

Vanadium Redox Flow Battery System for Use in Office Buildings

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Introduction

Nighttime power demand is substantially lower than daytime in Japan. In the Kansai Electric Power Company (KEPCO)'s service area, the nighttime demand is about 40% of daytime demand in the summer season. This promoted KEPCO to pursue studies for the development of power storage batteries that store electric power of the night and discharge it during the daytime.

In 1985, KEPCO began the development of the Redox Flow Battery (RFB) in cooperate with Sumitomo Electric Industries, Ltd. (SEI), and studies are still continuing. Since power demand was increasing yearly at a high rate around 1985, the initial target for RFB development was a large capacity system that could be used to substitute for the conventional pumped storage power station. Because IPPs have come into use and governmental policies for deregulation of power supply are being emphasized in Japan today. The target has modified to a system for installation in customer facilities that levels customer loads and prepares countermeasures to power shutdowns.

RFBs are now practically installable in customer facilities, which will be shown in this presentation.

1. RFB; Theoretical Basis, Construction, and Prototype Product

(1) Theoretical Basis of RFB

The theoretical basis of RFB is shown in Figure 1.

An electrolytic solution of diluted sulfuric acid including ions of dissolved vanadium is poured into a tank. To charge/discharge power, the solution is pumped from the tank to the cell, the charging/discharging part. During charging or discharging, the vanadium ionic charge changes as shown below:

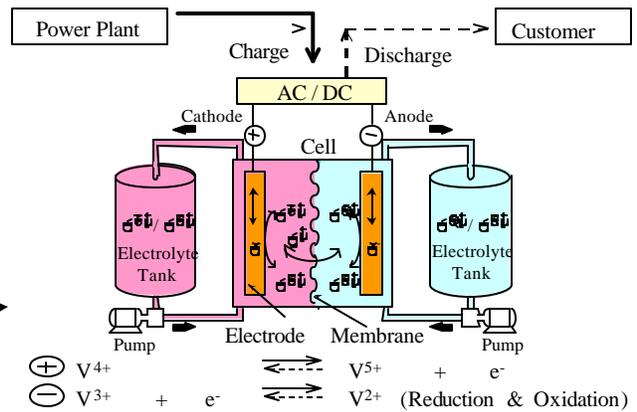
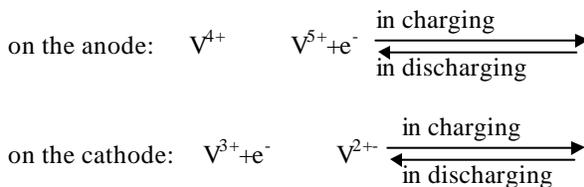


Fig. 1 - Principle of Redox Flow Battery

(2) Construction of Battery Cell Stack

1) Construction of Single Cell

Construction of the single cell is shown in the top of Figure 2. On both sides of the ion-exchange membrane are provided the carbon felt electrodes each of which electrolyte passes through. When we pass charged solution, we can remove power from the electrode. When we impose an electric voltage across the electrodes through which electrolyte is running, we can store electric power in the solution.

2) Construction of Cell Stack

Multiple numbers of single cells are combined in series with conductive carbon plastics in between to increase voltage and capacity, because the single cell voltage is as low as 1.4V. A 60-cell stack for 20kW output is shown at the bottom of Figure 2.

(3) Development of Prototype Product

In the initial stage of study, we adopted an electrolyte of Ferro-chromium type. But it was later changed to vanadium type for the reasons of performance. A 450kW system was erected in KEPCO 's Tatsumi Experiment Center to prove the theoretical basis of RFB with the vanadium type electrolyte and seek technologies for large-scale systems.

In considering future large systems, this system is composed of three connected modules of 150kW, each of which is composed of eight stacks of 20kW and 2 tanks. The system is shown in Figure 3.

