Investigation and Application of Redox Flow Battery for Energy Storage

Huamin Zhang
Chief Scientist of RFB Program of China
Prof. Dalian Institute of Chemical Physics (DICP CAS)
CTO. Dalian Rongke Power Co., Ltd.
Contents

- Challenges for VRB Commercialization
- Progress on Key Materials
- A PV-VRB System for Telecom Station
- Large Scale VRB System Integration
About My Group

Huamin Zhang
Prof.: Dalian Institute of Chemical Physics (DICP),
Chinese Academy of Sciences
Vice President and CTO: Dalian Rongke Power Co., Ltd.
National Chief Scientist of RFB Program

Research fields in my group in DICP
- Redox Flow Battery
- Proton Exchange Membrane Fuel Cell
- Regenerative Fuel Cell
- High Energy Density Battery
Advantages of RFB concluded as follows:

- Independent system design for power and capacity
  - Output Power Range: kW-MW;
  - Energy Storage Capacity: kWh-10MWh
- High efficiency (>75%)
- Long lifetime
- Deep discharge ability
- Low self-discharge, fast response
- Environmental friendly
- Operation safety
Durability and Reliability Test
(From Jul. 2007)

Up to today, lifetime test of a 2 kW VRB system has been carried out over 1419 days (over 34060 hours, 9933 charge-discharge cycles).
Challenges of VRB for Commercialization

- Poor electrolyte stability and less solubility lead to lower energy density.
- Low selectivity to the vanadium ions for ion exchange membrane lead to the unbalance of vanadium ions and water, and the capacity degradation after long operation time.
- Low rated operation current density lead to high material cost.
- High cost of the ion exchange membrane.

Limited the RFB practicability seriously.
Contents

- Challenges for VRB Commercialization
- Progress on VRB Key Materials
- A PV-VRB System for Telecom Station
- Large Scale VRB System Integration
Ion exchange membrane is employed to transport proton and prevent cross mixing of positive and negative electrolytes.

The ideal membrane for VRB application:

- Low permeability of vanadium ions
- High proton conductivity
- Good chemical stability
- Low cost
Nafion® Membrane for VRB

Membrane Function:

- Separate electrolyte (vanadium ions)
- Transport proton

High Cost !!!
Low Ions Selectivity !!!

Our Research focused on:

- A Nanofiltration (NF) Membranes
- A Non-Fluoride Membrane
Nanofiltration (NF) Membranes for VRB

Principles

- The stokes radius of vanadium ions is much larger than that of $\text{H}^+$.
- The charge density of vanadium ions ($\text{V(IV)}, \text{V(II)}, \text{V(III)}$) is much higher than protons.

NF membrane fabrication

- NF membrane prepared by phase inversion method.
- Pore size distribution of membranes can be controlled.

Cost is much lower than Nafion.
**DICP Non-fluoride Membranes for VRB**

**Lifetime Test of Non-Fluoride Membranes**

Performance of single cell with DICP Non-fluoride membrane (under 80 mA/cm²)

**The performance kept stable after running more than 12 months. The battery has finished more than 10000 cycles.**
Lifetime Test of Non-Fluoride Membranes

500W battery module with DICP Non-fluoride membrane (under 80 mA/cm²)

- Low Cost!
- Lower VE due to the higher ohmic resistance

<table>
<thead>
<tr>
<th></th>
<th>DICP Non-fluoride Membrane</th>
<th>Nafion 115 membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>99.5%</td>
<td>95%</td>
</tr>
<tr>
<td>VE</td>
<td>80%</td>
<td>85%</td>
</tr>
<tr>
<td>EE</td>
<td>80%</td>
<td>80%</td>
</tr>
</tbody>
</table>
Two Generation Non-Fluoride Membrane

<table>
<thead>
<tr>
<th></th>
<th>CE</th>
<th>VE</th>
<th>EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DICP-1</td>
<td>99.5%</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>DICP-2</td>
<td>99%</td>
<td>85%</td>
<td>84%</td>
</tr>
</tbody>
</table>

VE is improved by increasing the membrane conductivity.
Stack Modules with Non-Fluoride Membranes for VRB

- 5 W
- 100 W
- 500 W
- 1 kW
- 2 kW
Electrolyte Production

Vanadium Electrolyte Production Line

- Bolong New Material Co.
  - High quality vanadium supplier
- Yield --- 300 MWh/year
Carbon Plastic Bipolar Plate

