grid energy consumers often depend on fossil fuels or renewable energy for heat and electricity. To ensure a stable supply, energy storage is used to fill the gap between the variable supply resources and demand.

– Integration of variable supply resources: Store energy to change and optimize the output from fluctuating sources (wind, solar), mitigate the rapid and seasonal changes in output.

– Spinning and non-spinning reserve: Reserve capacity of the electric supply is used to compensate for sudden and rapid losses of electricity generation to ensure the stability of the system. This standby power is classified according to response time as spinning (<15 minutes) and non-spinning (>15 minutes). Generally, the faster the response time, the more valuable it is in the system.

Table 2. Applications of energy storage in energy system [5]

Applications	**Capacity (MW)**	**Discharge period**	**Discharge frequency**	**Response time**
Seasonal storage	500-2000	days - months	1 – 5 times /year	Day
Arbitrage	100-2000	8h-24h	0,25-1 times / day	>1 hour
Frequency regulation	1-2000	1-15 minutes	20-40 times / day	1 minutes
Load following	1-2000	15 minutes – 1 day	1-29 times / day	<15 minutes
Voltage support	1-40	1 second – 1 minute	10 – 100 times / day	Mili seconds – seconds

Applications	Capacity (MW)	Discharge period	Discharge frequency	Response time
Black start	0,1 – 400	1 hour - 4 hours	<1 times / year	< 1 hours
Transmission and Distribution (T&D) congestion relief	10-500	2 – 4 hours	0,14 – 1,25 times / day	> 1 hour
T&D infrastructure investment deferral	1-500	2 – 5 hours	0,75 – 1,25 times / day	> 1 hour
Demand shifting and peak reduction	0,001 – 1	Minutes – hours	1 – 29 times / day	<15 minutes
Off-grid	0,001 – 0,01	3 – 5 hours	0,75-1,5 times / day	<1 hours
Variable supply resource integration	1-400	1 minutes – nhiều hours	0,5 – 2 times / day	<15 minutes
Spinning reserve	10-2000	15 minutes – 2 hours	0,5 – 2 times / day	<15 minutes
Non-spinning reserve	10-2000	15 minutes – 2 hours	0,5 – 2 times / day	>15 minutes

III. THE PROSPECTS OF ENERGY STORAGE APPLICATIONS IN VIETNAM

A. Some characteristics of Vietnam's power system

By the end of 2019, electricity produced and imported of the entire power system in Vietnam reached 240 billion kWh, an increase of 2.35 times compared to 2010 (101.4 billion kWh). National commercial electricity output in 2019 reached 209.77 billion kWh, an increase of 2.46 times compared to 2010 (85.4 billion kWh), corresponding to the average growth of commercial electricity in the whole period 2011-2019 is 10 .5%/year (in the period 2011-2015 increased by 10.97%/year and in the period 2016-2019 increased by 9.49%/year). In 2020, electricity production of the whole power system is estimated to reach 246 billion kWh, an increase of 2.6% compared to 2019. The largest load capacity of the whole system (Pmax) in 2019 is 38.2 GW, in 2020 it is estimated to reach 38.2 GW. 38.7GW. Compared with other countries in the world, Vietnam's electricity system is currently ranked 22nd in the world in terms of electricity production [6].

By the end of 2019, the total electricity capacity of the country will reach about 56GW. It is estimated that by the end of 2020, Vietnam's power system will have a total installed capacity of about 69GW (including hydroelectric plants imported from Laos and rooftop solar power), in addition, the Northern power system will also importing electricity from China via transmission lines with a total maximum capacity of about 700MW. In the structure of national power capacity in 2020, coal-fired power accounts for about 30%, hydroelectricity accounts for 30%, gas turbines and oil-fired thermal power accounts for 13%, solar power (including rooftop solar power) accounts for 30%. 24%, wind power 1%, biomass power about 1%, imported hydropower from Laos accounted for 1%. The total number of power plants in operation is about 162 (excluding small hydropower plants and renewable energy). The maximum load capacity of the power system in 2020 is about 38.7 GW, the crude reserve ratio of the power system (except for wind and solar power) is 34.3%.

