DEVELOPING A REDOX FLOW BATTERY WITH SPANISH TECHNOLOGY. PROJECT REDOX2015

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1. INTRODUCTION

Project REDOX2015 is an example of the efforts to improve performance of one storage technology: Vanadium redox flow batteries. The objectives of the project were two: to develop a VRFB by Spanish partners and to increase knowledge in new components for the next generation of VRFB. The project consortium was made by EDP Spain, ZIGOR, ISASTUR , Oviedo University, TECNALIA, IREC, INCAR and TEKNIKER. The project is funded by the Economy and Competitiveness Ministry of Spain with FEDER funding from the European Commission (IPT-2011-1690-900000).

This paper describes key findings of the first objective of the project in designing, manufacturing and deployment of the battery connected to the grid.

2. DESIGN OF REDOX2015 BATTERY

The main challenges in the design of the REDOX2015 Redox Flow Battery have been related mainly to the stack design and more precisely to the design of the frame to avoid the shunt currents between cells and the design for an uniform distribution of the flow rate in all cells of the stack.

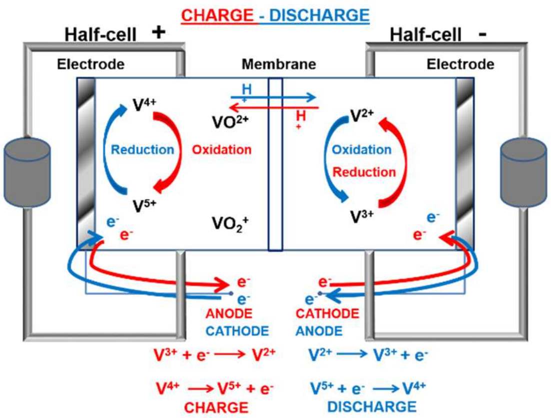

Fig 1 Vanadium Redox Flow Battery diagram

Concerning the design of the frame, two important issues have been considered, the electrical one and the fluidic one. The electrical subject deals with avoiding the shunt currents. It has been made an electrical model in SIMULINK based on the Fig. 2 to calculate the resistance needed in the electrical path [1].

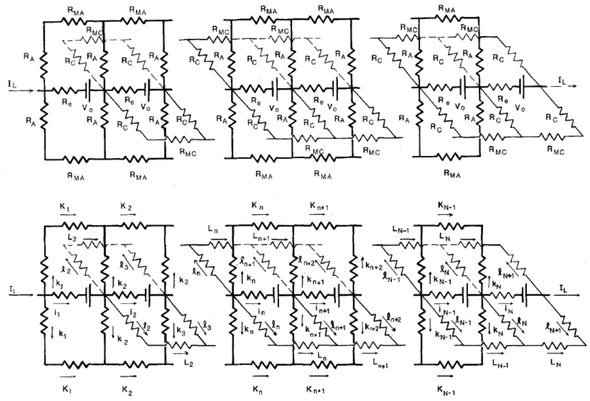

Fig. 2. Circuit analog model for a Stack of N single cells

The results of this model have been the starting data for designing the serpentine at the inlet and the outlet of the cell. In this design it is very important the relationship between the resistance and the pressure drop that is produced. Therefore, simulations with CFD (computational fluid dynamics) are highly important for serpentine design and to ensure that it does not increase the pressure drop in a large way.

Besides that, two additional effects have been analyzed with CFD. On one side, the distribution of the electrolyte along the carbon felt and, on the other side, the uniform distribution of the flow into the cells.

To do that, the serpentine pressure drop and the distribution of the flow along the carbon felt have been simulated with a single cell model. It is highly important the distribution of the electrolyte on the carbon felt where dry zones are dead zones that do not work. The figure below shows one of the results of electrolyte flow distribution. It can be seen that there is not any dead zones and that the biggest pressure drop is in the carbon felt. This means that predominant pressure drop does not happened in the serpentine.

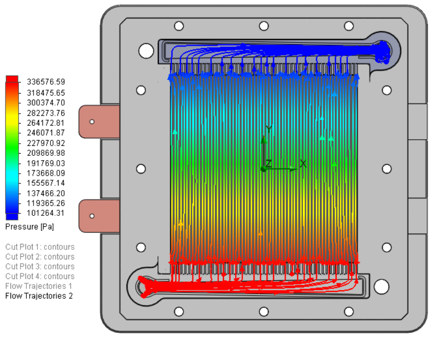

Fig. 3: Electrolyte distribution along the carbon felt.

