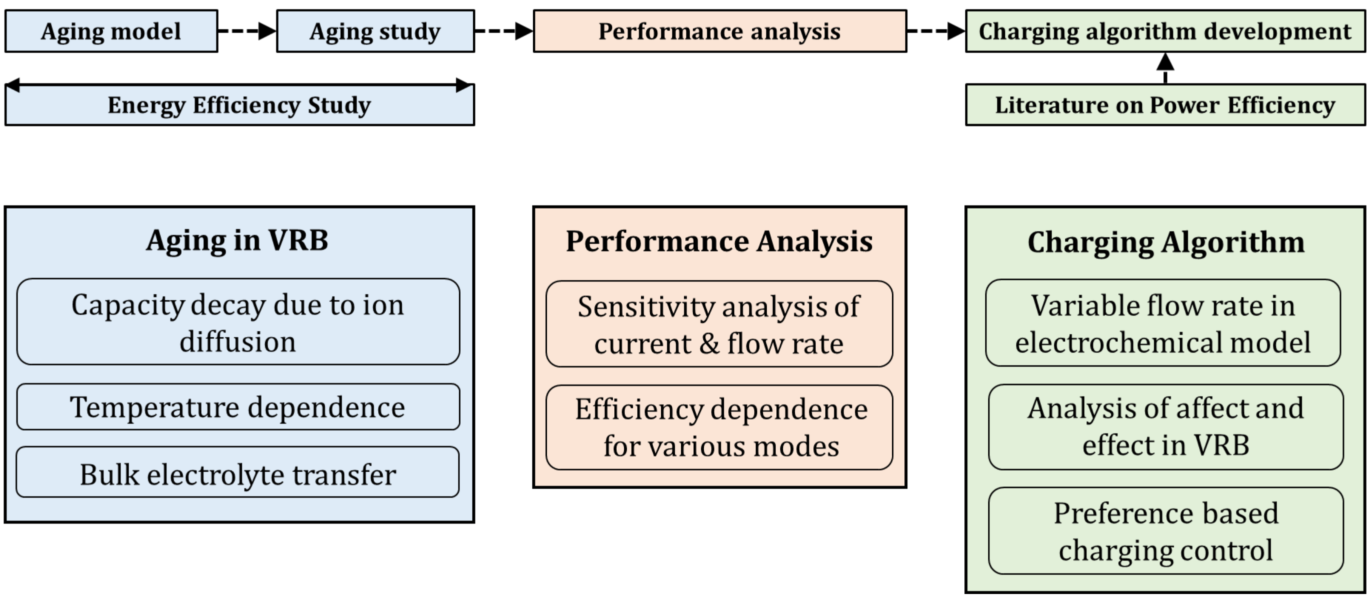
Investigation of Operational Characteristics of Vanadium Redox Flow Batteries

Abstract



Redox flow cell energy storage systems are becoming increasingly popular because of the numerous advantages they offer. These systems are modular, highly efficient and the cost is relatively low which makes it easy to scale up. The battery is however is not commercially widespread as Li-ion or Lead acid batteries. One of the major reasons for this is not having enough studies and lack of optimization which are specific to the battery. In this work we investigate aging of the battery due to ion diffusion which is one of the key aspects that are important but understudied for the use of VRB in buildings followed by devising a charging algorithm based on the electrochemical battery model developed in the process.

The work begins with the investigation of the issue of capacity decay in Vanadium Redox flow Batteries. The capacity loss due to vanadium ion diffusion is simulated for 10000 cycles of operation. The effect of flow rate on concentration flux in the cell is studied since concentration difference between two half cells is one of the major reasons for species crossover. As a consequence of diffusion, the charge transfer current density in the electrode varies. The relationship between charge transfer current density and the concentration of one species of vanadium is analyzed at different temperatures.

The concentration change of different species of vanadium ion is modeled with temperature influence for each of these vanadium ion variants. The concentration change of different vanadium ions due to diffusion is simulated for different temperatures. The change in capacity of the battery is calculated for different temperature profiles and the total loss was partially contributed by intrinsic loss and partly due to diffusion. It was also observed that the difference in the loss at different temperatures is higher during the initial 50% of the total lifecycle and stabilizes as it proceeds. At the end of 200 cycles, the capacity loss at 40^{o}C was higher (14.23%) than that of 30^{o}C (13.37%) and 20^{o}C (12.67%) of which a major part was contributed due to diffusion in the first 100 cycles of operation. Further, an extended dynamic model of the vanadium ion transfer is developed including the effect of temperature and bulk electrolyte transfer. The model is used to simulate capacity decay for a range of different ion exchange membranes that are being used in the VRB. The model is made more comprehensive by including the effect of bulk electrolyte transfer. A volume change of 19% is observed in each half-cell for Nafion 115 membrane based on the simulation parameters. The effect of this change in volume directly affects concentration, and the characteristics are analyzed for each vanadium species as well as the overall concentration in the half-cells.

Further, the parameter dependence is analyzed during the charging process of a Vanadium Redox Flow Battery (VRB) for a system-aware building which has distributed sources of energy production and amenable to flexible load scheduling. One of the key features of a flow battery is the ability to control the flow rate and current during the charging process. The flexibility however has a direct effect on charging time and efficiency which calls for a detailed performance study with various modes of charging. An electrical model of a kW scale VRB having an operating SOC range of 15-85% is presented. The presented model considers a 15 cell battery with current range of 80-160 mA/cm^{-2}, overall membrane area of 780 cm^{2} and a flow rate range of 2-6 L/min. The results obtained show that there is a trade-off between the charging time and the energy capacity depending on the charging current and the flow rate. This work would aid the process of charging optimization by selecting various modes of operation of VRB, depending on the weightage given by the system for charging time or the energy efficiency. By using the previous knowledge on the capacity fade (aging) of VRB and the performance analysis based on input parameters to develop a comprehensive charging algorithm is developed to enhance the battery operation. This would take both the state of charge as well as state of health into account while satisfying the user needs without causing much damage to either power or energy efficiency of the battery. Thus, by the comprehensive aging model and specific charging algorithm, we hope to have contributed to move the use of VRB in buildings one step closer.