Vanadium Flow Battery Technology and Application

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Energy storage technologies and applications

System power ratings

UPS
Bridging Power
Energy Management

Power quality
Peak shaving
Large scale energy scheming

Metal-Air batteries
Flow batteries
Pumped hyrdo

High energy super capacitors
NaS battery
CAES

Lead-acid batteries
Lead-acid superbatteries

Li-ion

Ni-Cd

NiMH

High power fly wheels

High power supercaps
SMES

Discharge time at rated power

Hour
Minute
Second

1 kW 10 kW 100 kW 1 MW 10 MW 100 MW 1 GW

Power system requirements for energy storage

User-side energy storage

Distributed energy storage

Concentrated energy storage

Energy Density and Cost

Stationary

Lifetime and Capital Cost

Capital cost ($/kWh)

Li Ion Battery

Fly Wheels

NaS, Na metal halide

Flow Batteries

Stationary power applications

Stationary energy applications

PHEV Target

1 kW

10 kW

100 kW

1 MW

10 MW

100 MW

1 GW

Power
Principles and features of Vanadium Flow Battery System

Energy recharge by the change of Vanadium ion status

**Anode:**

**Cathode:**

**Overall reaction:**

\[
\begin{align*}
\text{Anode:} & \quad \text{VO}^{2+} + \text{H}_2\text{O} - \text{e}^- & \xrightarrow{\text{放电}} & \text{VO}_2^{+} + 2\text{H}^+ \\
\text{Cathode:} & \quad \text{V}^{3+} + \text{e}^- & \xrightarrow{\text{放电}} & \text{V}^{2+} \\
\text{Overall reaction:} & \quad \text{VO}^{2+} + \text{V}^{3+} + \text{H}_2\text{O} & \xrightarrow{\text{放电}} & \text{V}^{2+} + \text{VO}_2^{+} + 2\text{H}^+ 
\end{align*}
\]
Output energy volume and power capacity can be designed independently

Output power (KW) determined by size and number of battery modules

Energy volume determined by density and volume of electrolyte
Vanadium electrolyte solution

The performance decline of vanadium electrolyte solution is due to substance imbalance and valence imbalanced caused by accumulation of minor side effects over time, and the performance can be restored by re-generation technology.

The electrolyte solution can be recycled and reused!
High-performance, low-cost sulfonated poly (fluorenyl ether ketone) porous ion-conducting membrane

Function:
- conduct $H^+$ to form charge-discharge circuit
- separate positive and negative vanadium electrodes

Harsh requirements on environment:
- strong oxidizing $VO_2^+$
- high potential, high current

Requirements of membrane:
- High ion-selectivity
- High $H^+$ conductivity
- High chemical stability
- Low cost

Our long term research shows: The fundamental reason for stability decline is the existence of ionic exchange group in sulfonated poly (fluorenyl ether ketone) ion exchange membrane!

Research on sulfonated poly (fluorenyl ether ketone) ion exchange membrane has been over a decade

Low cost

Poor stability

Environmental friendly
Design and manufacturing technology of high-performance sulfonated poly (fluorenyl ether ketone) porous ion-conducting membrane

Principle of conventional ion exchange membrane

- Membrane material must contain ionic exchange groups, otherwise, no ion exchange.
- Ionic exchange groups reduce stability.

Principle of original ion sieving and conductivity membrane

- Break the bound of conventional ion exchange principle, and originally bring up the “ion sieving and conductivity” concept which exclude ionic exchange groups.
- Use “pore size sieve effect” to sieve and transmit vanadium ion and vanadium proton at molecular scale.
Research and breakthrough of sulfonated poly (fluorenyl ether ketone) porous ion-conducting membrane material

After 10,000 charge/discharge cycles tests, the performance of battery has no obvious degradation, showing the good durability and stability of sulfonated poly (fluorenyl ether ketone) ion-conducting membrane, proving the correctness of "ion sieving and conductivity" concept.

"Ion-conducting membrane" has been included in National Flow Battery Technical Terminology Standard. Sulfonated poly (fluorenyl ether ketone) ion-conducting membrane has attracted lots of attention by international academic community and industrial community.

