Vanadium Flow Battery Technology

Dalian Rongke Power Co., Ltd.

Introduction

Beijing Energy Club
北京国际能源专家俱乐部

April 23, 2016

Introduction of Vanadium Flow Battery Technology of Dalian Rongke Power Co., Ltd.

Beijing Energy Club[1]

Energy storage is a technology which changes the traditional model of "generate-and-use" and real-time balancing of the electric power industry. It is also an important technology in the transition of energy system from fossil fuels to renewables and is regarded to be one of the 12 disruptive technologies that will determine the future economy.

The applications for energy storage include power supplies for mobile terminals (such as mobile phones and laptops), automotive power batteries and storage for the electric power system. In fact, energy storage is used extensively in the electric power system, from generation through transmission and distribution to consumption. Large-scale energy storage is able to regulate the fluctuations from renewables, provide auxiliary services for the electric power system, including frequency regulation, peak shaving, spinning reserve and black start, improve the quality of electricity supply, facilitate the power supply of the power grid (micro-grid and terminal grid), provide emergency standby power, and enhance demand response.

Energy storage technology has broad market prospects. McKinsey & Co., the renowned international consulting firm, estimated that energy storage could contribute more than one trillion US dollars globally in economic value by 2025. Piper Jaffrey and Boston Consulting Group forecasted that the market for energy storage could amount to 400 to 600 billion US dollars by 2020. Another authoritative international consulting firm, Pike Research, forecasted that flow batteries will account for

[1]Disclaimer: This Introduction has been prepared based on the information that the Secretariat of Beijing Energy Club (BEC) has at its hand, the materials supplied by Dalian Rongke Power Co. Ltd. and the discussions from the Technology Assessment & Dissemination conference on Apr. 23rd, 2016. BEC shall not be held responsible for any risks, losses, damages, costs or expenditures, claims, and/or any other rights of claim that may arise from any investment or other business decisions made by any business organizations or individuals in accordance with the conclusive comments contained in this Introduction.

one-third of the market shares for energy storage applications in the electric power sector in 2021.

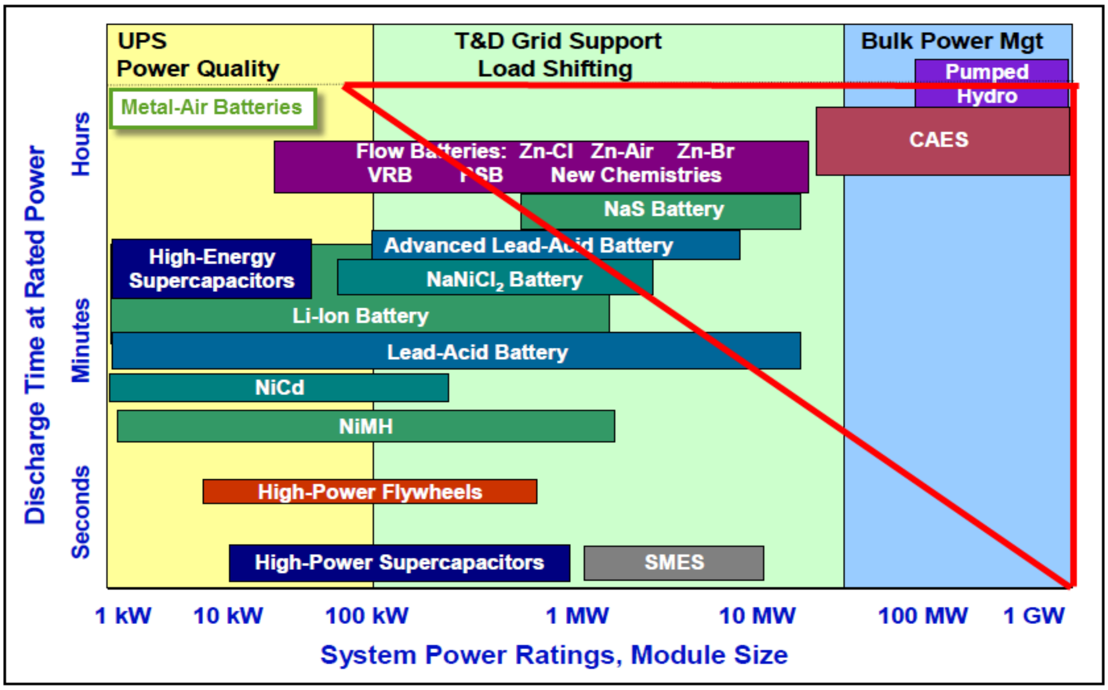
On Apr. 23rd, 2016, the Clean Energy Technology Assessment & Dissemination platform was launched by BEC and the vanadium flow battery (VFB) technology of Dalian Rongke Power Co., Ltd. ("Rongke Power") was selected to be the first technology to be assessed and disseminated.