2. Features of RFB

RFB has the advantages as listed below:

- * Long cycle life
- * No standby loss
- * Quick Restarting
- * Strong against abrupt overloads
- * Easy maintenance
- * Moderately Large Scale Tank

Descriptions of each feature:

1) Long Cycle Life

Charging and discharging of the RFB depends solely on the change of vanadium ionic charge in the electrolyte, and not on the electrode. Hence, the battery operation causes deterioration of the minimal materials.

We produced a battery system with one 20kW stack, which completes one cycle of charging and discharging in about an hour, before we erected the 450kW system. In addition, we made a test of cycle life, whose result is given in Figure 4. The test continued up to more than 13,000 cycles in about two years and the system proved still operable after the test. The test was terminated to begin erection of the 450kW system.

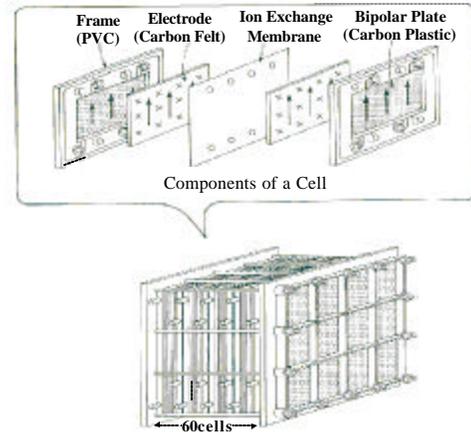


Fig. 2 - Construction of a Cell Stack (Output 20kW)



Fig. 3 - RFB for 450kW 2.0H

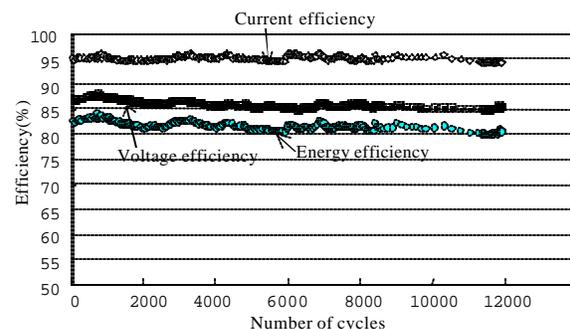


Fig. 4 - Result of Cycle Life Test of 20kW Class Battery

2) Standby Loss

In a long-term halt of RFB operation, the electrolyte is stored in two separate tanks each for the anode and the cathode. Self-discharging is completely prevented by this means. Pumps and other appending units are also at a standstill. Therefore, there is almost no standby loss.

We charged the 450kW system, and discharged it after a term of stand by which we modified in test each. We measured battery efficiency and capacity, whose results are shown in Figure 5. No difference is seen between the results for a stand term of 1 day and 15 days both for the battery efficiency and for capacity. Both efficiency and capacity decrease for a standby term of 1 to 15 days as compared to 0 days. The reason: when we stop operation of the RFB, the electrolyte returns to the tank but a slight quantity remains in the cell causing self-discharge. The efficiency reduction depends on the system conditions, a reduction of about 0.2% for system capacity of 8 hours.

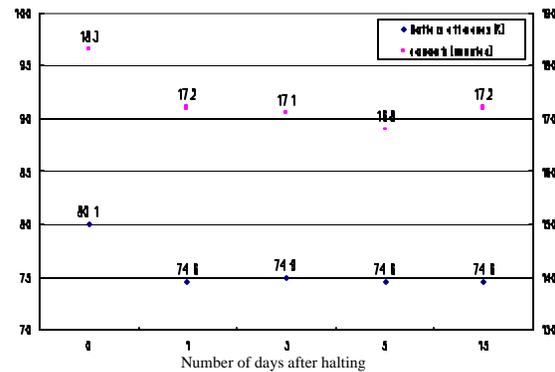


Fig. 5 - Change of Capacity and Energy Efficiency in Long-Term Standby

3) Quick Restarting

The RFB restarts even after a long term halt simply by starting the pump. This allows very quick restarting. Figure 6 shows the battery performance of the 450kW system when it is restarted with a setting of the electrolyte flow to reach the normal rating in 30 seconds. The battery voltage is established in about 30 seconds and a discharge at the normal rating is achieved in about 60 seconds. An even quicker restarting is possible.

