New Vanadium Batteries – A Breakthrough Solution for Electricity Storage

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Abstract

A vanadium battery consists of vanadium salt electrolytes flowing through electrochemical cells. The storage capacity (kilowatt-hours) is determined by the quantity of electrolytes used. The power rating (kilowatts) is determined by the active area of the electrochemical cells. These two parameters can be sized independently over wide ranges (watts to megawatts). Vanadium batteries are more durable than lead-acid batteries because they have no liquid-solid phase changes to cause the electrodes to deteriorate. The durability and wide design options of vanadium batteries promise large markets for many applications, such as load leveling, storage in renewable energy systems (e.g. wind and solar), uninterruptable power supplies and for mobile power supplies (e.g. land vehicles and boats).

The Cellennium Company Limited has recently launched a program to commercialize new designs of regenerative fuel cells using vanadium salts as electrolytes. The technology has been licensed from Squirrel Holdings Limited, which owns the rights to the patents. The new vanadium batteries are working successfully in the laboratory, and are giving excellent results. Among the technology's key advantages are:

- A negligible amount of energy is used to pump the electrolytes.
- Shunt or bypass current losses are practically nil..
- More than 100 cells per stack are possible in a compact design which allows easy assembly and easy transportation.
- The battery is easily scalable to megawatt size.

Introduction

Electricity is useful only if it is available when needed in a usable form. Without the capability to time-shift and level the supply of energy via efficient and affordable storage, prime movers that generate electricity from fossil fuels along with transmission and distribution infrastructure will continue to operate wastefully. All of the most promising renewable energy sources, such as solar radiation and wind, occur intermittently and can never be harnessed to their full potential unless proper energy storage systems are developed.

The currently preferred energy storage solution, notably the lead-acid battery, has not really changed since its first invention over one hundred years ago. There have been improvements in efficiency of the lead-acid batteries and commendable developments in some advanced batteries. Nevertheless, there has been no major leap in performance and cost of energy storage required to minimize this weakness in our electricity infrastructure. Given the history of electricity storage technology, there is great need for some breakthrough to occur.

The redox flow battery using vanadium salts as electrolytes has been identified within the scientific community as having good likelihood of becoming a commercial breakthrough solution in stationary energy storage. The technology appears elegantly simple in theory, and holds much promise as an ideal energy storage medium. Certain technical limitations as observed in the designs of the major players in the industry, however, remain as major obstacles in the technology's road map.

This paper presents a novel, design architecture of a new vanadium battery, which apparently solves many of the problems inherent in the currently practiced design of the vanadium battery. The novel technology has the potential to make the vanadium redox chemistry more commercially viable as energy storage systems and products.

Background

The original patent related to the vanadium battery technology was granted in 1978 to Pellegri and Spaziante [1]. Unisearch (University of New South Wales, Australia) further developed a similar battery technology in 1985, exploring various applications. Various organizations have been licensed to use the Unisearch technology, including Thai Gypsum Products Public Company Limited (1992), the Mitsubishi Corporation (1993), Federation Resources Plc. (1998) and the Sumitomo Electric Corporation (1999). Mitsubishi, via its affiliate Osaki Kansai electric power station, tested a vanadium battery over 12,000 deep charge-discharge cycles until October 1995. Following successful testing of smaller prototypes Mitsubishi constructed and tested the first 20 kilowatt prototype module in 1996 at its Kashima Kita Power Station. In 1997, the company constructed and operated a large battery (200 kW, 400 kWh).

Pinnacle VRB acquired in 1997 the Unisearch vanadium battery technology and added Sumitomo Electric Corporation as another licensee of the technology in 1999. Sumitomo has been actively developing the vanadium battery for load leveling and peak shaving applications for office buildings in Japan [2]. System sizes have been in the range of 200 kW to 500 kW.

In all of the above-mentioned applications, the vanadium batteries have the components, including plastic frames, membrane, electrodes, etc., stacked together and bolted in a "filter press" configuration. Electrolytes are pumped through the cell stack flowing in a parallel geometry, and are distributed to each cell by channels in the plastic frame typical of a filter press. The current is collected at the side of the stack by exposed copper plates.

Although the vanadium battery is an inherently simple battery with great potential for low manufacturing cost, very long life and high efficiency, achieving this potential will be very difficult to realize with the existing design of the technology. A better solution is required.