This document contains an introduction of the performance attributes, fields of application and actual cases for Rongke Power's technology.

I. Introduction of Energy Storage Technology

There are many different types of energy storage (ES) technologies. Mechanical ES includes pumped hydroelectric energy storage (PHES), compressed air energy storage (CAES) and flywheel energy storage (FES). Electric ES includes super capacitors and superconducting magnetic energy storage (SMES). Electrochemical ES includes lead-acid batteries, lithium-ion batteries, sodium-sulfur (NaS) batteries and flow batteries. Chemical ES includes synthetic natural gas (SNG).

Figure 1 Positioning of ES Technologies

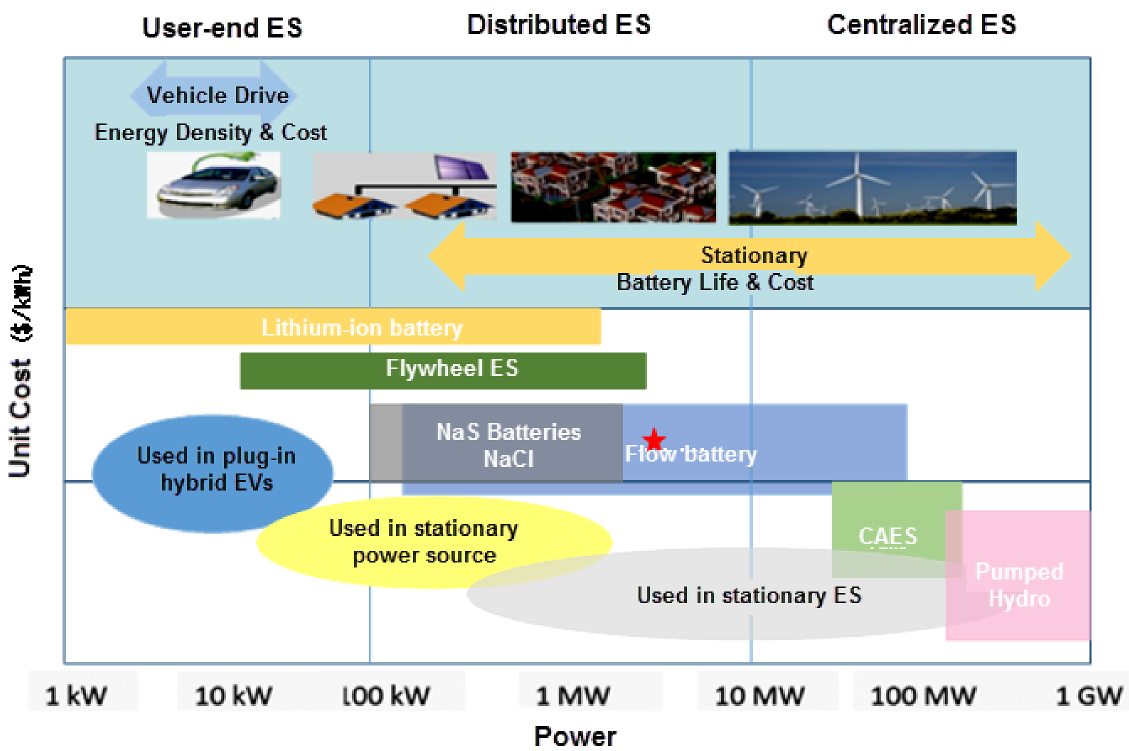


Source: Rastler,D.; EPRI: Alto, P., 2010; Rongke Power

As shown in Figure 1 above, different ES technologies vary significantly in performance and none of the current ES technologies can meet all ES demands. Large-scale ES technologies applied in the electric power industry are mainly in the triangle demarcated by the red lines, including pumped hydro, lead-acid batteries, lithium batteries and flow batteries. Pike Research forecasted a remarkable increase for mainstream ES technologies in 2014 and 2017, driven largely by demands for ES from renewables and smart grid and a market share of one third in the entire electric power ES market for vanadium flow batteries (source: Pike Research. 2011-07. Energy Storage on the Grid).

In terms of size and cost, flow batteries are more suitable for large-scale energy storage, especially high-capacity energy storage, with a mediocre unit cost (see red asterisk in Figure 2).

Figure 2 Requirements of the Electric Power System on ES Technologies



Source: Rongke Power

II. Company Profile

Incorporated in 2008, Dalian Rongke Power Co., Ltd. (www.rongkepower.com) is a world-leading service provider of VFB ES solutions and one of the world's few companies with complete technical service capabilities across the value chain of VFB. Rongke Power has developed from the R&D team of Dalian Institute of Chemical Physics, Chinese Academy of Sciences, which started the research on flow battery technologies in 2000 and established the platform for technology industrialization in 2010. With 168 employees today, Rongke Power has implemented many commercial application demonstration projects and owns complete proprietary intellectual property rights of the core technologies for VFB.

