Vanadium Redox Flow Battery for Remote Area Power Supply

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Introduction

Intermittent electricity from renewable energies such as solar, wind and bio-mass can be upgraded when utilized in combination with a storage unit. The most versatile technology to date to serve this purpose is the vanadium redox flow battery technology. Customer requirements to be met range from high safety and reliability to product life cycle of approx. 20 years at decent cost.

For most energy storage systems, high volumetric and specific energy are among the most desired. For utility applications life time, reliability and state of charge control are the most important requisites and are often ranked on the expense of weight and volume. This paper describes the Cellstrom product FB10/100 design and performance.

Experimental

The Vanadium Redox Flow Battery technology, first introduced by M. Skyllas-Kazacos in 1986, is an energy storage technology that differs significantly from conventional rechargeable battery technologies. It uses 2 liquid energy storage media, often called electrolytes, instead of solid energy storing electrodes like in Pb/acid and Lithium Ion batteries.

The principle of operation of a Vanadium Redox Flow Battery is easily explained:
Every flow battery consists of a cell block, often called the transformer, and two tanks with pipes and pumps connected to the cell block.
The cell block contains the electrochemical cells. In FB10/100 2 cellblocks of 1 kW power each are connected in series to form a string. 5 strings are then connected in parallel to the terminals. Almost all of the energy is stored outside the transformer cells in two tanks. The liquids are pumped through the transformer cells while charging and discharging. Each cell is divided into two compartments using a proton conducting membrane. During charging, V^{3+} ions are converted into V^{2+} ions, and at the positive electrode, V^{4+} ions are converted into V^{5+} ions. During discharge the opposite reactions occur.

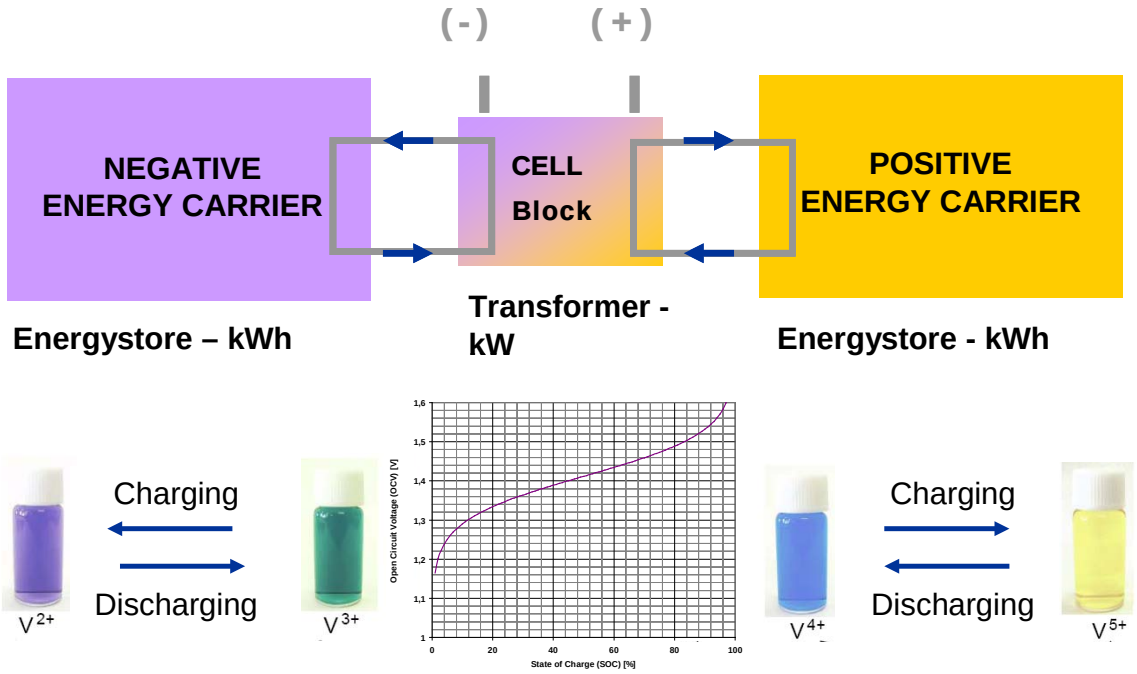

Figure 1: Schematic of the Vanadium Redox Flow Battery

The tank sizes are always related to the kWh's of the storage and are designed independent of the cell block, which is related to the kW total power. Upon charge and discharge, the open circuit voltage (OCV) of the individual cell changes in a s-shaped behaviour as a function of state of charge (SOC). From chemical thermodynamics, this is due to the liquid state solution regime at all SOC values. The OCV voltage in combination with the temperature are then used to determine the state of charge of the battery. Conventional batteries such as lead/acid, Ni/Cd, and many Lithium-ion batteries do show plateau voltages on open circuit over a wide range of SOC. In remote area power supplies, SOC control is a very important issue and relates directly to the reliability of the power station.

