NOVEL DESIGN AND NON-CONVENTIONAL APPLICATIONS FOR THE VANADIUM REDOX FLOW TECHNOLOGY

The International Flow Battery Forum
15 & 16 June 2010

Dr. Placido M. Spaziante
Cellennium (Thailand) Co. Ltd.
Topics of the presentation

1. Novel design for Stacks of cells with Bipolar Electrodes

2. Squirrel Stacks with Monopolar Electrodes

3. The Redox Flow Technology as Novel Inductionless Power Converter

4. The Redox Flow Technology for the Generation of Electricity
Conventional way of assembling a stack of cells

Fig. 1. A conventional horizontal stack of vertical cells. The cells are connected electrically in series using bipolar electrodes. The electrolytes are fed to the cells in parallel.
Limitations of the bipolar configuration:

1. **The voltage cannot be maintained constant** while the load on the battery or the state of charge of the electrolytes varies.

2. **Bypass currents** reduce the electrical storage efficiency of the battery, limit the number of cells that can be fed using the same manifold and can cause undesirable corrosion of the electrodes.

3. **It is practically impossible** to manufacture **single circuits** with **load > 500 Ampere** and **power > 200 kW using** the available components (membranes, felt, bipolar plates, etc.)

4. **It is impossible** to charge or discharge the electrolytes **in one pass through the cells**, for example it is impossible to enter the cells with charged electrolytes and discharge completely spend electrolyte.
Unique flow architecture of the Squirrel design

- Fig. 2. The flow architecture in a Squirrel stack of cells. The electrolytes are fed through the cells in series. Dashed lines represent membranes.
Unique features of the Squirrel bipolar electrodes stack design

1. **Flow pattern:** the electrolytes are fed through the stack of cells in series instead of in parallel as in conventional designs. Channels incorporated in the molded elements provide paths for the flow of the electrolytes between the cells.

2. **The design of the interdigital electrolyte distribution channels** in the electrodes. These channels provide a low pressure-drop across the cells in series and a uniform electrolyte distribution.

3. The particular configuration of electrodes that allow the **possibility of an electrical tap.** The electrodes are designed so that electrical connections can be tapped into the stack of cells at any point. These taps are needed for the inductionless power conversion method described later in this presentation.
Advantages of the Squirrel Bipolar Electrodes Design

1. **Possibility to maintain a more uniform voltage of the stack**
   Using taps on the electrodes or feeding fully charged (or fully discharged) electrolyte to the cell in series and adjusting the flow so that the electrolyte leaves the other end of the stack fully discharged (or fully charged); the stack operating voltage will be the average between the inlet and outlet voltage and will therefore remain constant.

2. **Lower Electrolyte Flow Rate and Lower Pumping Energy**
   The flow of the electrolyte is much lower because cells or groups of cells are fed in series and the cells have a low flow resistance. The total power needed for pumping can be reduced to only 1% of the total power.

3. **The Bypass Currents are negligible** because the electrolyte flows in series through the cells or through groups of cells.
Squirrel Monopolar Electrode Technology

- Fig. 3. Representation of a single cell with 6 monopolar electrode (3 negative and 3 positive). Several cells can be connected in series in the same stack. Electrolyte channels in the molding components provide paths for the electrolyte.
### Comparison between bipolar and monopolar technology

<table>
<thead>
<tr>
<th><strong>Bipolar technology</strong></th>
<th><strong>Monopolar technology</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stack voltage changes with load and state of charge of the electrolytes</td>
<td>1. A constant stack voltage can be obtained through switches on the single electrode</td>
</tr>
<tr>
<td>2. Impossible to have circuits with high current. The maximum load is less than 500 Ampere, power less than 200 kW per circuit.</td>
<td>2. Single circuit of one MA and power of several MW can be easily made. More than 1 MW can be installed in a 40’ container.</td>
</tr>
<tr>
<td>3. All cells of a stack must have the same membrane-electrode area</td>
<td>3. Cells with different membrane area can be used in the same stack. Important for the sinusoidal output voltage of the Squirrel inverter</td>
</tr>
<tr>
<td>4. Bipolar plate have to be impervious to the electrolytes and has to withstand a potentially high differential pressure</td>
<td>4. No special mechanical strength is required for the plates. The plates can be open mesh or porous</td>
</tr>
<tr>
<td>5. Difficult to use different material for the negative and positive side of the bipolar plate</td>
<td>5. Different material can be used for the negative and positive plate</td>
</tr>
</tbody>
</table>
The Squirrel DC-DC Auto-transformer

Fig. 4. An "auto-transformer" for stepping up the voltage of a continuous direct current by means of a stack of vanadium fuel cells.
The Squirrel DC-AC Inverter

Fig. 5. The principle of the Squirrel inductionless inverter. Only one quarter-wave and six voltage steps are shown. The actual inverter gives a full wave form and has more voltage steps.
Variable input - output

Voltage taps and switching circuits can be used to control the manner in which variable electrical inputs are fed into the battery so as to maximize the storage efficiency.

Applications include:

- Maximum power point tracking of the inputs from solar photovoltaic arrays.
- Acceptance of alternating current from wind turbines running at variable rotation frequencies depending on wind strengths.
- Acceptance of alternating current from diesel generator sets running at variable speeds adjusted to suit average loads.
- Charging and discharging of the storage battery in alternating current in general
4. The Redox Flow Technology for the generation of electricity

Fig 6. The Redox Flow Carbohydrate Fuel Cell
Outputs from sugar-powered fuel cell

The electrical current is produced as follows:
- On the negative electrode: \( V^{3+} = V^{4+} + e^- \); \( V^{4+} \) is then reduced to \( V^{3+} \) using sugar
- On the positive electrode: \( V^{5+} + e^- = V^{4+} \); \( V^{4+} \) is then oxidized to \( V^{5+} \) using O\(_2\) or air

Standard open circuit potential: 0.66 V

Gibbs free energy change for the combustion of sugar to CO\(_2\) and H\(_2\)O: \( \Delta G = 5684 \text{ kJ/mol} \)

The electrical potential corresponding to this \( \Delta G \) is: 1.23 V;

Therefore the efficiency of direct conversion of the chemical energy in sugar to electricity by this method has a **theoretical upper limit of 54\%** (= 0.66 V / 1.23 V) under standard conditions.

**Conversion efficiencies of sugar into electricity in the range 41–45\%** have been obtained in a 50 W prototype.

**One ton of sugar will give 1.85 MWh** of electricity, almost four times the amount of electricity thermally generated by the alcohol produced from 1 kg of sugar.

**The carbon dioxide** produced by this Redox Flow Fuel Cell is **chemically pure** and can be widely used for many applications.