Rongke Power offers VFB major materials, cell stacks, modules, KW to MW energy storage systems (ESS) and tailor-made ES solutions. It currently has annual capacity of 50MW, which will be increased to 300MW by the end of 2016 with the launching of its Energy Storage Equipment Industrialization Base. It has exported its products to America, Europe and Japan and is No. 1 globally in terms of market share. It is worth noting that in the international vanadium electrolyte market, its market share is about 90%.

By the end of 2015, Rongke Power's total installed capacity was 12.5 MW and 1.2 MW projects were under construction. The 200MW/800MWh VFBES Project, which is being implemented by Rongke Power and supported by the Municipal Government of Dalian, has been listed by the National Energy Administration (NEA) as a National Demonstration ES Project. The installed capacity of this project alone is about 20% of the total combined installed capacity of battery ES in the world[2].

Rongke Power has received many awards for its VFB technology, including the 2014 Chinese Academy of Sciences (CAS) Award for Excellent Achievements, the 2015 National Second Award for Technology Invention, One of the Twenty Major

[2] *The Energy Storage White Paper 2016* published by China Energy Storage Alliance (CNESA) shows that the total installed capacity of accumulated operational ES projects (exclusive of pumped hydro, CAES and heat storage) worldwide was 946.8MW by the end of 2015.

Advancements of CAS during the 12th Five-year Plan Period (2011-2015), and the 2015 Award for Indigenous Technology of China.

Rongke Power is leading the establishment of flow battery standards in China, having two national standards and three industrial standards announced and adopted, is fully participating in the formulation of the European standards, and has become the leading agency of the joint task force of the International Electrotechnical Commission (IEC).

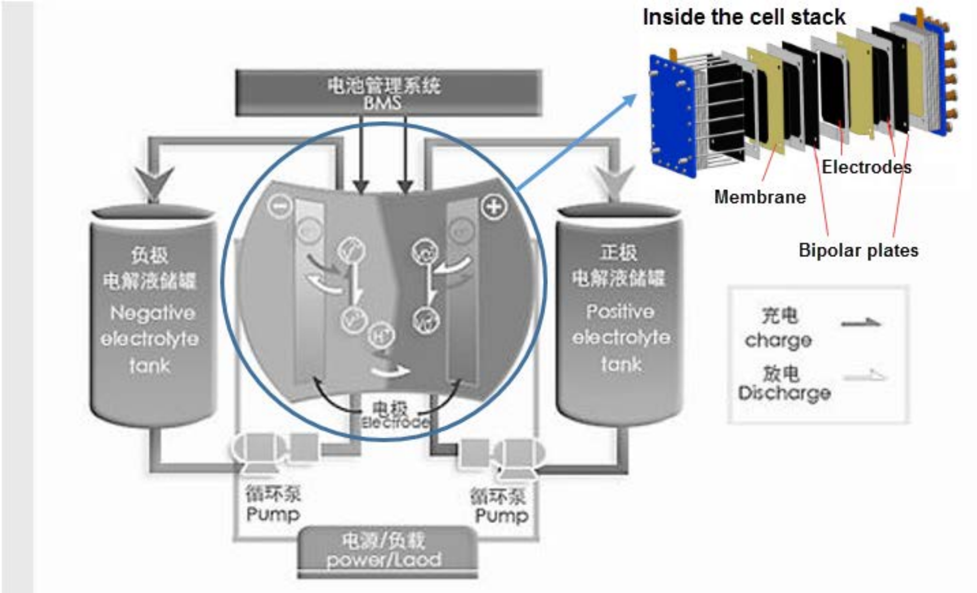
III. Introduction of VFB

1. Technical Principals of VFB

VFB is a secondary battery technology which uses fluids containing the active materials to achieve electric energy storage and discharge by back-and-forth conversion between chemical energy and electric energy through the valence state change of vanadium ions. Started in the University of New South Wales, Australia in 1980s, VFB has been applied and proved in Australia, Japan, the U.S., Germany and China in energy storage in wind energy systems, power station peaking, and micro-grid energy storage. Currently, VFB is the most popular and the most extensively applied flow battery technology.

A flow battery system is consisted of a cell stack, which is a set of cells stacked with anodes, cathodes and ion conducting membranes (Figure 3, middle and top right), an electrolyte unit, including electrolyte containing the active materials and auxiliary parts for containing and circulation of the electrolyte, such as tanks, piping, valves, pumps and sensors (Figure 3, left and right sides), and a control system, including a battery management system (BMS) (Figure 3, top) and a power variation unit.