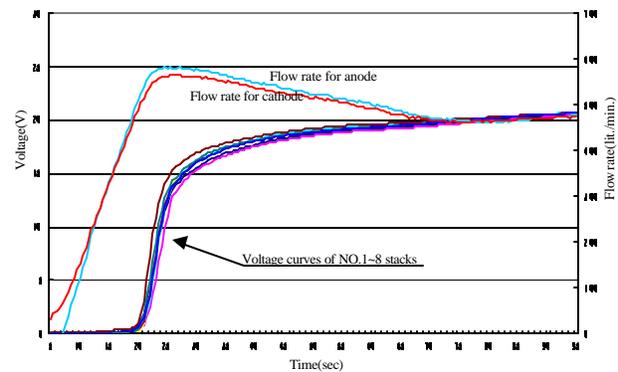


Fig. 6 - Restarting Performance of 450kW RF Battery System

4) Strong against Overload

The RFB can discharge large volume of power for a brief period to compensate an overload, because its tank contains a considerable amount of electrolyte.

We conducted an overload test with a small cell having an electrode area of 9 cm^2 , using an electrolyte quantity compatible to about a 2-hour capacity (for a discharging rate of 60 mA/cm^2) and setting the same solution feeding rate as the actual cell stack. Figure 7 presents the results. It shows that a considerable overload is tolerable. Another test showed that the overload performance is improved when we increase the solution amount. However, it is thought that the overload performance will be degraded down with an actual cell stack compared to the results shown here, because there is a higher increase of the internal resistance in the test.

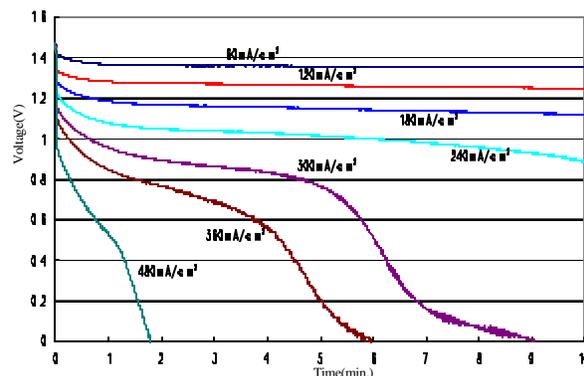


Fig. 7 - Results of Overload Test on Small Cell

5) Easy Maintenance

Yearly maintenance of the RFB mainly includes the sensor calibration and the inspection of protection functions. Consumable parts in units such as moving portions in pumps and fans, and condensers and batteries assembled in the control units should be replaced once every 3 to 8 years. No major maintenance operation, however, such as overhauling of batteries is necessary.

6) Moderately Large Scale Tank

The electrolyte tank is an essential need of RFB. The tank is rather large for a system of long time capacity.

If we install an 8 to 10 hour capacity RFB system as a substitute for the pumped storage power station, the size of the system is much smaller than the station. However, we install a several hundred kW system in a customer's facility, securing a place for installing the tank may be a problem.

As a solution of this problem, we have developed rubber tanks having good adaptability and workability as well as high electrical insulation. We put the rubber tank in cistern located at the building bottom. Buildings provided with some underground floors generally have a cistern with space left unused in most cases.