In order to analyze uniformity of the flow distribution, CFD simulations have been carried out using N cell models. In the analysis 30 cell stack simulation has been performed. The results of this simulation are shown in Fig. . In the simulations, a minimum and a maximum flow rate have been established. Figure 4 shows the percentage of the total flow that is entering in each cell. A variation between 90% y 115% have been obtained, although main variation range is between 95% and 105%.

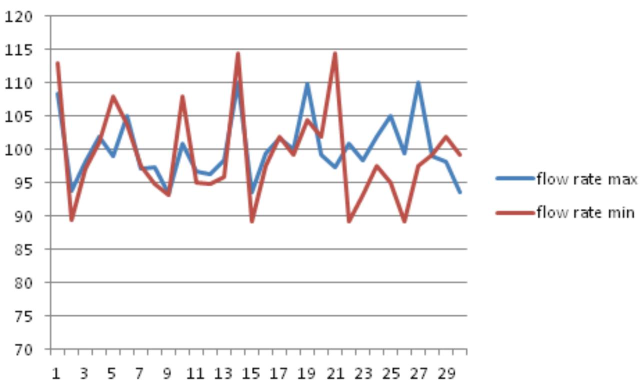

Fig. 4: flow distribution in cells

The storage prototype was designed to be connected to the LV grid, to prove its operation as demand balancing tool. A simulation model was needed in order to conceive and design different control strategies for the following implementation and operation of the prototype. ISASTUR and the University of Oviedo were involved in the control strategies development.

As regards the energy storage system model, it was developed in Digsilent Power Factory software. In order to improve the model reliability, it does not only consider the voltage source model, the converter and the connection transformer but also the detailed electrochemical relationships among the battery stack magnitudes, the pump operation and the state of charge (SOC) to determine the voltage between the battery terminals and the charge controller behaviour.

In order to support different storage management strategies, the project includes a Demand Balance Controller, specifically designed to optimize usage of the storage system and integrate it within grid operation. The Demand Balance Controller is connected with different measurement units in order to receive actual grid and main storage parameters, as well as to send power set points to the Battery Management System (BMS).

The strategies implemented in the Demand Balance Controller are:

- Peak shaving, in order to limit active power consumed by the loads.
- Price mode strategies. Real time bill optimization following either price signals or flat rates (two different modes).

Moreover, the Demand Balance Controller introduces trafo protection mode by limiting the apparent power flowing through the ML/LV transformers.

These three control strategies: transformer protection, peak shaving and price mode, have been tested and validated through simulations for different operational scenerios by means of Digsilent Power Factory software [2].

The simulation results showed that the control strategies developed can achieve an excellent performance as demand support tool and can lead to efficient energy usage, reducing the end user cost of energy and decreasing the distribution networks equipment stress.

The alarms and relevant parameters of the storage system are continuously monitored in the Distribution Management System (DMS) at the Control Centre of grid operator EDP through its communication with the Demand Balance Controller.

3. MANUFACTURING

Concerning manufacturing stage, there are two main issues to deal with: the compression of the carbon felt and sealing to avoid leakages. In REDOX2015 stack design, membrane, carbon felt and bipolar plates have been selected from commercial materials, whereas the design of the frame has been specifically developed for the project as mentioned in previous section. The frame is a critical part of the stack and for the battery as a whole too. On one side, frame is responsible for distributing the electrolyte along the cell and, on the other hand, it determines the exact space in the cell for the optimal compression of the felt.

Therefore the manufacturing process of this piece, normally made by injection molding, is one of the critical aspects for the correct stack assembly. The frame measures must be fulfilled with extremely precision during the manufacturing process so that any small difference on them will cause leakages or loss of compression in the felt.

Due to the big area of the piece in comparison with its thickness, it has been really difficult to obtaining the required tolerances during the injection molding of frame. Figures 5 and 6 show some of the problems that have been exhibit by the first pieces manufactured.