Figure 3. Schematic of VFB



Source: China Science Daily, 2014-10-28 issue, Page 6; Rongke Power

The solution of vanadium ions at different valence states is used as the active materials for anodes and cathodes and stored separately in the electrolyte tanks of a VFB. After being pumped into the cell stack, the electrolyte stored in the tanks becomes circulating in the closed loop formed by the different tanks and the half cell. With the ion conducting membrane used as the cell isolation, the electrolyte flows in a parallel manner through the surface of the electrode when an electrochemical reaction occurs. Then, the electric current is collected and conducted by the bipolar plates and conversion between chemical energy from the electrolyte and electric energy is realized.

The electron pair at the anode is VO^{2+}/VO_2^+ whereas the electron pair at the cathode is V^{2+}/V^{3+}. Below is the electrochemical reaction that occurs. The typical potential difference between anode and cathode Eθ is 1.26 V.

Anode: $VO^{2+} + H_2O - e \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} VO_2^+ + 2H^+$ E^θ=0.999 V vs NHE

Cathode: $V^{3+} + e \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{2+}$ E^θ= -0.255 V vs NHE

Overall reaction: $VO^{2+} + V^{3+} + H_2O \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} VO_2^+ + V^{2+} + 2H^+$

2. Technical Advantages & Challenges

VFBs are stationary large-capacity energy storage systems (ESSs) suitable for the electric power system. Compared with other ES technologies, VFBs have the following key characteristics:

- **Are safer**. The active material for energy storage is a dilute sulfuric acid solution containing vanadium ions which operates in normal temperature and normal pressure. Even when there is a blending of the active materials for the anode and for the cathode after a long period of operation, there will not be blasting or combustion. Heat management is easy because heat produced by the cell stack during operation as a result of circulation of the electrolyte in the cell stack and tanks can be efficiently discharged. There has been no record of fire in relation to installed VFB systems globally.
- **Have a long life**. VFBs have good homogeneity and allow deep discharge. Because the electric energy is stored in the electrolyte, not on the anode or the cathode, theoretically VFBs can discharge an indefinite number of times. Any decline in capacity after operation for a period of time can be restored online or offline.
- **Have a good cost performance over the lifecycle**. The electrolyte, which accounts for 30% to 50% of the entire battery cost (depending on the hours of energy storage), can be recycled and reused.
- **Have good charge/discharge performance**, fast response, and an energy efficiency of 80% and allow deep discharge. Vanadium ions, with high electrochemical reversibility and little electrochemical polarization, are suitable for quick charge and discharge at large currents and it takes only 0.02 second to switch between charge and discharge.
- **Allow separate design of power and capacity**, which are determined respectively by the quantity of cell stack and of electrolyte. This enables more flexible designs. Featuring an energy storage capacity in the range of several hundred KWhs to several hundred MWhs and an output power in the range of several hundred KWs to several hundred MWs, VFBs are more suitable for large-scale energy storage.
- **Are environment-friendly during their lifecycle** in that the electrolyte is reusable and recyclable, there are rich vanadium resources and related

materials, the processing techniques are mature, and the vanadium and related materials are easy to recover and reuse. The VFB technology actually is an important direction for the comprehensive utilization of vanadium resources.

Nevertheless, VFBs need to continually improve and address a number of issues. For example:

- The ion conducting membrane may affect the ability of vanadium ions in the positive and negative electrolyte to permeate each other and the efficiency and life of the flow battery. Besides, the ion conducting membranes currently are very expensive. Therefore, it is urgent to develop highly selective, highly conducting and low-cost conducting membranes and achieve mass production and localization.
- The electrolyte accounts for 30% to 50% of the cost of the battery, which is quite high. There is a demand for developing low-cost electrolyte.
- Due to the limited solubility of vanadium ions, the energy density of VFBs is quite low, approximately equivalent to that of lead-acid batteries. Besides, VFBs are quite big in size and not suitable yet to be used as power batteries.
- The battery system requires the installation of a lot of auxiliary parts and has a complicated structure. The behavior of frequent start and stop and operational stability need to be improved.
- The operational temperature for the battery system has a relatively narrow window. This affects to a certain extent the efficiency of the ESS.

3. Rongke Power's Core Technologies & Critical Materials

As the National Key Laboratory for Flow Battery Technologies approved by the NEA, Rongke Power had applied for 140 national patents and 13 international patents and more than 70 patents had been approved by March 2016. Through these patents, Rongke Power has built a complete system of independent intellectual property rights covering material mass production, module design and manufacture, system integration and control and actual applications.