Table 3. Installed capacity and energy production in Vietnam classified by primary energy sources as of 2020 [7]

Item	Capacity (MW)	Energy production (MWh)	Capacity shares (%)	Energy production shares (%)
Hydroelectric (including small hydroelectric)	20,685	72,892	29.94%	29.50%
Coal thermal power	20,867	123,177	30.20%	49.85%
Gas and oil thermal power	9,070	35,850	13.13%	14.51%
Renewable energy, in which:	17,900	12,084	25.91%	4.89%
Wind	630		0.91%	
Solar	16,700		24.17%	
Biomass	570		0.82%	
Import (from Laos)	572	3,067	0.83%	1 .24%
Total	69,094	247,085		
Pmax	38,706			

Typical working day load chart for the years 2015 to 2019 (Figure 2) and energy consumption by week of year (Figure 3) show the changes of demand during a day and a year (seasonal change):
– There are 3 peak times during the day: the morning peak mainly occurs around 10:00, afternoon peak occurs between 14:00-16:00 and the evening peak mainly occurs at 18:00.
– Winter peak usually occurs in the evening, summer peak usually occurs in the afternoon
– Pmax occurs in summer

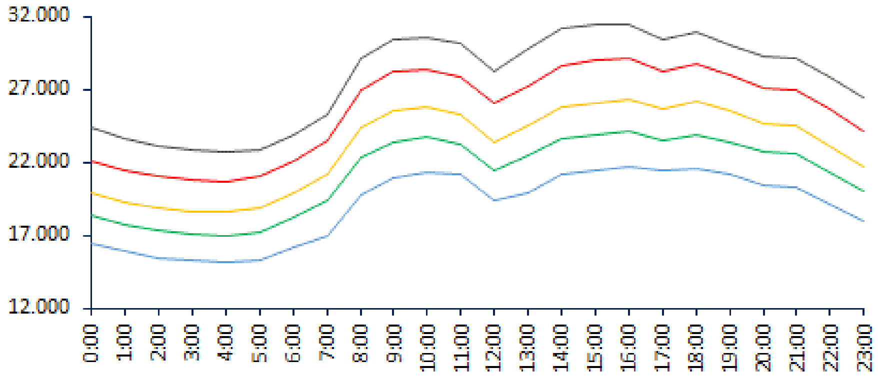

Figure 2. Typical load by hour during a typical work day of year 2015-2019

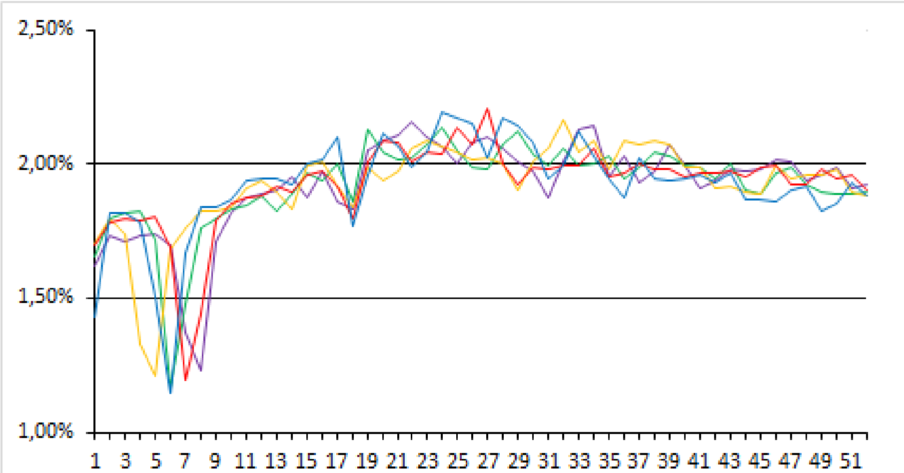

Figure 3. Energy consumption by week of year 2015-2019 (unit: percentage of total consumption of the year) [7]

B. Issues due to the deep penetration of renewable energy into the power system

With the sudden growth of solar power in the years 2019-2020 due to the Feed-in tariff policy (FIT). By the end of 2019, solar power (including rooftop solar) only reached about 4.7GW, but by the end of 2020, it is estimated that solar power nationwide is about 16.7 GW. At present, renewable energy sources (wind and solar) has accounted for nearly 26% of the total installed capacity.

Regarding wind power, as of March 2020, Vietnam had 78 wind power projects with a total capacity of about 4,800 MW supplemented with Power Development Plan (PDP) VII, of which 11 projects (total capacity 377 MW) were already in operation. electricity generation; 31 projects (total capacity of 1,620 MW) have signed power purchase agreements and are expected to come into operation before December 2021.

With wind and solar power sources continuing to develop in the coming period, especially when PDP VIII is approved, paving the way for the lists of wind and solar power sources to participate in the supply system with a high proportion, the power system will will face many difficulties and challenges as follows [8]:

– The problem of reducing the capacity of wind and solar power sources due to excess power, especially at low demand times during holidays and new year eve.

– The operation of frequency regulation and voltage regulation of the power system faces many difficulties because electric generation of wind and solar power sources fluctuates depending on the weather conditions. When there is a change in weather, the loss of a large amount of power will cause a drop in the frequency and voltage of the power system that may reach the threshold causing the phenomenon of "collapse".

