SIMULATION AND OPTIMIZATION OF A FLOW BATTERY IN AN AREA REGULATION APPLICATION

James A. Mellentine and Robert F. Savinell

Case Western Reserve University, Department of Chemical Engineering, Cleveland, OH, USA

Flow batteries have the potential to provide a variety of grid storage services. A recent report by Sandia National Laboratories presents value propositions for energy storage in 17 distinct grid service applications, two of which are further sub-divided [1]. Flow batteries have the potential to fulfill the requirements of many of these applications. However, there is a range of flow battery types from fully decoupled power-energy capacity characteristic of redox flow batteries to hybrid flow batteries with limited decoupling of power-energy capacity. This paper focuses on the potential of flow batteries to provide area regulation ancillary grid services. Area regulation matches grid capacity with consumer demand in real time. To maintain grid voltage and frequency values within preset limits, the power capacity of the grid must be closely matched to the actual grid demand at any given time.

In this analysis we consider a hypothetical 2-megawatt (MW) generic flow battery that is simulated in an area regulation application to find the optimal energy-to-power ratio that maximizes the net present value (NPV) of a 10-year project based on a range of installation costs [2]. Using real market data obtained from the California Independent Service Operator (CAISO) [3] (e.g., see Figure 1), an optimal energy-to-power ratio for a range of battery costs is determined to maximize the NPV of this hypothetical battery installation using risk analysis software [4]. See Figure 2 for a schematic of the algorithm used for the simulation and Table 1 for a summary of simulation results. A simplified model of battery installation costs (dollars per kilowatt hour [kWh]) resulted in a positive NPV for installation costs below \$400 kWh^{-1}. For installation costs between \$250 kWh^{-1} and \$400 kWh^{-1}, an optimal energy-to-power ratio is 1.73. The traditional advantage of decoupling power and energy capacity may not be realized in area regulation; therefore, hybrid or other low-cost flow battery chemistries such as iron-chromium or even lower-cost new developments may be more appropriate for area regulation in the future.

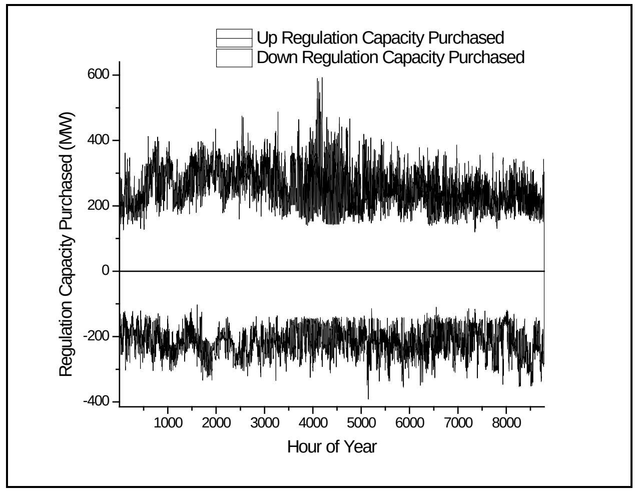

Fig. 1. The amount of up and down regulation capacity purchased by CAISO for every hour of 2008. Positive numbers represent up regulation purchases and negative numbers represent down regulation purchases [2].

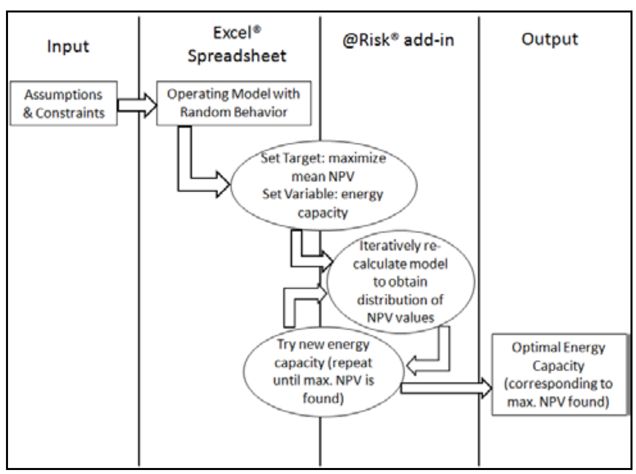

Fig. 2. Graphic representation of the simulation and optimization process used to find the optimal energy-to-power ratio of a flow battery performing an area regulation application.

Table 1. A Summary of Simulation Results.

Installation Cost (kWh^{-1})	Optimal E/P Ratio	Mean NPV	Mean IRR	Average SOC
$150	2.52	$766,900	70%	45%
$200	1.93	$586,800	55%	47%
$250	1.74	$437,100	40%	48%
$300	1.74	$300,800	27%	48%
$350	1.73	$160,500	18%	48%
$400	1.73	$19,700	11%	48%

REFERENCES

[1] J. Eyer and G. Corey, *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*, Sandia National Laboratories: Albuquerque, New Mexico, 2010.

[2] This abstract represents a paper presented at the Electrochemical Society Meeting held in Boston, Massachusetts, the week of October 9, 2011. The details of this analysis is the subject of a manuscript accepted for publication and in press of the *J. Applied Electrochemistry*.

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[4] Palisade, 2010. @Risk risk analysis software, v5.7. Available via http://www.palisade.com/risk/. Cited January 16, 2011.

BIOGRAPHICAL NOTE

Conference presenter: Robert F. Savinell is the George S. Dively Professor of Engineering at Case Western Reserve University (CWRU). He has been engaged in electrochemical engineering research and development for over 35 years with a focus on the understanding of fundamentals and mechanisms of electrochemical systems and devices, and their design, development, and optimization. Dr. Savinell has over 100 publications and seven patents in the electrochemical field. He earned his Ph.D. in Chemical Engineering at the University of Pittsburgh, worked for the Diamond Shamrock Corporation, and taught at the University of Akron before joining CWRU in 1986. He was appointed Dean of the Case School of Engineering in 2001. In 2007 he took a one-.year sabbatical at the Massachusetts Institute of Technology as a Visiting Professor, then returned to the CWRU faculty to pursue full-time his teaching and research interests. He is a former Director of the Yeager Center for Electrochemical Sciences, a former associate editor of the Journal of the Electrochemical Society, and a former North American editor of the Journal of Applied Electrochemistry. He is an elected Fellow of the Electrochemical Society and a Fellow of the American Institute of Chemical Engineers.