Rongke Power owns the following core technologies:

- **Mass production of high-performance electrolyte**. Rongke Power invented a technology to stabilize the electrolyte of high-stability, high-reactivity vanadium ions of multiple valence states and developed the online restoration of electrolyte capacity. This solved the decline of capacity of the ESS after a long period of operation and realized an electrolyte capacity of 150 MWh per annum. In the past two years, Rongke Power has sold more than 100 MWh of vanadium electrolyte, accounting for over 90% of the global market share.

- **Manufacture of high-performance carbon plastic compound bipolar plates**. Rongke Power invented a process to manufacture highly resilient, highly conducting carbon plastic compound bipolar plates, which are suitable for assembly of large-power cell stacks. The price is 1/40 that of graphite. The scrapped plates can be disposed of by burning and the only pollutant from burning is carbon dioxide.
- **Design/manufacture of high-performance non-fluorine ion conducting membranes**. Thinking outside of the box of “ion exchange conducting”, Rongke Power proposed “ion-screening conducting” and developed highly selective, highly conducting, environment-friendly and low-cost non-fluorine ion conducting membranes. This improved the efficiency of VFBs. For this technology, Rongke Power applied for 50 national invention patents and 6 international patents. It has become internationally recognized.
- **Standardized, modularized battery modules**. Rongke Power developed 250kW, 125kW, 60kW, and 30kW “ALL-IN-ONE” full-containerized and half-containerized battery modules. These modules are easy to install and allow individual applications or serial and/or parallel connections, meeting customers’ various requirements on powers and capacities. Monitoring can be performed online remotely.
- **Excellent durability**. An accelerated life test made in 2007 demonstrated excellent durability. The battery was in normal and continuous operation for over 1,678 days or more than 40,000 hours, recording 12,420 effective charge and discharge cycles. When the test was terminated, the decline in energy efficiency was detected to be 5% only while the capacity could be restored through technical measures.

4. The Economics of Rongke Power's VFBs

Given an average battery system of 1MW/4MWh, the price of VFB ranges from 3,500 to 4,000 Yuan per kWh. It is estimated that the cost of the battery system will drop to 2,500 Yuan per kWh by 2020 with the mass production of VFBs. VFBs feature economies of scale; the higher the energy storage capacity, the lower the per unit investment.

Table 1. VFB vs. Pumped Hydro and Lithium-ion Batteries

	Item	VFB	PH	LIB
Technical Characteristics	Efficiency	65 - 75%	70 - 75%	80 - 85%
	Consistency	Good	-	Medium
	Deep Discharge	100% SOC full utilization	-	80% SOC utilization range
	Response Time	Seconds	Minutes	Seconds
	Heat Management	Effective radiation, safe	-	Difficult, risky
	Safety	Good	Good	Medium
	Calendar Life	20 years	40 years	3 - 5 years
	Recycle Life	> 16,000 times	-	2,000 - 5,000 times
	Siting	Flexible	Inflexible	Flexible
	Environmental Impact	Minor	Big	Big
	Construction Schedule	Short	Long	Short
Cost	Initial Investment	3,000 - 4,000 Yuan/kWh 10,000 - 15,000 Yuan/kW	5,000 - 7,000 Yuan/kW	3,000 - 4,000 Yuan/kWh
Resource & Environment	Recovery	Easy to recover, high salvage value	-	Difficult and costly to recover
	Resource-friendliness	Vanadium resources are rich and recyclable	Ecological impacts	Lithium resources are limited
Application	Specific Scenarios	Large-scale energy storage (MW, long time) Peak shaving, distributed energy storage	Super-large energy storage (kMW) Grid peak shaving	Medium- to small-scale energy storage (<MW, short time) Frequency regulation, small micro-grid

Source: Rongke Power, SOC = State of Charge

Table 1 above shows a comparison of the performance of VFB vs. pumped hydro and lithium-ion batteries.

IV. Application Fields of VFBs

The main task of the electric power dispatching system is to maintain the real-time balance between the generation output and the consumption load as well as the stability of the frequency and voltage of the electric power system. This requires not only precise forecast of the consumption load curves and pre-arrangement of various generation sources, but also primary and secondary frequency regulation to ensure the stability of the frequency and voltage of the grid. Sometimes a third frequency regulation is needed to optimize the system-wide efficiency.

With the rapid development of renewables in China and the rest of the world (such as Germany) in recent years, grid-connected installed capacity has increased substantially. This intermittent and largely fluctuating power supply makes electric system scheduling more difficult and has an urgent need for excellent frequency regulation and peaking shaving resources that match the profile so as to minimize the risks for safe operation of the electric power system and increase the economics for the operation of the electric power system.

