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ANALYSIS OF VARIOUS POWER LOSSES IN VANADIUM REDOX FLOW BATTERY

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Abstract**:** As technologies grow up, the consumption of electricity goes on increasing in such way that the demand is more than that of supply. Nowadays electricity is mainly obtained by burning fossil fuels. So, environment pollution reaches its peak level due to release of environmental pollutant gases such as CO2, CO etc. The solution for this is, use of renewable sources of energies such as solar and wind energy instead of fossil fuels. But problem with use of these energies, they are not uniform all the time. So in order to store these energies when availability is more the concept of battery came to existence. Vanadium redox flow battery is also a very good promising battery technology which can stores energy in most efficient way. This paper explains the history, constructional details and working principle of the vanadium redox flow battery. This will also deals about various losses such as power loss due to resistance, pump power loss and chemical power loss occurs in vanadium redox flow battery. The simulations are carried out using MATLAB/SIMULINK tool.

Index Terms: Vanadium redox flow battery, Redox, half-cell, Oxidation state.

I. BACKGROUND OF REDOX FLOW BATTERY

In the 1970s NASA studied the Redox Flow Battery (RFB) for building stationary energy storage systems. In early 1984 Maria Skyllas-Kazacos[1]and co-workers at the University of New South Wales, Australia developed the first Vanadium Redox Flow Battery (VRB). In 1998 the Australian Pinnacle Vanadium Redox Batteries Company bought the basic patents, and later Sumitomo Electric Industries (SEI) designed cell stacks and completed integrated systems under a license from Pinnacle VRB Company (S. Eckroad, 2007).

Among various kinds of RFBs, the Vanadium Redox Flow Battery (VRB) was the first one introduced into commercial energy storage applications by SEI in 1996. In 1996, Kashima Kita Power Station utilized an in-load leveling application with 800kWh[5]. Between 1996 and 2005, SEI had built VRB plants for solar energy storage (240kWh), wind turbine output stabilization and storage (6MWh), power quality (1500kWh), and peak shaving (5MWh) (S. Eckroad, 2007).

II. VANADIUM REDOX FLOW BATTERY

Vanadium redox flow battery(VRB) stores the energy in the form of chemical energy. The electricity is generated by the reaction of different vanadium ions which have different valences in the electrolyte[2]. The power of the battery is determined bythe number and size of the cells stack, the total capacity of the cell is determined bythe amount of electrolyte stored in the tank. The electrolyte is stored in tanks and flow through pumps to react in the battery cells.

The general characteristics of vanadium redox flow battery are as follows:

- The reaction is occurred between two electrolytes but not between the electrodes and the electrolyte. Therefore, the
  Loss of electro-substances which often occurs in conventional batteries is reduced.
- The electrolytes are stored in the tanks. Therefore, the capacity of the VRB will be larger than a conventional battery.

A. CONSTRUCTIONAL DETAILS OF VANADIUM REDOX FLOW BATTERY

The block diagram of vanadium redox flow battery is as shown in Fig.1.The cell is the core of the battery. The cell consists of end plate, carbon felt and membrane. During the discharging process, the electron is removed from the anolyte (electrolyte at negative half-cell) and moved to the catholyte (electrolyte at positive half-cell) through the external circuit which connects the load and provide electricity to the load.

In charging direction, the electron flowing direction is reversed. Across the membrane, there are only hydrogen ions flowing through in order to balance the charge on both sides.

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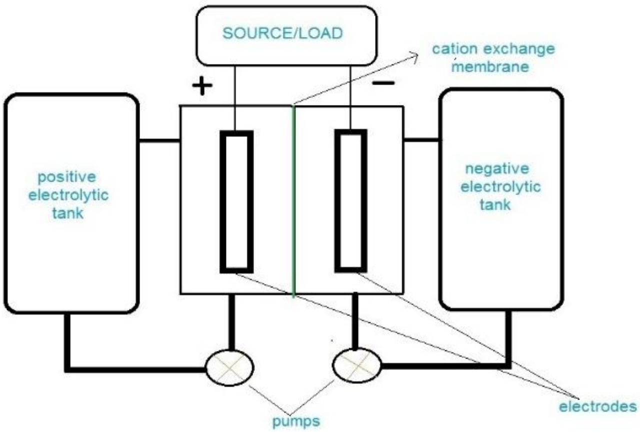