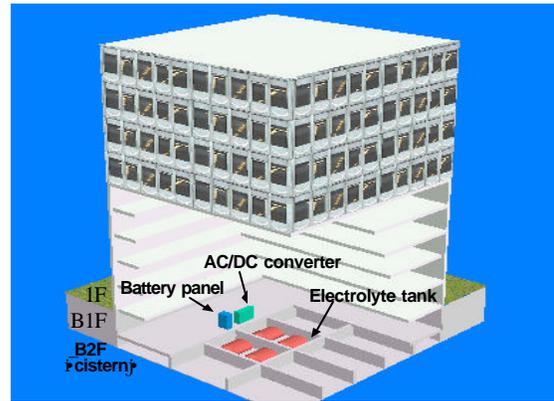


Fig. 8 - Outlines of RF Battery for Building

3. Development of RFB for Use in Buildings

(1) Development of 50kW (*3.5h) Class Prototype System

We prepared a space simulating the cistern using concrete in a room of KEPCO's Tatsumi Experiment Center to assure reality of the above-mentioned building system. Thus we erected an RFB putting the rubber tank and the pump therein, and the cubicle containing a 50kW class stack on the floor. This system has been running since August 1999.

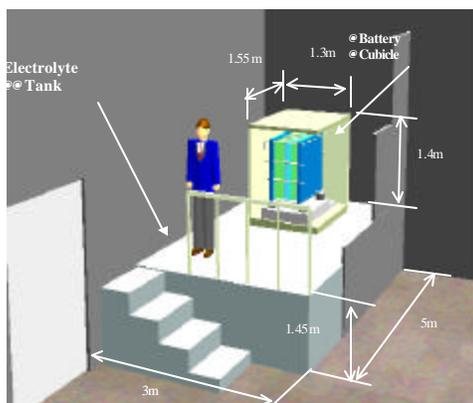


Fig. 9 - RF Battery for 50kW 3.5H (Image)



Fig. 10 - RF Battery for 50kW 3.5H

(2) 100kW(*8h) Class System Erected in an Existing Building

A RFB of 100kW class was actually installed in a typical business office building in Central Osaka. We located the rubber tank in the cistern and the battery cell stack and the inverter on the B1 floor, used as the parking lot.

Whereas this system has a quadruple cell stack construction to secure an AC output of 100kW, installation of the total of the cell stack and the inverter required only a small space equivalent to a passenger car. This system has been running since March 2000..

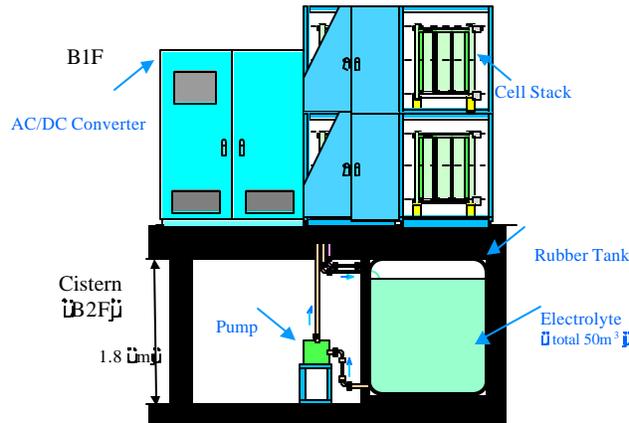


Fig. 11 - Application Image of RFB to Office Building (100kW 8H)



Fig. 12 - RF Battery for 100kW 8.0H

(3) 200kW(*8h) Class System for New Building

We have constructed a building with a vacant underground chamber on the premises of KEPCO's Tatsumi Experiment Center. A 200 kW class RFB system is now under erection placing the rubber tank and the pump in the underground chamber. This system, constituting the base for future products, uses 2 battery systems of 100 kW class connected in series and an inverter for DC/AC conversion. It aims at a total efficiency of 70% at the AC terminal involving all losses in the system such as that in the inverter and the pump. Target construction cost of this system is less than \$5,700(1\$=105Yen) per kW.