Pumped hydro remains the most economical option for energy storage on a big power grid. But where pumped hydro is not available and there are not many restrictions on the size and weight of an energy storage system, large-scale chemical energy storage enjoys some advantages. To switch between charge and discharge, the energy storage unit of Rongke Power’s 500kW VFB has a response time of less than 90ms at rated power. The response time of its 5MW energy storage station for charge and discharge is less than 1 second. Compared with pumped hydro and conventional thermal power generation units, VFBs have much better ramp-up rate and frequency regulation efficiency. The installation of proper quantity of energy storage batteries in regions where renewables, including wind energy, supply a big proportion of electricity will achieve better frequency regulation. Besides, the power capacity of the energy storage system of a VFB can be independently designed. This makes it easily achievable to configure an energy storage capacity of more than 5 hours. As a result, VFBs will be able not only to participate in secondary frequency regulation of the system, but also to shave the peak, optimize the economics for the operation of the electric power system and participate in third frequency regulation at the same time.

In reality, electric power companies make huge and uneconomical investments to meet seasonal peak loads (which do not exceed 400 hours in a year). However, if they choose to install energy storage systems at 8 – 10% of average daily load at load centers (such as big cities) at the user end to shave the peak, they will save significant investments and improve the economics of the system.

To sum up, the fields for the application of VFBs include: 1) VFBs used as supporting facilities for wind farms and solar farms to improve the grid's ability to absorb power from renewables, stabilize output fluctuations, track generation plans, participate in peak shaving and frequency regulation and improve power supply reliability and the economics of operation; 2) VFBs for demand side management, peak shaving and demand side response to improve demand-side economics and reliability; 3) VFBs in micro-grids, distributed wind, solar and storage projects and smart grids; and 4) VFBs in other fields, such as VFBs replacing diesel generators as standby power and VFBs as emergency backup in industrial parks, as power supply in remote areas, as recharging stations for electric vehicles and as standby power source for communication equipment.

In general, VFBs have distinct advantages and are a top choice for large-scale high-efficiency energy storage in large-scale stationary energy storage scenarios with an output power of several hundred kW to several hundred MW and an energy storage capacity of more than two hours.

V. Application Cases of VFBs

Worldwide a total of 40 – 50 VFB systems have been installed. Main VFB R&D and manufacture companies include Sumitomo Electric Industries (SEI) (Japan), Dalian Rongke Power Co., Ltd. (China), UniEnergy Technologies (U.S.A.), Gildemeister (Austria), and Prudent Energy (China). Recently, REDT (UK), H2 (South Korea), Imergy (India), and Vanadis Power and Fraunhofer (Germany) have also launched VFB products and projects.

SEI began research on VFBs in the beginning of 1980s and started to build a 4MW/6MWh VFB ESS for a 30.6MW wind farm in 2005, which was tested for three years starting in 2005 and recorded 276,000 charge/discharge cycles. In 2011 SEI built two more VFB ESSs (1MW/5MWh and 15MW/60MWh).

Gildemeister, which started VFB R&D in 2002, developed two types of systems (10kW/100kWh and 200kW/400kWh), primarily for solar PV cells, as power supply in remote areas, recharging station for electric vehicles and standby power for communication equipment.

UniEnergy Technologies is the owner of mixed acid VFB technology and the developer of the U.S.'s first transmission and transformer station-side MWh-scale VFB energy storage station. UniEnergy Technologies and Rongke Power have formed strategic alliance, whereby Rongke Power provides cell stacks and electrolyte.

Rongke Power has started to develop commercialization demonstration projects in China, Germany and the U.S. in 2013 and its electrolyte products have entered European, American and Japanese markets. It has implemented nearly 30 application demonstration projects in recent years (see Table 2 on the following page), including the globally large-scale 5MW/10MWh VFB ESS, and is the first to realize industrialization in China and the rest of the world. The 200MW/800MWh VFBES Project, which is being implemented by Rongke Power and supported by the Municipal Government of Dalian, has been listed by the NEA as a National Demonstration ES Project.

Rongke Power's typical projects in large-scale grid connection of wind power, smart micro-grid and offline power supply are described as below.

1) **GD Power Longyuan ES Station Demonstration Project at Woniushi in Liaoning Province (5MW/10MWh)**. The station was built for a 49.5MW wind farm (33*1.5MW wind turbines). When put into operation, it had the internationally largest power capacity. Modularized design was employed and operation started in March 2013. After operation for four months, all technical metrics were met or outperformed. The station has been in steady operation for three years, recording an accumulated 1,586 times of charge/discharge. The operation control and energy management technology of the Demonstration Project was applied in two other wind farm ES stations. According to the owner electric power company, the utilization hours of the three wind farms are over 2,100 hours each, much higher than the all-grid average of 1,780 utilization hours.

