Performance evaluation of single cell VFB at low temperatures

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Introduction

Increasing carbon footprint brings the immediate demand to use solar and wind energy. The Indian government is working towards GW scale solar projects to reduce the dependency on fossil fuels. Some of the cold regions in India receive considerable amounts of solar radiation throughout the year. For example, the cold arid Leh and Ladakh gets the highest amount of radiation, which is about 7 to 7.5 kWh m^{-2} day^{-1}. So there is a pressing need for good technology to use solar power to generate electricity in cold climatic conditions. Rechargeable batteries play a vital role in effective utilization of solar and wind energy. Extreme cold conditions reduce the performance of batteries severely. Even though the lithium ion battery is used everywhere, it suffers from many problems at low temperatures like aging, reduced power, battery degradation due to lithium plating. Several studies have shown the encouraging performance of VFB at low temperatures. But these studies are mostly in cells of less than 100cm^2 active surface area. Vanadium electrolyte is stable up to −25ºC [1],[2]. The present work reports the performance of vanadium redox flow battery (VFB) below ambient temperature up to −10ºC in 426 cm^2. Comparative study of performance of single cell VFB is carried out at cell temperatures 25ºC, 10ºC, −10ºC. The influence of compression of the electrode on the performance of VFB was evaluated at different compressions

Experimental

Single cell VFB is fabricated with Sigracell graphite felt electrode (with active area of 426 cm^2), SGL graphite plate with serpentine flow field, Nafion 117 membrane and copper current collectors. 340 ml electrolyte with concentration of 1.7 M $VOSO_4$ (Noah Technologies) and 5M H_2SO_4 was pumped at two different flow rates. VFB and electrolyte solution is kept inside the environmental chamber (Scientific Innovations, −50 to 150°C) to maintain the constant temperature. Peristaltic pumps are kept outside the chamber and electrolyte tubes are thermally insulated. Experiments were conducted by keeping the set up in the required temperature at least for 30 min. The electrolyte temperature was monitored using a high sensitive and calibrated thermocouple. Silicon gaskets with different thickness were used to provide the required compression for the electrode of the cell. Compression ratio was derived from the equation $(1-t_c/t_u) \times 100\%$, where t_c and t_u are the thickness of compressed and uncompressed electrodes respectively. Charge discharge studies were carried out at compression ratios (CR) 17%, 35% and 50% with 6 mm electrode at 25°C, 10°C, −10°C. Charge discharge studies carried out at current densities 40, 60, 80 mA cm^{-2} for 5 cycles in each condition.

Electrolyte circulation rate was varies in terms of stoichiometric factor (SF) 5 and 10. Stoichiometric factor was calculated as the ratio of actual flow rate to the theoretical flow rate. The solution is charged to 1.8 V and discharged upto 0.8 V.

Electrochemical impedance spectroscopy (EIS) was carried out at 10mV amplitude with frequency range 10 mHz to 10 MHz. Peak power density of the of the cell was evaluated by monitoring the cell power while increasing the current density in short steps while maintaining a constant circulation rate.

Result and discussions

EIS results are obtained in terms of Nyquist plot (Figure 1).

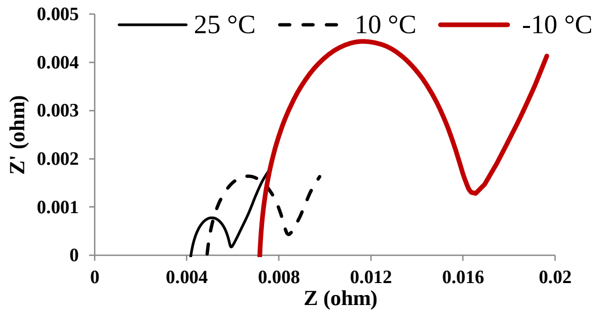

Figure 1: Effect of cell temperature on the cell impedance.

The x-axis intercept of plot corresponding to high frequency represents the ohmic resistance and the diameter of the semi-circle represents the charge transfer resistance of the VFB. EIS results showed that ohmic and charge transfer resistances also increase with decrease in temperatures as shown in the table 1. It can be observed that charge transfer resistance increases almost four times at −10ºC. This leads to widening of voltage window in charge discharge cycles and reduces discharge capacity.

Temperature (ºC)	Resistance(mΩ)	
	Ohmic	Charge transfer
+25	4.19	1.81
+10	4.92	3.48
-10	7.17	9.83

Table 1: Resistances obtained from EIS for the single cell VFB

Peak power density represents the performance of VFB at rapid power transient. It was observed from figure 2 that peak power density at −10ºC reduces to half of the value obtained at 25ºC at lesser current density.

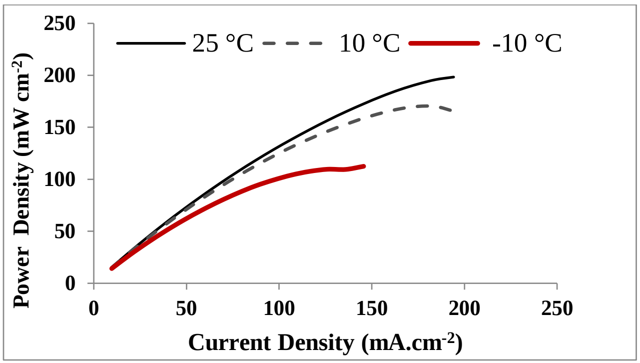

Figure 2. Effect of cell temperature on power density at CR 35% and SF 10

We have seen degrading performance of the VFB at lower temperatures through EIS and power density measurements. To improve the performance, experiments were carried out at different compressions. One can see that discharge capacity reduces to less than half at CR 17% when compared to CR 50% at −10 ºC. This is due to increase in overpotential at lower compressions (figure 3).

Further, the cell was unable to discharge at high current density 80 mA cm^{-2}, SF 10 even at CR 35%. Increasing CR beyond 50% may not be suitable as the pressure drop increases significantly [3].

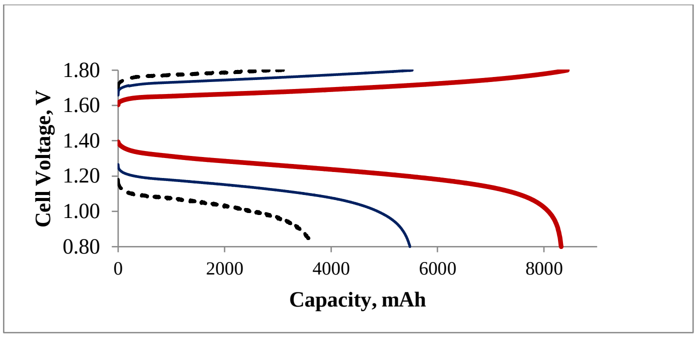

Figure 3. Effect of compression on performance at −10ºC at CR 17% (dashed), CR 35% (blue), CR 50% (red)

Conclusion

Significant loss of performance is observed when the cell is operated at −10ºC. This is in the form of reduced energy efficiency ((by about 15%) and inability to operate in a sustained manner at high current density ((of the order of 100 mA cm−2) which is possible at 25ºC. EIS studies show that both ohmic and charge transfer resistance increase significantly in comparison with 25 ºC, by about 75% and 400%, respectively, when the cell operating temperature is −10ºC. Increasing the compression of the electrode to 50% improved the performance of the VFB at low temperatures with acceptable energy efficiency. Apart from increasing compression of electrode, using thinner electrode and coating the electrocatalysts on the electrode can be alternative options for improving the performance at low temperatures.

Acknowledgements

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