GLOBAL

VANADIUM FLOW BATTERY

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A LITERATURE REVIEW OF THE VANADIUM FLOW BATTERY

INTRODUCTION

It is widely known that we are living in a time where in it, it is of critical need to simultaneously conserve our environment and also produce electricity that meets human consumption in South Africa. Most of the electricity that's produced in South Africa is from thermal coal. This kind of electricity generation produces a lot of greenhouse gases, which contribute to global warming. Over the past few years, the South African electricity public utility (ESKOM), has been under pressure due to breakdowns in their power stations, which resulted in the introduction of load-shedding to conserve electricity to meet human consumption.

In an effort to reduce carbon emissions and also reduce load-shedding, there is a need to introduce a cleaner way of producing energy or storing energy that will serve as a backup to the nation's power utility. Renewable energy sources (solar, wind and marine) can be an answer to this, however according to (Clemente et al.,2020) most renewable energy sources are normally discontinuous, due to their inter-dependence on weather conditions.

This makes it challenging and even impossible at times to schedule this type of energy sources. In order to meet the energy demand in times of low energy production, the requirement of an energy storage system (ESS) is important. There are different types of energy storage systems namely, mechanical, electrical and electrochemical storage systems but in this document, we are going to focus on the Vanadium-Flow-Battery, which falls under the Electrochemical Storage Systems.

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WHAT ARE FLOW BATTERIES?

Vanadium Redox Flow Batteries (VRB) are large stationary electricity storage systems with numerous potential applications in a deregulated and decentralized network. Flow batteries (FB) store chemical energy and produce electricity by a redox reaction between vanadium ions dissolved in the electrolytes (Blanc et al., 2010). Flow batteries have remarkable characteristics which make them attractive when compared to regular batteries, due to their capacity to decouple rated maximum power from rated energy capacity, as well as their more astonishing design flexibility. The vanadium redox flow battery appears to be more advantageous over the existing types of flow batteries. Flow batteries utilize a similar material (in liquid form) in both half cells, eliminating the danger of cross contamination and resulting in electrolytes with a potentially unlimited life (Cunha et al., 2015).

OPERATING PRINCIPLES OF A REDOX FLOW BATTERY

Redox flow batteries (RFB) are secondary batteries, this means that they are rechargeable. Its principle of energy conversion is based on electrochemical reactions of two redox couples (Alotto et al., 2014). A redox flow battery operates on a principle similar to that of conventional batteries, although it has a distinction of having the active materials separated from the place where electric current is generated (Shigematsu, 2011).

A typical vanadium system is made up of two electrodes (anode and cathode) and an ion exchange membrane separator that allows for the diffusion of hydrogen ions across a membrane while preventing the cross diffusion of the electrolyte solutions from the two tanks (Parasuraman, 2013). The electrolyte is one of the most integral part/s of the battery because it carries the chemical energy that's converted to electrical energy during operation.

According to (Ghirlanda, 2018), The electrolyte is stored in tanks and it flows into the cell through the porous electrodes, where the reactions take place and the charge is transferred. The produced electrons then flow into an external electric current and they determine the continuous current supplied or absorbed from the battery. The two electrolytes are always separated from one another, because of the presence of the proton exchange membrane as it permits the proton transfer from one half-cell to the next.

Ghirlanda, 2018 further states in his thesis that, in a vanadium redox flow battery, the electrolyte is made up of vanadium ions dissolved in sulfuric acid and water. They are pumped from the storage tanks into the respective half-cell and discharge mode, the oxidation takes place on the anode with the release of one electron while the reduction occurs at the cathode where the electron is absorbed. The electrons are transferred from the porous carbon electrode towards the current collector through the graphite plates, on which the flow field distribution is engraved. Proton exchange membranes are used to separate the two electrolytes, usually Nafion. The redox reactions involve the four different vanadium oxidation states at which corresponds different colors.

ADVANTAGES AND CONSTRAINTS OF THE VRFB

The long lifetime of the material of the battery and potentially endless durability of the electrolytes is an astonishing advantage when compared to other batteries. Since the reaction occurs only between the electrolytes and the electrodes, the active surfaces where the reactions takes place there will be no electrodeposition or losses in the electroactive operation of the battery (blanc et al., 2010).

VRB has other notable advantages such as quick response times, high electricity to electricity equalization requirement, simple (SOC) indication (electrolytes will be different colors when they reach equilibrium), low maintenance, the tolerance to overcharge and one of the most important factors is the ability for deep discharges without affecting the cycle life (Trung, 2010).

Although VRB's have a lot of attractive advantages, there are also downsides. One of the disadvantages is the high cost that is associated with Vanadium because it is already commonly used in many applications. However, there is a possibility to obtain it cheaply during the leaching of coal. In order to obtain a higher value of the fuel, vanadium is one of the elements that can be separated (Zhao et al., 2014).