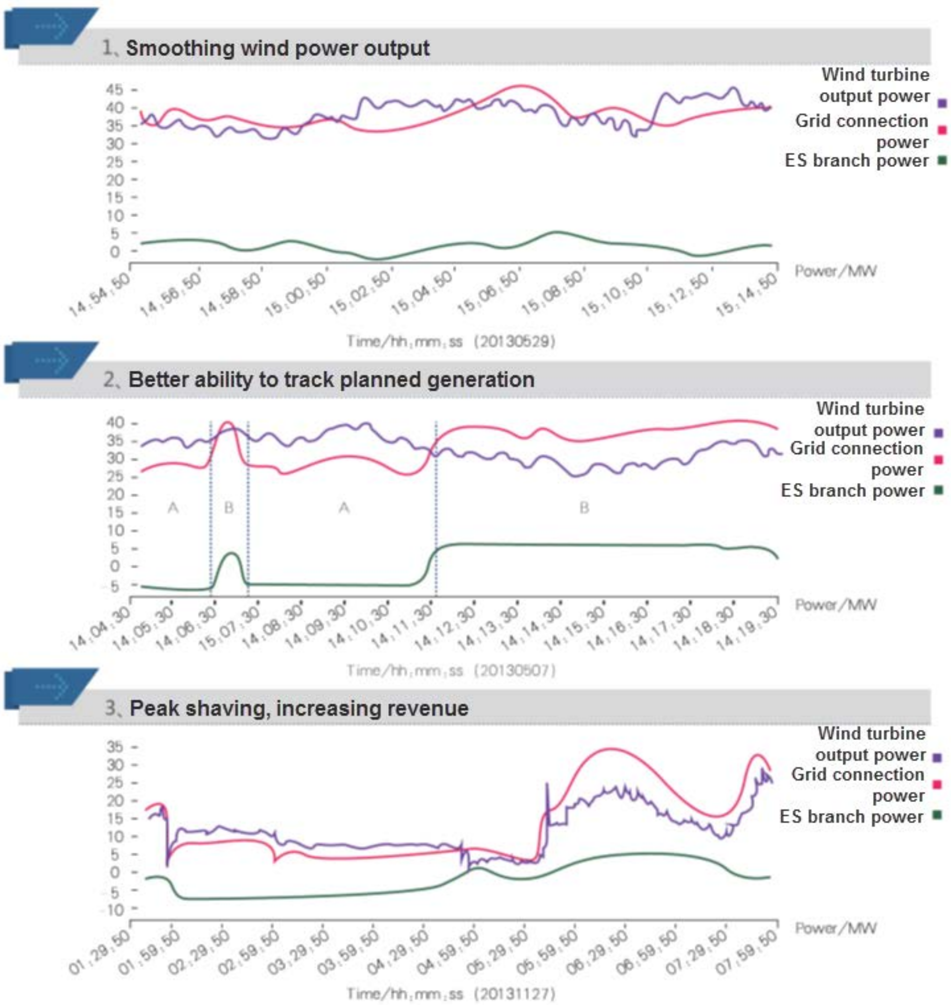
Table 2 Partial List of VFB ES Projects Implemented by Rongke Power

Owner & Site	Application	ES Scale	Implement
Grid connection of renewables			
BOSCH Group Braderup wind farm	Smooth output of wind power, regional energy management and auxiliary services	250kW1MWh	2014
GD Power Hefeng Jinzhou Wind Farm	Smooth output of wind power, planned generation	2MW/4MWh	2014
Liaoning Wind Power Co., Ltd. Heishan Wind Farm	Smooth output of wind power, planned generation, light load management	3MW/6MWh	2013
GD Power Longyuan Shenyang Woniushi Wind Farm	Smooth output of wind power, planned generation	5MW/10MWh	2012
Distributed generation and micro-grid			
Goldwind Ningxia Jiaze Micro-grid Project (under construction)	Micro-grid	125kW/625 kWh	2015
Beijing New Energy Industry Base	Micro-grid	600kW/2400kWh	2015
Nuremberg, Germany	Distributed generation	60kW/120kWh	2015
Liaoning Electric Power Science Research Institute Smart Micro-grid Demonstration Project	Micro-grid	100kW/40kWh	2014
Dalian Borong Co. Smart Micro-grid Project	Micro-grid	100kW/500kWh	2013
Goldwind Yizhuang Smart Micro-grid Project	Micro-grid	200kW/800kWh	2011
Dalian Electric Power Co. Youyi Street Recharging Station ES Project	Improving solar utilization, decreasing impact on the grid	60kW/600kWh	2011
Offline power supply systems			
CGN Qinghai Gonghe Large-scale Offline Power Supply System	Solar & energy storage large-scale offline micro-grid system	125kW /1MWh	2014
Shaanxi Yanchang Petroleum HQ Independent Power Supply System	Solar energy storage power supply system	5kW/50kWh	2012
Dalian Snake Island Administration Offline Solar ES Project	Offline solar, diesel and ES power supply system	10kW/200kWh	2011
Rongke Power R&D Center ES Project	Solar & energy storage power supply system	60kW/300kWh	2010
A telecom service provider's base station project	Wind, solar & energy storage offline power supply system	4kW/54kWh	2011
Rongke Power Green Building Demonstration Project	Wind, solar & energy storage offline power supply system	5.0kW/50kWh	2009
Tibet Energy Research Center Solar ES & Power Supply Project	Solar & energy storage offline power supply system	5kW/50kWh	2009
China Electric Power Research Institute ES Testing Project	Distributed energy experiment platform	100kW/200kWh	2008