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk resistance</td>
<td>&lt; 0.17 Ω.cm</td>
</tr>
<tr>
<td>Bending strength</td>
<td>&gt;28 MPa</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td>&lt;0.7 uA.cm²</td>
</tr>
<tr>
<td>Thickness</td>
<td>1 mm</td>
</tr>
<tr>
<td>Cost</td>
<td>&lt;100 RMB/m²</td>
</tr>
<tr>
<td>Yield</td>
<td>10,000 m²/year</td>
</tr>
</tbody>
</table>

Carbon/plastic plates showed similar properties with commercial graphite plates, while the cost almost the 1/10 of the graphite plates. It has been used in stacks for demonstration widely.
Latest Progress on Key Materials and Components of VRB in My group

Electric Control Components

Sealing

Bipolar Plate

Electrolyte

Ion Exchange Membrane

Electrode

Stack Module
Contents

- Challenges for VRB Commercialization
- Progress on Key Materials
- A PV-VRB System for Telecom Station
- Large Scale VRB System Integration
Circuit Diagram for an off-grid PV-VRB System For telecom station

<table>
<thead>
<tr>
<th>Specification</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>6 kW</td>
</tr>
<tr>
<td>VRB System</td>
<td>2.4 kW / 54 kWh Back up 72h</td>
</tr>
<tr>
<td>Load</td>
<td>500 W</td>
</tr>
<tr>
<td>Voltage Class</td>
<td>48V DC</td>
</tr>
</tbody>
</table>
VRB System Design

- Bipolar plate, electrode, membrane and electrolyte are all home-made.
- Monitor and Protection Functions
- Thermal management system

<table>
<thead>
<tr>
<th>Technical specification</th>
<th>VRB-ESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power/Capacity</td>
<td>2.4kW/54kWh</td>
</tr>
<tr>
<td>Voltage class</td>
<td>48V DC</td>
</tr>
<tr>
<td>Battery Stack Modules</td>
<td>1.2kW, 2 in series</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>up to 75% (DC-DC)</td>
</tr>
<tr>
<td>Operation condition</td>
<td>-20 ~ 40°C</td>
</tr>
<tr>
<td>Size (L × W × H)</td>
<td>2.5×1.9×2.0 (m)</td>
</tr>
</tbody>
</table>
Telecom Station Installed in Dalian

- 6kW PV on the roof
- Telecom Station with load of 500W
- 2 kW/54kWh VRB
System Operation

Different loads were used to optimize the system

Operation data from Feb 26 to Apr 14

- **200W load**
  - Charge > Discharge,
  - SOC increase

- **500W load**
  - Charge ≈ Discharge,
  - SOC stable

- **700W load**
  - Charge < Discharge
  - SOC decrease

This PV-VRB system is suitable for 500W load, which certify the original design.

Diesel generator works to charge the VRB, helping to get a higher SOC.
The temperature inside the VRB cabinet and the electrolyte increase stably with the increase of environment temp.

- Inside temp. is 15~20°C higher than the environment temp. due to the using of insulating materials.
- When the temp. inside is higher than 40°C, the heat emitter will work.
Contents

- Challenges for VRB Commercialization
- Progress on Key Materials
- A PV-VRB System for Telecom Station
- Large Scale VRB System Integration
# A VRB System for Smart Grid

## Technical Specification

<table>
<thead>
<tr>
<th>Technical Specification</th>
<th>VRB-ESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power/Capacity</td>
<td>80kW/160kWh</td>
</tr>
<tr>
<td>Voltage Class</td>
<td>220V DC</td>
</tr>
<tr>
<td>System Efficiency (DC-DC)</td>
<td>Large then 70%</td>
</tr>
<tr>
<td>Operation Condition</td>
<td>-20 ~ 40°C</td>
</tr>
<tr>
<td>Size (L × W × H)</td>
<td>6.5×2.6×2.8 (m)</td>
</tr>
</tbody>
</table>
R&D of 520kW/1MWh VRB for MW Class System

5MW VRB for 30-50MW wind farm
Acknowledgments

- National Basic Research Program of China (973 Program) of Ministry of Science and Technology (MOST), Grant No. 2010CB227200.
- The Knowledge Innovation Program of the Chinese Academy of Sciences (ACS), Grant No. KGCX2-YW-322-2

Many thanks go to MOST and ACS for the financial support.
Thank you for your attention.