– Since solar power sources have no rotational inertia and wind power sources have low rotational inertia and the dynamic response depends on the inverter's characteristics. Therefore, when solar power and wind power take a large portion in the power system, it will reduce energy inertia of the system, leading to an increased risk of power system instability.

– The economic efficiency of investment in transmission infrastructure for releasing the capacity of wind and solar power plant is low, because those transmission lines and substations required to carry high capacity but have very low operating hours (<3,000 h/year).

C. Potential energy storage technologies for application in Vietnam

From the characteristics and problems in the Vietnam power system, the deployment of energy storage systems is a necessary and urgent matter in order to increase the economic efficiency of the grid to release capacity, increase stability of the power system.

The authors has considered the following energy storage technologies as the most potential to be deployed in Vietnam:

– Pumped storage hydroelectricity (PSH)

– Battery energy storage system (BESS): Lithium battery (LiB) and Vanadium redox flow battery (VRFB)

– Hydrogen

1) Pumped storage hydroelectricity (PSH)

PSH is a mature technology that includes pumping water from a lower reservoir to a higher one where it is stored until needed. When released, the water from the upper reservoir flows back down through a turbine and generates electricity. There are various configurations of this technology, including open-loop (one or more of the reservoirs are connected to a natural body of water) and closed loop (reservoirs are separate from natural waterways). Existing turbine technologies also offer different features and capabilities, including fixed speed, advanced speed, and ternary.

Three quarters of Vietnam's territory are made up of mountains and hilly regions. Vietnam has high potential for hydropower in general and pumped storage hydroelectricity in particular.

Currently, Bac Ai Hydroelectricity project, Ninh Thuan province (capacity of 1,200 MW) is the first stored hydroelectric power project in Vietnam, expected to start construction in early 2023 with a total investment of about 21,100 billion VND is on the list of power source projects included in the Electricity Master Plan VII (adjusted) by the Prime Minister, invested by EVN.

In addition to Bac Ai Hydroelectricity project, there are also 3 storage hydropower projects, namely Phu Yen Dong (Son La), Don Duong, and Ham Thuan Bac, which are planning to invest. And according to the plan of storage hydropower, there are at least 10 highly feasible storage hydropower projects that can be considered for construction according to electricity development needs.

2) Lithium-ion battery

Lithium-ion batteries are a proven and widely used technology. A lithium-ion battery system for energy storage (BESS) can be deployed very quickly.

The advantages of Lithium-ion battery are: High energy density, high efficiency, long cycle number, low discharge rate as well as no memory effect. Additionally, Li-ion batteries are characterised by stable discharge voltage, wide operating temperature, depth of charge up to 85% [9].

The disadvantages of Lithium-ion battery: heating of internal resistance can cause battery' failure, requirements of internal overcharge protection circuits, complex charging circuitry. Environmental issues can also arise due to the fact that lithium is highly reactive and flammable, while some electrodes and electrolytes are toxic.

Besides stationary battery energy storage system, electric vehicles are also a strong influence on the current electricity system. As electric vehicles begin to gain momentum at a higher rate globally, utility companies, system operators and policymakers have begun to address issues related to vehicle charging management for smooth integration of the loads from electric vehicles into the grid. Thus the concept Vehicle to Grid (V2G) is being mentioned more frequently.

V2G can provide many services to grid operators such as renewable energy peak balancing, frequency regulation, spinning reserve, excess energy storage, and more. But on the other hand, there are many limitations associated with V2G such as battery degradation, complex connectivity between vehicles and the grid, requirement of changes in infrastructure, distribution grid equipment, etc...

3) Vanadium redox flow battery

Vanadium redox flow (VRF) batteries are the most widely employed flow batteries. They differ from conventional batteries in terms of storing process, since they utilise two external tanks for the storage of the electrolyte, which is pumped through the electrochemical cells during the process of charging and discharging. These batteries make use of two liquid electrolytes—a positively and a negatively charged—separated by an ion-selective membrane.

The advantages of VRF are: Has a long life cycle of 15 years, 10,000 recharges; depth of discharge is very deep: 100% complete discharge; can be made with a very large capacity; Low operating temperature, does not cause fire and explosion, good heat dissipation due to electrolyte flow will help dissipate heat, battery stops working as soon as the pump is turned off; easy to recycle and less toxic, safe for the environment; the storage capacity and power capacity can be independently upgraded,; low maintenance cost, each part (module) can be replaced without affecting the whole.