New Vanadium Batteries

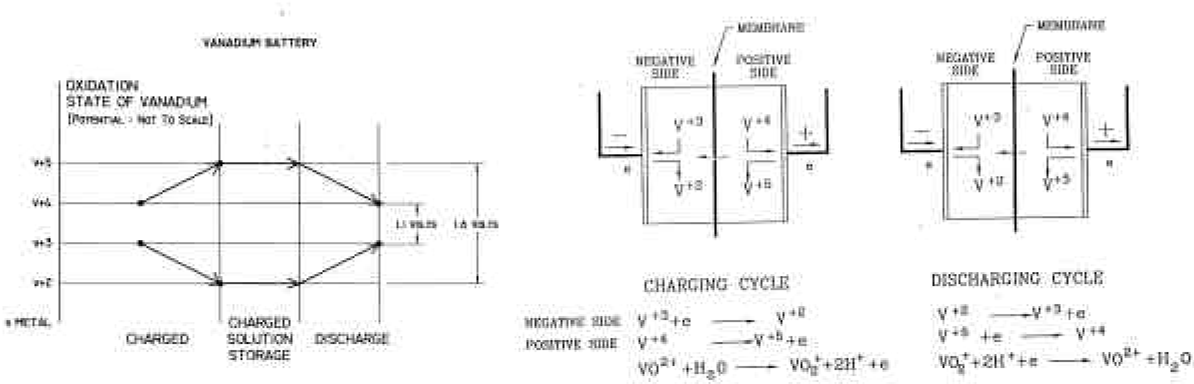
Following the science of the original vanadium battery technology patented by Pellegri and Spaziante in 1978, a team of European scientists, with long history in academic and industrial research and development, working since 1996, has achieved a major breakthrough in creating a novel design architecture of the vanadium battery. As a result of this achievement, the prospects are much better for realizing very low-cost manufacturing methods to produce vanadium batteries that will be significantly more durable and more efficient than the best lead-acid batteries available in the market today. Moreover, economical production is possible for vanadium batteries in modular sizes as small as 3 to 5 kilowatts, thus potentially enabling wide-spread use of energy storage for small, distributed applications. The technology of the new vanadium batteries is also easily scalable to megawatt sizes.

This novel technology is now owned by Squirrel Holdings Limited, and Cellennium Company Limited has acquired from Squirrel the rights of the use and development of the new vanadium batteries in Thailand.

How a vanadium battery works

A vanadium battery consists of vanadium sulfate electrolytes, which store and deliver electricity by means of reduction-oxidation reactions in electrochemical cells. In the design of vanadium batteries the electrical storage capacity (kilowatt-hours) and the electrical power rating (kilowatts) can be chosen independently over wide ranges (watts to megawatts). This is because the storage capacity is determined by the quantity of liquid electrolytes used, and the power rating is determined by the area of the membranes in the electrochemical cells.

The battery consists of two electrolyte tanks with the electrolytes of V2+/ V3+ and V4+/V5+ in a weak acid solution, pumps and a cell stack. The two electrolytes are pumped into the stack where they are separated by an ionic membrane. The electron exchange in the aqueous phase takes place at carbon electrodes with corresponding changes in oxidation states according to the following illustrations (Figures 1a and 1b):



Figures 1a and 1b: Changes in Oxidation States of Vanadium Ions During Charge and Discharge Cycles of the Battery.

One advantage of the vanadium-vanadium battery over other redox flow batteries is that cross contamination of the electrolytes does not damage the system since the metal ions are of the same element. Mixing of the electrolytes creates only heat, and does not destroy the usefulness of the electrolytes. Electrolyte service life is thus indefinite.

Unique features of the New Vanadium Battery

The unique features developed by Squirrel Holdings Limited are as follows:

- The electrolytes are fed through a stack of cells in series instead of in parallel as in other designs.
- The cells in a stack consist of pairs of high precision molded structural components designed for speedy "LEGO style" error-free assembly with o-ring sealing to prevent leaks.
- The electrodes, sandwiched between novel glassy carbon bipolar plates and the cell membranes, consist of carbon fiber mats permeated by a system of fine channels to distribute the electrolyte through the whole area with very small flow resistance.
- The cells are placed horizontally in a vertical stack to make a compact and structurally stable unit.

- A novel hydraulic feature within the system allows the battery to be “black started” from a state of total inactivity without the need for priming of the electrolytes from outside sources.
- Production of the electrolytes can be done modularly and electrochemically, operating at room temperature, without the addition of chemicals.