Fig. 1. Block diagram of vanadium redox flow battery

B. WORKING PRINCIPLE OF VANADIUM REDOX FLOW BATTERY

The vanadium ions exist with four different oxidation states which are 2+, 3+, 4+and 5+ as shown in Fig.2. For the discharging process for example, in the positive side, the v^{5+} gains an electron to be reduced to v^{4+} and on the negative side the v^{2+}gives out an electron to be oxidized to v^{3+}.The hydrogen ion will flow through the membrane tobalance the charges for both sides. Therefore Fig.3 and following equations represents the reactions that are takes place in positive and negative half cells.

$$v^{4+} \rightarrow v^{5+} + e^{-}$$
$$v^{2+} \rightarrow v^{3+} + e^{-}$$
$$v^{3+} + e^{-} \rightarrow v^{2+}$$
$$v^{5+} + e^{-} \rightarrow v^{4+}$$

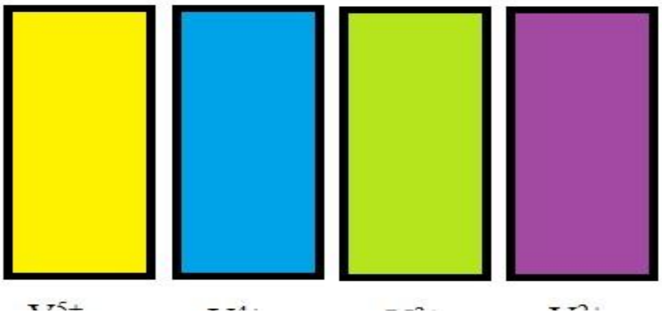
Fig.2.Various oxidation states of vanadium

VRB has become an inexpensive and reliable stationary energy storage system. In comparison to other redox flow batteries, zinc bromide, polysulfide bromide, cerium zinc, etc. The VRB is simple to use and it has rather low cost. What is more important to the people and the environment, it does not contain any toxic element. The VRB has a large scale of storing capacity to store electricity or rather unlimited capacity by just changing the size of the tanks. If there is no electricity to charge the battery, it still can work by just replacing the electrolytes in the tanks with new electrolytes. If the electrolytes are mixed by accident, there will be no permanent damages to the battery, so it is very safe.

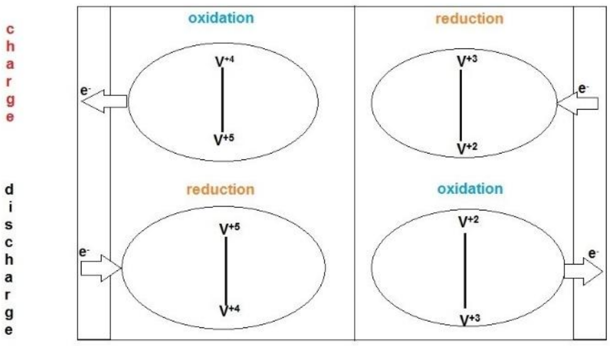

Fig.3. Redox reaction in vanadium redox flow battery during charging and discharging process

If the temperature exceeds a certain temperature limit, the precipitation of the vanadium will form at the electrode which will block the electrodes and prevent the normal working of the battery. This rage is from 15 to 35 degree Celsius[3]. If the temperature is below 5 degree Celsius, the precipitation of v^{+2}/v^{+3}will form in the negative electrolyte. Likewise, if the temperature exceeds 35 degree Celsius, the v^{+4}/v^{+5} precipitation will form in the positive electrolyte. If the temperature is not controlled properly, the batteries performance will be deteriorated. An investigation on how the different currents and flow rates of the electrolyte will affect the temperatures of the VRB is carried out by using the equation of balanced energy relations. The temperatures of two element of the battery are simulated respect to the time, one is the stack temperature and the other is the tank temperature.

III. VARIOUS POWER LOSES IN VANADIUM REDOX FLOW BATTERY

Mainly three types of power losses occurs during charging as well as discharging process VRB, they are listed as follows[1],

- Internal resistance power loss
- Pump power loss
- Chemical power loss

A. INTERNAL RESISTANCE POWER LOSS

This power losses due to the ohmic-resistance of the charging or discharging current. The current can be either charging current or discharging current. When the battery is in charging process, current will have a positive value otherwise the current will have a negative value. R is the resistance varying depending on charging process or discharging process. Internal resistance power loss is shown in Fig.4.a

B. PUMP POWER LOSS

The power loss in VRB due to flow of electrolyte is called Pump power loss.
Mathematically given by following equations,
$P_{pump}= \Delta P *Q$
$\Delta P = \Delta P_{friction} + \Delta P_{form}$
There are mainly two kinds of losses due to the flow of electrolyte.