Disadvantages of VRF are: High cost, Low efficiency and low power density, Complex structure, Has many moving parts that require pumps, sensors, and other flow management mechanisms, so it can only be used as a stationary energy storage station.

4) Hydrogen

Hydrogen production from wind or solar power plants shows a high potential for applications due to the ability to electrolyze water into hydrogen and oxygen without the emission of greenhouse gases by not consuming fossil fuels. The generated hydrogen is stored for later use at hydrogen fuel stations, (for transportation or some industrial processes), or converted back into electricity to feed the grid at peak hours [10].

The most promising hydrogen production technologies from water are PEM (Polymer electrolyte membrane) and alkaline water electrolysis. In terms of application to energy storage, PEM electrolysis has the advantage of operating with high current density [11]. This can help reduce operating costs, especially for the location where the grid is connected to highly variable energy sources such as wind and solar.

Currently, hydrogen produced in Vietnam is mainly by thermochemical fuel technology to serve the needs of industrial hydrogen in fertilizer production, petrochemical refining, etc., the energy hydrogen industry has received little attention.

D. Technology Cost

The total installed cost is consisted of [2]:

– Capital cost (USD/kW or USD/kWh) for main part
– Power conversion system (PCS) (USD/kW)
– Balance of Plant (BOP) (USD/kW): wiring, transformers and other ancillary equipment
– Construction & Commissioning: design, transportation, installation and commissioning cost

The total installed cost of Li-ion, redox flow battery and pumped storage hydroelectricity was referenced from [2] [12], and is presented on

Table **4**.

Table 4. Installed cost of the considered energy storage technologies [2] [12]

		Capital cost	PCS	BOP	C&C	Installed cost (USD/kW)	Installed cost (USD/kWh)
Li-ion	**2018**	223-323	230-470	80-120	92-110	1,570-2,322	393-581
		271	**288**	**100**	**101**	**1876**	**469**
	2025	156-203	184-329	75-115	87-105	1,231-1,676	308-419
		189	**211**	**95**	**96**	**1446**	**362**
Vanadium redox flow battery	**2018**	435-952	230-470	80-120	173-207	2,742-5,226	686-1,307
		555	**350**	**100**	**190**	**3430**	**858**
	2025	326-643	184-329	75-115	164-197	2,219-3,804	555-951
		393	**211**	**95**	**180**	**2598**	**650**
Pumped storage hydroelectricity	**All**	1,700-3,200	-	-	-	1,700-3,200	106-200
		2,638	**-**	**-**	**-**	**2,638**	**165**
Hydrogen	**2020**	2,793-3,488	-	-	-	2,793-3,488	279-349
		3,117	**-**	**-**	**-**	**3,117**	**312**
	2030	1,440-1,824	-	-	-	1,440-1,824	144-182
		1,612	**-**	**-**	**-**	**1,612**	**161**

The installed cost shows that the cost of Battery energy storage systems is decreasing, and are catching up with Pumped storage hydroelectricity, the dominance technology in energy storage market. Among those hydrogen might be the fastest to be able lower the cost lower than PSH, both in term of kW and kWh. Li-ion Battery has the lowest installed cost per kW but not per kWh. Vanadium redox flow battery has the highest installed cost, but also has other advantages for energy storage.

IV. CONCLUSIONS AND RECOMMENDATIONS

Energy storage systems can be used for many applications in the power system such as: seasonal storage, frequency regulation, voltage regulation, load shifting, peak shaving, black start, spinning reserve, transmission and distribution congestion relief, etc. Each application has different requirements for response time, storage capacity, discharge time, .etc. Therefore it it necessary to choose suitable energy storage technologies.

Vietnam's power system in the last two years has encountered many problems as renewable energy are booming: excess energy at low demand time like noon and holidays; frequency and voltage regulation is difficult due to the dependency of the renewable energy on the weather; renewable energy power plants have no inertia (solar) or low inertia (wind) that makes the system more unstable; low efficiency of grid infrastructure for releasing the power generated by renewable energy sources; household rooftop solar power is single phase which can lead to phase unbalance etc. The deployment of energy storage system to reduce the above problems is necessary and urgent.

After considering the conditions of power system in Vietnam and the characteristics of potential energy storage technologies, author recommended following energy storage technologies to be applied in Vietnam:

- Pumped storage hydroelectricity: for long-term energy storage, arbitrage, and adding inertia to the system
- Battery energy storage system (Vanadium redox flow batteries, Lithium-ion batteries): for frequency regulation, voltage regulation, load shifting, peak shaving, black start, spinning reserve, transmission and distribution congestion relief.
- Hydrogen: utilize the excess energy of renewable sources to produce hydrogen and can be used later in the form of fuel cells

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