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VFB ion conducting membrane is made of non-fluorocarbon high molecular material, such material of scrap batteries can be burned as fuel, containing no pollutants except for CO2.
Vanadium Flow Battery Features

- **Safety**: sulfuric acid solution of vanadium ion as energy storage medium
- Independent design of energy volume and power capacity, flexible, fit for scalability
  - large energy volume: 100skWh– 100sMWh
  - large output power: 10skW— 100sMW
- Long lifetime, long cycle life 15-20 years
  - 80% energy efficiency, 100% deep discharge, 13,000+ cycles
- Quick response time: no phase change, 0.02sec for charge/discharge switch
- Operating in room temperature, electrolyte solution can be used almost forever, highly cost efficient
- Recyclable materials and components, environmental friendly
- **Low energy density**: not suitable for dynamic battery, suitable for energy storage power station
Application of Vanadium Flow Battery
The R&D team started VFB research in 2000. In 2010, the company set up industrial production and successfully carried out several commercial demonstration projects.

History of Vanadium Flow Battery technology development by Dalian Institute of Chemical Physics-Dalian Rongke

- **2000**: The R&D team started VFB research.
- **2003**: 1 kW stack.
- **2005**: 10 kW stack.
- **2007**: 22 kW stack.
- **2008**: 100 kW system.
- **2009**: 260 kW system.
- **2010**: 352 kW energy storage module.
- **2011**: The world’s largest 5 MW/10 MWh commercial demo project.
- **2012**: 2007 22 kW stack. 250 kW containerized system.
- **2013**: 2015 32kW stack.
- **2014**: Sumitomo resumed development.
- **2015**: Sumitomo halted development.

Canada VRB bankrupted.

The world’s largest 5 MW/10 MWh commercial demo project.
Flow battery material mass production, module design and manufacturing, system control

286 Chinese patent applications, 12 international patent applications, 111 patents awarded
About 30 VFB energy storage system demonstration projects, including the world’s largest 5MW/10MWh VFB project by then, taking the worldwide lead in industrialization of VFB system.

2008, Beijing, micro-grid, 200kW/800kWh
2008, Beijing, smart-grid, 100kW/200kWh
2011, Ningxia, VFB energy storage system, 3.5kWh
2014, Liaoning, wind farm VFB energy storage system, 2MW/4MWh
2013, Jizhou Liaoning, wind farm VFB energy storage system, 3MW/6MWh
2012, Liaoning, wind farm VFB energy storage system, 5MW/10MWh
2010, Dalian, PV/VFB building, 60kW/300kWh
2011, Dalian, telecommunication power storage, 3.5kW/54kWh
2010, Dalian, wind-PV-VFB energy storage system, 5kW/50kWh
2010, Shandao Dalian, remote area power supply system, 8.5kW/200kWh
2014, Shenyang Liaoning, VFB energy storage system, 100kW/400kWh
2015, Germany, BOSCH energy storage system, 250kW/1MWh
2015, Germany, 60kW/120Wh
2014, Qinghai, VFB energy storage system, 125kW/1MWh
2009, Tibet, PV-VFB system, 5kW/50kWh
2012, Shaanxi, PV-VBF system, 6kW/50kWh
2014, Shandao Dalian, remote area power supply system, 8.5kW/200kWh
2010, Dalian, wind-PV-VFB energy storage system, 5kW/50kWh
2010, Shenyang Liaoning, VFB energy storage system, 100kW/400kWh
2015, Seattle USA, 250kW/1MWh
Accelerated life test proves VFB’s outstanding durability

From July 6th 2007 to May 15th 2012, the VFB was normally performing for over 1678 days, more than 40,000 hours, 12,420 charge/discharge cycles. Only 5% degradation of battery system energy.
The world’s largest (2012) 5MW/10MWh VFB energy storage system

After 4-month operation, VFB system passed the test, meeting or outperforming all the technical requirements. Reaching the international leading level.
2MW containerized VFB system on the move
Rongke Power is now building a

200MW/800 MWh

National Power Storage Demo Project
for
Liaoning Province, China
The outlook of Vanadium Flow Battery technology
Development of High Power Density VFB Stacks

Materials and structural optimization

<table>
<thead>
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<th>Current density (mA/cm²)</th>
<th>CE (%)</th>
<th>VE (%)</th>
<th>EE (%)</th>
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<td>80</td>
<td>97.4</td>
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<tr>
<td>160</td>
<td>98.9</td>
<td>81.9</td>
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The operating current density increased from 80 to 160 mA/cm².

Dramatically lower the stack cost can be obtained by the doubled increased operating current density.
Performances of 40kW high power density VFB stacks

40kW stacks assembled, tested for charge/discharge

Under 145mA/cm² current density, energy efficiency reaches 80%, output power 40.2kW.

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For more information, please visit:

www.rongkepower.com