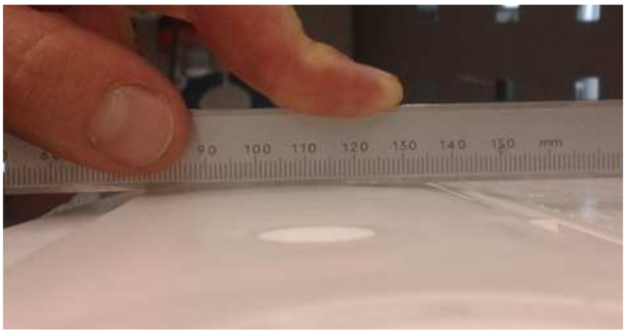

Fig. 5: : flatness failure of the piece

Fig. 6: deformations by contraction in cooling

Different test pieces have been fabricated to adapt the manufacturing process to reach the tolerances needed. Measurement in all critical zones have been needed as well as the development of a seal test to ensure that the process is adequate.

The seal test has been done to all pieces fulfilling tolerances to verify correct sealing of the frame. This test consists in assembling some cells with a compression film where red patches appear on the film wherever contact pressure is applied. Color density varies according to the differing contact pressure levels. Fig. 7 shows the result after one of the test where seal zones in red color can be seen.

Fig. 7: seal test

Three cell assembly has been done to verify in a real test the results of the simulation. In Fig. 8 are shown some cycles of the three cell stack. In this figure can be seen each cell voltage separately. There is no much difference in between them, this means that shunt current between cells are small and that the electrolyte is entering in all the cells similarly.

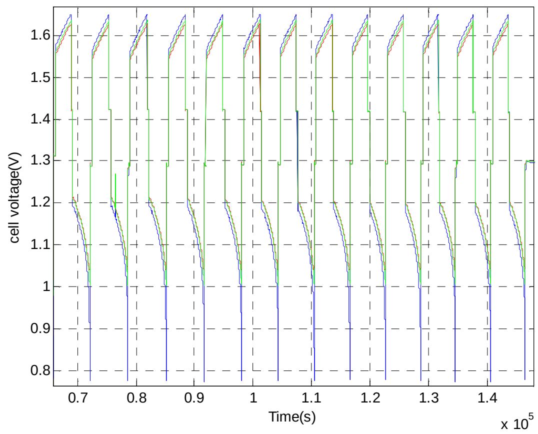

Fig. 8: cycles with three cell stack, measuring each cell separately

Fig 9 Manufacturing of power cabinet with 6 stacks

4. DEPLOYMENT

EDP Spain has carried out a study to find the best location in its grid to perform the tests of the system according to the battery size and other constraints. The selected location was near a HV/LV substation called Pumarin in Gijón (northwest Spain) and connected to the LV grid through a small MV/LV substation in order to feed a building of EDPs offices.

Fig 10. .Location of Redox2015 battery

In order to have a better understanding of the behaviour of the battery, a self-contained solution was discarded. Using an old building out of service and fully dedicated for the battery was considered a better solution. The battery building had been used for HV/LV transformers maintenance but it was no longer used for this purpose.

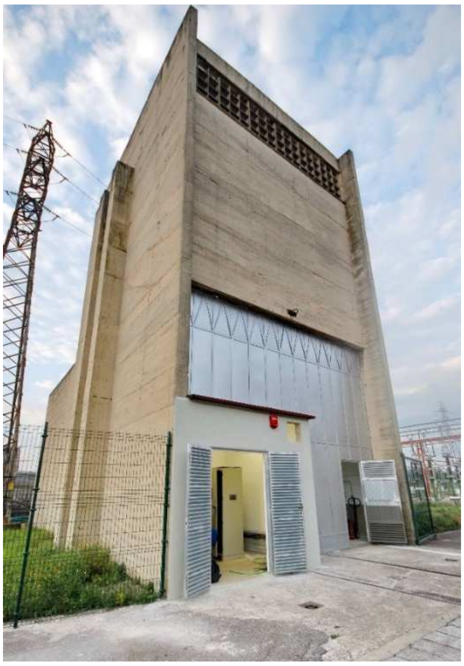

Fig 11. Building devoted for transformers maintenance and used now as battery building.

The REDOX2015 battery, with a 30 kW rated power, is composed of two power cabinets holding two sets of stacks and two electrolyte tanks holding 2.000 l of electrolyte with a 3.000 l capacity each one.