In summary, the VRFB has a number of very exceptional properties:

- external storage
- transformer size independent of storage size
- transformer cells are at equal SOC due to parallel feeders
- no cross contamination due to single metal (V) system
- endothermic cooling during discharge
- high degree of design modularity
- reliable state of charge reading
- the cells are robust against deep discharges

Results and Discussion

The 2008 announced product FB 10-100 provides 10 kW maximum power at 20°C and 100 kWh's in terms of energy.

In the FB10/100 system, the exceptional properties of the vanadium redox flow concept were built into an advanced battery turnkey design with

- weatherproof housing
- charge controllers and inverters included
- intelligent battery management
- temperature management
- optimized transformer cells
- multi stage operation reacting to applied load
- energy carriers are reusable
- installation and full operation within two to three days

In remote areas electricity is generated from diesel engines and more recently from renewable but intermittent resources such as solar and wind. These intermittent resources need fast storage when they are available. Therefore, high power is needed for charging, and typically, relatively low power is needed for discharging. FB10/100 is equipped with a multi stage operation system to accommodate these requirements.
Multi stage operation refers to the use of individual strings of cells during operation, depending on the applied load. Each string is connected to a relay, which was designed to switch high currents. At small loads up to 2 kW, only one string is in operation and the other strings are electrically disconnected. The not operating cells are allowed to discharge the volume of electrolyte within the cell. But other than that, no self discharge does occur in the off-state mode. Also the pump power is limited to the one string in operation. In total, this operation modes is very energy efficient and savings of 25% at one string pumping compared to operating all strings at low power have been observed.

The VRFB reacts very quickly to changing loads. A response time in the 10 Milliseconds regime is typical.

Figure 2 shows the FB10/100 storage unit with service flaps open at the transformer side. The cell stacks are on top of the fluid lines. Tanks are below. The switch cabinet on the side provides all connections for generator and load and related fuses. It is accessible to the customer.

Figure 2:
In Table 1, the specifications for the FB10/100 storage system are given.

FB10/100	Parameter	Value
Performance and Energy	Nominal rated charge power (15 – 80% SOC)	9 kW - 18 kW
	Nominal rated discharge power (15 – 95% SOC)	10 kW - 15 kW
	Nominal rated energy (15 – 95% SOC)	100 kWh
Performance Control	Multi - stage Control and Regulation	2/6/10 kW
Power - Battery and System	Configurable outputs (with suitable inverters/ converters)	48 VDC 120 VAC 230 VAC (1-phase) 400 VAC (3-phase)
	DC operating voltage range	36 VDC – 58 VDC
	Typical open circuit voltage range	45 VDC– 54 VDC
Charge Control	Remote observation parameters	State-of-charge (SOC), remaining capacity, charge/discharge power, etc.
Efficiency	DC round-trip efficiency (typical)	70% - 80%
Bridging Time	Discharge (bridging) times @ 10 kW to 95% - 15% SOC	10 hours
Self Discharge	self-discharge in stand by (1 string)	0,033 kW
	Self-discharge in tank	Negligible
Dimensions and Weight	Dimensions (L x W x H)	4500 x 2200 x 2403 mm³
	Weight (Dry system)	3.500 kg
	Weight (filled system)	10.300 kg

* All Data measured @ 30°C Electrolyte temperature

Table 1: FB10/100 battery specifications

There are several applications for the FB10/100 of which the remote area power supply is the most demanding. Loads such as electric vehicles, family homes, telco electronics, radar, and telemetric equipments require fully automatic operation and as little maintenance as necessary. The FB10/100 is very well equipped for these applications. In the following pictures, two examples are given for the utilization of FB10/100.

Figure 3: Solar filling station at the Solon Headquarter in Berlin: 7,5 kWp PV generator, FB10/100 intermediate storage to charge electric scooters.

Figure 4: Finalizing the installation at the Telemetric station of the 8 MW solar power plant in Merida, Spain.

In summary, the Vanadium redox flow battery technology has proven as a viable storage system for remote area applications. It is anticipated to bring the total costs down to the costs of a comparable lead/acid installation.

References

[1] M. Skyllas-Kazacos et al., *AU Patent 575247*, (1986)