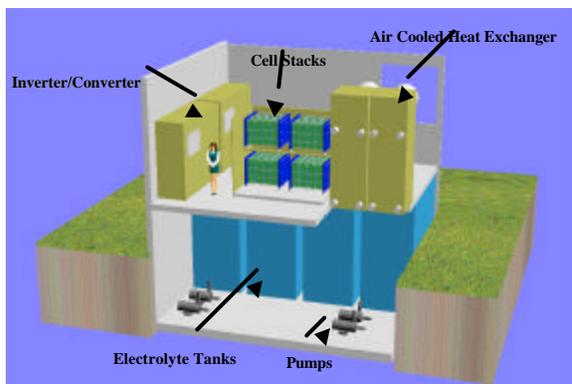


Fig. 13 - RF Battery for 200kW 8.0H (Image)



Fig. 14 - RF Battery for 200kW 8.0H

4. Real Applications to Facilities

(1) Installation at New University Campus (for Leveling Loads)

Three units of the above-mentioned 200 kW class RFB system will be installed in a building on a newly developed university campus in Kansai District. The purpose is to cut power cost as well as minimize the power receiving installation by charging the units at night and discharging them during the daytime in order to level loads.

(2) Installation in a Semiconductor Factory (for Protection against Instantaneous Power Shutdown)

This system will be installed in a semiconductor factory in Japan. An RFB of 1.5MWx1h will be kept connected to the load all the times to cut load peaks for an hour in the daytime as well as put itself into running at the double load (3MW) once a power shutdown occurs.

(3) Co-Installation in a Wind Power Plant (for Absorption of Load Fluctuations)

A unit of a 200 kW class RFB system will be installed at a wind power plant of The Hokkaido Electric Power Company to level its output by absorbing fluctuations. This project is included in the current national research program.

(4) Others (Systems in the Future)

. System Used Also as Emergency Power Source

For a protection against outbreaks of fire, facilities such as office buildings are equipped with fire fighting units and non-utility generating units. Often, however, non-utility generators do not start up immediately because of their infrequent use. Since the RFB system runs ordinary to level building loads, it operates as an emergency unit reliably when a fire occurs.

. System Co-Installed with Solar Generating Plant

If an accident or natural calamity such like as an earthquake occurs, utility services such as power and gas may stop for a prolonged period. As a protective measure a public or other facility can be equipped with a combined system of the solar generator and the RFB. The RFB is considered suitable to such a system because it has no standby loss and is compatible to a long-term capacity system.

. Large Capacity System Installed in Electric Power Station

The RFB has advantages such as no standby loss, high strength against severe charging/discharging conditions and negligible production of uneven charging because electrolyte in the tank easily gets homogeneous. This makes the RFB system suitable for connection to a large capacity system to adjust the power frequency and stabilize the power system. Different from other battery systems, the RFB system can cope with an increase of the system capacity by upsizing the tank. Hence, it occupies less installation area than other systems. Figure 15 shows an example of a 300 MW class system outline design.

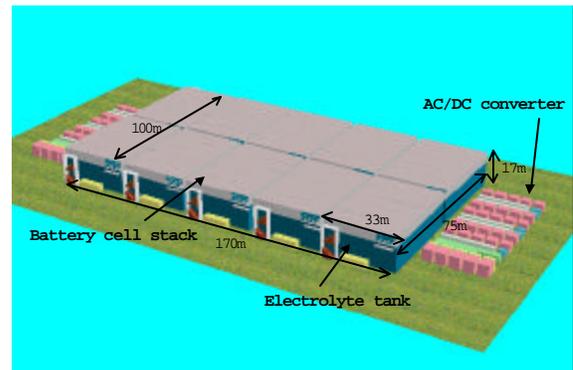


Fig.15 - Outline Design of RFB for 300MW 8.0H

Conclusion

The RFB technology, on which KEPCO and SEI have persistently pursued studies since 1985, produced an RFB system for buildings several years ago, which drew attention and general enthusiasm as a practically applicable technology. This spurred technical improvements to the practicable level. The remaining hurdle is cost reduction that is our primary focus to expand the market. We believe that the RFB is promising product that is a candidate for continued growth in both performance and cost.