The following figures show a prototype 1kW cell stack (Figure 3), and a schematic illustration of the new vanadium battery system (Figure 4):

Figure 3: “Squirrel 200” prototype cell stack, 1 kW.

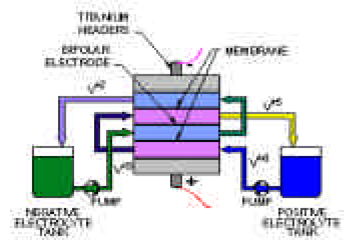


Figure 4: New Vanadium Battery

Advantages of the New Vanadium Battery Features

- The series flow pattern eliminates electrical losses suffered by other designs where a short circuit current flows through pipes feeding electrolytes to the cells in parallel.
- The series flow pattern ensures that every cell receives the same amount of electrolyte and no cell can become dry while the battery is operating. *In designs with parallel flow an undetected blockage in one cell during charging will cause the evolution of hydrogen and oxygen gases, a large pressure difference across the membrane, and an explosion if the membrane breaks and the gases are ignited electrically*. In the new vanadium battery volumetric pumps keep all the cells clear of blockages, but charging is stopped automatically by a pressure switch if a blockage is not cleared at once.
- Vertical stacking of the cells in the new vanadium battery with the electrolyte flowing upwards allows any unwanted hydrogen and oxygen gas to be flushed safely to the top and removed.
- In the new vanadium battery, because of the low resistance to flow in the carbon fiber electrodes and the impossibility of single cell blockages, only 1% of the total power rating is needed to pump the electrolytes at the optimum rate. Other designs have twenty times the necessary minimum flow in order to guard against cell blockages, and at least 10% of the total power is needed for pumping.
- In the new vanadium battery the total voltage across the stack remains constant equal to the average of the charged and uncharged voltages. This is because the series flow pattern and slow pumping speed allow the electrolytes to enter a stack of cells in the uncharged state and exit the stack fully charged during charging, or vice versa during discharging. In parallel flow designs the total voltage varies widely during repeated recirculation of the electrolytes (1.1 V to 1.6 V per cell). The new vanadium battery will not suffer the serious difficulties created in many applications by this voltage variation.

- The unique design of the components in the stack of cells ensures that only a small percentage of the valuable membrane area is wasted to hold the membrane in place.
- The compact stacks of cells in the new vanadium battery occupy only 20% of the space used by the current vanadium battery with the same power rating.
- The power efficiency of the new vanadium battery is expected to reach 90% overall, as compared with 70%-80%, not taking into account the pumping power, of other designs.
- The electrolytes can be produced anywhere on a just-in-time basis without the need for long-distance transportation of water, which comprises over 50% of the electrolyte's weight and volume.

Conclusions

Just as the system of water storage tank and filtration can provide availability of clean water for the homeowner, so too can a proper battery storage system enhance the reliability and quality of electricity for its stakeholders. With efficient, durable and affordable storage of electricity, both suppliers of electricity, namely generation, transmission and distribution companies, and end users, namely offices, factories and even residential customers, will benefit.

On the supply side, the electrical utilities benefit from the ability to level the load of their generators, allowing these prime movers to run closer to the average rather than the peak level of electricity demand. The end results would be the saving of valuable fuel and the deferral of investment to build more power plants. Additionally, the transmission and distribution companies benefit from the effectively increased capacity of their installed infrastructure.

On the demand side, end users benefit from the reliable and high-quality power, even when the electricity coming off the grid is poor and intermittent. In fact, with proper storage, the end user can even choose not to be grid-connected, opting instead for his own small-scale generation, whether it be from micro turbines, hydrogen fuel cells, bio-mass, solar PV or wind turbines.

Just imagine a city like Bangkok without the ubiquitous household water tanks. In the morning rush to take baths and showers, the nightmare would become apparent for the public water works authorities whose piping network is all but woefully undersized, and for the city's residents who are left high and dry. With technologies such as the new vanadium batteries, affordable electricity storage, properly sized for the end users, may become just as indispensable to the developing world's population as the ubiquitous water tanks of Bangkok are to that city's residents.

References

[1] Pellegri A. and Spaziante P.M., *UK Patent GB 2 030 349 A 10, July 1978.*

[2] Takefumi I., Takashi K., Atsuo I., Kouhei K. and Hara T. and Nobuyuki T., "Development of Vanadium Redox Flow Battery System", *Proceedings of the Society of Automotive Engineers, Inc. (1999) 1999-01-2616.*