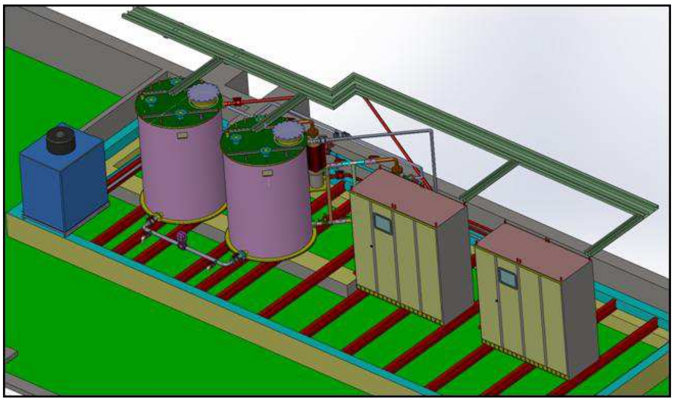

Fig 12. Battery layout: tanks and cabinets holding stacks.

Although H_2 generation likelihood was very low for this technology, this risk was even more reduced thanks to the building dimensions that guaranteed a large volume of air.

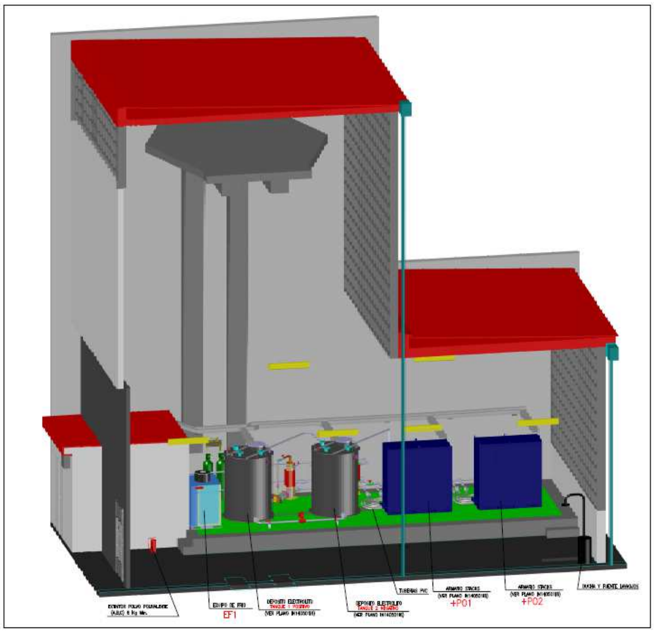

Fig 13. View of the battery building. The volume of the building reduces H_2 generation risks.

Fig 14 View of the two 3.000 l tanks for electrolyte.

In order to prevent any possibility of electrolyte leakage, a specially reinforced tray was built. The tray has been dimensioned to hold the total amount of electrolyte for the two tanks and epoxy painting was used to avoid any potential leakage.

Fig 15 View of the tray structure specifically built before deployment of equipment.

In the commissioning phase, some problems came up regarding electrolyte precipitation. This was caused by low temperatures during the stocking of electrolyte before commissioning. This made advisable to replace the electrolyte for a new one during 2015.

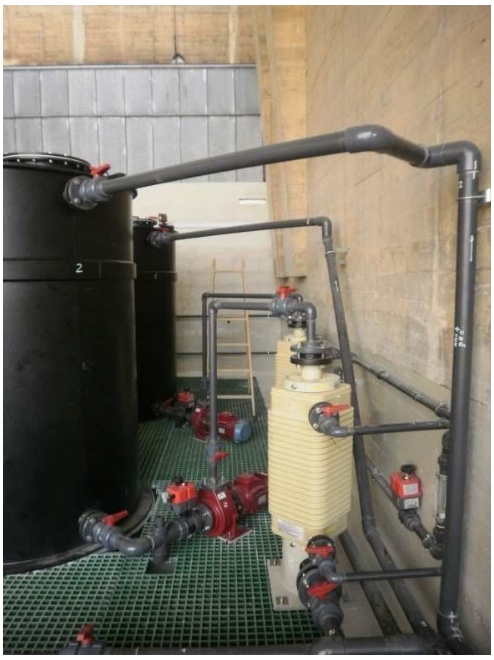

Fig 16.Detail of piping for the electrolyte circuit

5. FURTHER STEPS

In order to increase the rated power of the battery, TEKINER carried out research with the outcome of a second version of improved stacks with a rated power improvement between 15% and 20%. This second generation stacks replaced the first one during first half of 2015.

After the replacement of electrolyte and with the improved stacks, the battery will be commissioned again in order to carry out the experimental tests of the charge/discharge modeling conducted during the project.

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