- Friction loss
- Form loss

1. Friction Loss:

The friction pressure drop is due to the viscosity of the fluid against the walls of the pipe, the cell and the tank as well as the shear stress within the fluid itself. For the form pressure drop, it is because when the fluid is owing in the pipe or the cell there will be sudden change of the pipe shape or change of flowing directions. Therefore, some amount of energy is spent to make a sudden change of fluid owing direction and cause the pressure dropping.

2. Form Loss:

The Form loss is due to elbows, bends and valves, which are common components in the battery design. They are all responsible for the hydraulic circuits pressure drop. The fluid owing in the circuits will change owing direction due to changes of pipe shape or open or close valve.

C. CHEMICAL POWER LOSS

$P_{ch}$is the chemical power. Heat is absorbed during the discharging reaction and generated during the charging process.
During charging process,

$$v^{5+} + 2H^{+} + e^{-} \leftarrow v^{4+} + H_2O$$
$$v^{2+} \leftarrow v^{3+} + e^{-}$$

During discharging process,

$$v^{5+} + 2H^{+} + e^{-} \rightarrow v^{4+} + H_2O$$
$$v^{2+} \rightarrow v^{3+} + e^{-}$$

To calculate the heat generated by the chemical reactions, entropy changes need for consideration, which is as shown in Table I.

Table I. Vanadium component thermodynamic data[1]

Formula	ΔHf(kJ/mol)	ΔSf(J/mol.k)
V^{2+}	-226	-130
V^{3+}	-259	-230
V^{4+}	-486.6	-133.9
V^{5+}	649.8	-42.3
H_2O	285.8	69.9
H^{+}	0	0

The chemical power loss during discharging/charging process is calculated using following equations and shown in Fig.4.b

- $P_{ch}=q*n$
- $q=T\Delta S=T(\sum S_{products}-\sum\_S_{reactants})$
- $n=I/zF$

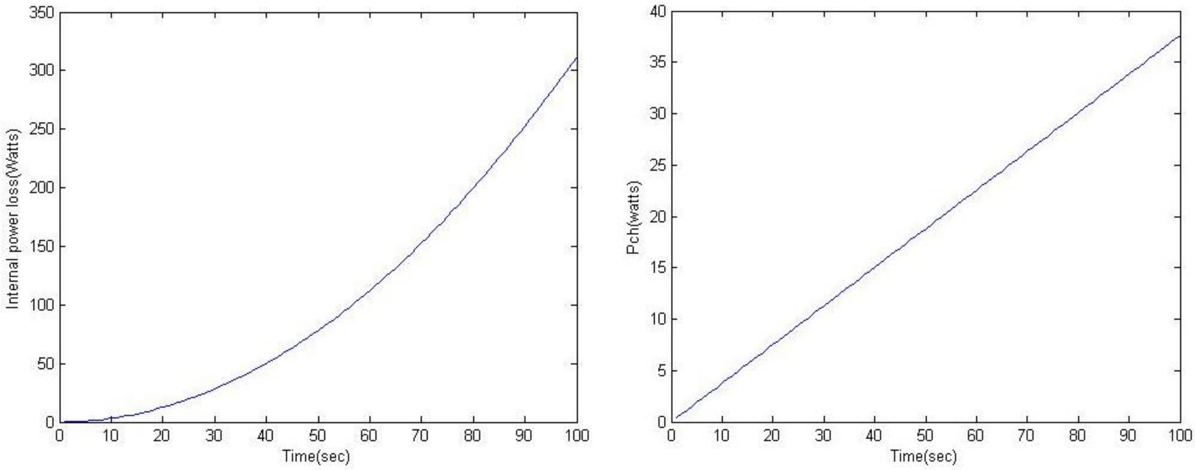

Fig.4. Various power losses in Vanadium Redox Flow Battery: a) Internal power loss; b) Chemical power loss.

IV. CONCLUSION

The various losses such as power loss due to internal resistance, pump and chemical power are analysed. Internal power loss is due to ohmic resistance offers during charging and discharging current. The pump loss is mainly due to hydraulic circuit components like valve, inlet, outlet and eblow. The chemical loss is due to pressure drop in electrolyte flow during reaction. All the three basic losses in redox flow battery are done in MATLAB and results are also shown.

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