Source: Rongke Power

The functions of the ESS for smoothing wind power outupt, tracking planned consumption, participating in frequency regulation and shaving the peak are proven (see Figure 4). As a result, the quality of the electric energy at the connection point and the precision of wind power forecast have been improved and wind curtailment has been lowered. Additionally, the safety, O&M user-friendliness, overload capacity, and control system openness of VFBs are initially demonstrated.

Figure 4 Operation Data of GD Power Longyuan ES Station at Woniushi, Liaojing



Source: State Grid Liaoning Electric Power Co.

2) **The 10kW/200kWh Offline Demonstration Project in Dalian Snake Island Nature Reserve**. Built in 2011, the project works with a solar PV power station to achieve steady offline power supply and meet industrial, commercial and residential demand in an island far away from the continent and beyond the reach of

the municipal grid. The VFB system outperformed the subsea cable in terms of cost. The typical data from June 2014 in Table 3 suggest a daily average efficiency of 70%. According to the user, there has never been an outage due to bad weather since the operation of the ESS.

Table 3 Typical Operation Data (June 2014)

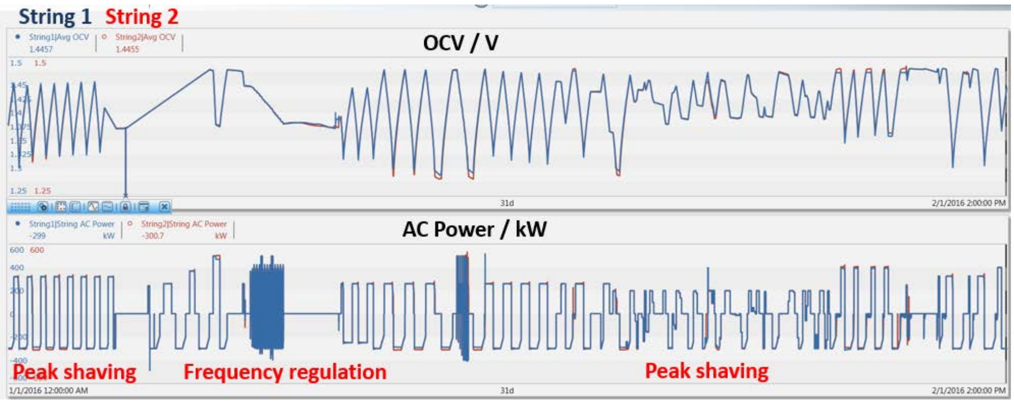
Dalian Snake Island Offline Demonstration Project

System Operation Data	Monthly	Total Charge (DC)/kWh	Total Discharge (DC)/kWh	System Consumption (AC)/kWh	Load Consumption (AC)/kWh
		812.22	568.55	54.36	715.23
	Daily average	System efficiency (DC)%	Discharge (DC)/kWh	System consumption (AC)/kWh	Load consumption (AC)/kWh
		70	18.95	1.81	23.84

Source: Rongke Power

3) **Smart Grid Energy Storage in Washington, the U.S.** In collaboration with UniEnergy Technologies, Rongke Power built the first MW-scale VFB ES station in the U.S. A 1MW/4MWh new-type VFB (mixed-acid electrolyte) was used and the project was delivered in June 2015, connected to AVISTA's micro-grid system. The system was installed to move the peak (electricity price arbitrage, trading in reserve capacity market), improve grid flexibility (frequency regulation, load tracking and real-time wind farm output control), increase the efficiency of the distribution system (powerless regulation and load management), and delay investment (peak shaving). Figure 5 shows the data for peak shaving and frequency regulation from operations for a consecutive month.

Figure 5 Peak Shaving and Frequency Regulation Data, Washington Smart Grid Project



Source: Rongke Power

4) **BOSCH Wind Power ESS**. In collaboration with BOSCH Group, Rongke Power built a 250kW/1MWh VFB ESS in a wind farm in North Germany, the largest VFB system even in today's Europe. The system has been connected to the local smart grid and recorded a system efficiency of over 68%, spoken highly of by the German owner.

It is worth noting that a 60kW/120kWh All-in-One integrated system installed by Rongke Power in Nuremberg in 2015 recorded a system efficiency of up to 70%.