VRFB's also have a low energy density. (Zakeri et al., 2015), stated that the energy density recorded for VRFB comprises of values that ranges between 10 kWh/kg and 75 kWh/kg and the power density does not exceed 800 MW/cm2 (Xu et al., 2013). These values are fairly low compared to the traditional ESS. This is due to the number of transferred electrons for the reaction, the low OCP (open circuit potential) and the low vanadium solubility. In addition, the vanadium solubility presents temperature boundaries.

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COST ANALYSIS

Membranes and electrodes are the main components of the vanadium redox flow battery (VRFB) in respect to electrochemical performance as well as costs. These factors are usually taken into consideration during the design of electrochemical storage systems (Minke et al. 2015). A deep analysis is required to understand the feasibility of meeting the market targets with the actual technology and to evaluate the possible changes which might result in capital cost decrease (Ghirlanda, 2018).

There are several cost components associated with the installation of the batteries namely, operation and maintenance (OM) cost, both fixed and variable, power connection system (PCS) and balance of plant (BOP). The major part of the cost is associated to the ESS which is mainly due to the electrolytes, which represent about 45% of the entire cost of the battery. The intention was to reduce the capital cost to 250$/kwh before 2015 and another reduction up to 100$/kwh before 2030 (Weber et al., 2011). So far, the results are far from the plan because the actual cost is around 400$/kwh (Zakeri et al., 2015). The content in this section is extracted from a paper written by Mikhail Nikomarov for Business Live, 22nd March 2019.

Batteries add flexibility and reliability to generation, transmission and distribution. Vanadium redox flow batteries (VRFBs) are particularly well suited to large-scale uses. Using locally mined vanadium as the basis for local VRFB manufacture would serve both Eskom and other local customers as well as helping the government achieve its goal of developing more local manufacturing and skilled jobs based on the country's competitive advantages. SA has the world's largest resource of high-grade primary vanadium (that is, not mined as a by-product), nestled in the world-renowned Bushveld complex in the Limpopo and the North West provinces.

COST ANALYSIS

Batteries allow consumers to avoid the most expensive peak-time tariffs, usually on mornings and in the early evenings. That benefits the whole system because it reduces the demand at critical times, when everyone wants to use electricity and load-shedding becomes most necessary.

For Eskom, there are multiple benefits to using batteries as part of the generation mix. Batteries help to offset the inflexibility of baseload generation from coal and nuclear by supplementing supply through demand peaks and troughs. They also allow Eskom to capture energy from solar and wind when they are available and supply it when customers actually need it, and are considerably cheaper than using diesel-powered open-cycle gas turbines.

The costs of VRFBs are falling fast due to intense research in a number of countries, particularly China and the US. Although the vanadium price has soared in recent years, a unique advantage of the technology allows the vanadium to be leased to customers, rather than sold, or cheaply recycled, which helps lower its cost in the battery.

Batteries are particularly powerful when combined with variable generation sources such as renewable energy, especially solar, which is plentiful in Africa and increasingly the cheapest source of electricity. When paired with solar generation, VRFBs can already deliver energy cheaper than peaking plants and on a par with some of SA's coal power plants.

Batteries can deliver electricity when it is needed rather than when wind and sun are available, which is rarely during peak demand times. Batteries can be located anywhere, relieving congestion in the transmission and distribution networks and obviating the need for investment in upgrading transmission lines.

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COST ANALYSIS

Solar plants and batteries take months to build, much faster than nuclear, coal or gas-fired power plants, and they are modular. In developing economies where demand for power fluctuates, it is important to have electricity solutions that can be added quickly and incrementally.

The legal and regulatory structures that SA will be putting in place for generation, transmission and distribution needs to make provision for battery technology, as it plays a role in all three areas. Sharing these benefits across all three is clearly desirable. This can keep SA from overbuilding in the power system and ensure lower electricity bills for consumers.

Although the draft IRP 2018 did not acknowledge batteries in the generation mix to 2050, Eskom is exploring their viability in place of concentrated solar power for flexible generation. It is currently testing various battery technologies, including a VRFB provided by Bushveld Minerals and the Industrial Development Corporation. The World Bank has recently announced a major battery energy storage programme that will mobilize $5bn and 17,500 megawatt hours of energy storage in developing countries, including SA. These developments suggest that the role of batteries may also increase once the IRP is finalized.

In addition to supporting the government and Eskom, Bushveld Minerals, which owns the Vametco vanadium mine near Brits, is planning to install its own solar/VRFB mining grid for the mine. This will be a commercial proof of the concept, reduce its carbon footprint and provide protection against rising electricity tariffs and interruptions. The mine will supply the vanadium for the project, showcasing how SA minerals can be used to solve the country's power challenges.

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