STATCOM With Energy Storage To Smooth Out Intermittent Power Output Of Wind Farms[1]

Mesut Baran (SPEC, NC State University – Raleigh, NC, USA), baran@ncsu.edu; Sercan Teleke, Alex Huang, Subhashish Bhattacharya (NCSU); Loren Anderson (Bonneville Power Administration); Stanley Atcitty (Sandia National Laboratories);[2] Imre Gyuk **(**DOE**)**

In recent years, due to technology innovation and cost reduction, wind energy has shown a rapid growth as a clean and renewable energy source around the world. However, integration of large wind farms, especially into weak power systems, poses serious challenges [1,2]. The main challenge arises due to the dependency of power output to changing wind conditions; i.e., the intermittent real power output of the wind farm. The second challenge is voltage fluctuations caused by the intermittent power output and, thus, the reactive power compensation needed to suppress these voltage fluctuations.

The system considered in this study is a 69 kV subtransmission loop with two wind farms. The farms have total ratings of 50 and 100 MVA, and the subtransmision loop serves mostly rural loads. The focus of this study has been on the 50 MW wind farm, which is in the middle of the weak subtransmission loop. The wind farm's intermittent power output and its reactive power demand impact the system operation considerablyt.

The STATic synchronous COMpensator (STATCOM) with Battery Energy Storage Systems (BESS) is a promising technology for facilitating the integration of large wind farms because that combination can provide both rapid reactive power support and smooth power fluctuations [2,3]. Hence, this system has the potential to make a wind farm dispatchable, like other conventional, generation plants.

In this paper, the basic feasibility and design of STATCOM with BESS is explored for the actual system considered, and the effectiveness of this system in smoothing the power output of the wind farms is illustrated. In addition, various sizes of storage options are simulated in PSCAD/EMTDC in order to obtain energy storage size vs. smoothing performance.

The STATCOM system considered is a cascaded, multilevel converter (CMC) [4] with a BESS connected in parallel to the DC bus, as Fig. 2 illustrates. The STATCOM is connected to the same system bus as the wind farm. For this study, a harmonics-free dynamic model of the STATCOM [4] with a battery equivalent circuit, shown in Fig. 3 [6,7], is implemented in PSCAD/EMTDC [9].

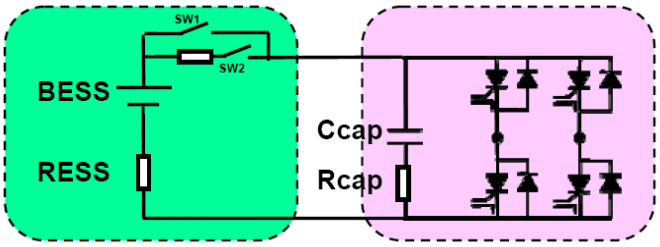

Figure 1: Interconnection of the BESS and ETO Light Converter.

[1] Funded in part by the Energy Storage Systems Program of the U.S. Department Of Energy (DOE/ESS) through Sandia National Laboratories (SNL)

[2] Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security.

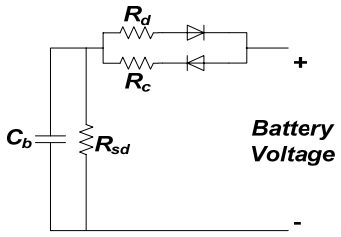

Figure 2: Equivalent Circuit Model for the BESS

The basic control strategy adopted for the STATCOM is the vector control technique, because it provides fast control of the d-axis and q-axis currents, i_d and i_q [4,5]. These currents, in turn, primarily determine the real and reactive power output of the STATCOM as

$$P_o = \frac{3}{2} U_d i_d \; ; \; Q_o = \frac{3}{2} U_d i_q$$

provided that U_d is aligned with the terminal voltage. An outer control loop has been added to determine the set points for the currents i_d and i_q based on the measured real and reactive power feedback. Note that the BESS is charged/discharged by controlling the real power output (P_o) of the STATCOM. Figure 3 shows the power output change of the STATCOM-BESS for a step change in i_d. As the figure indicates, the system has quite fast response time, about 5 msec.

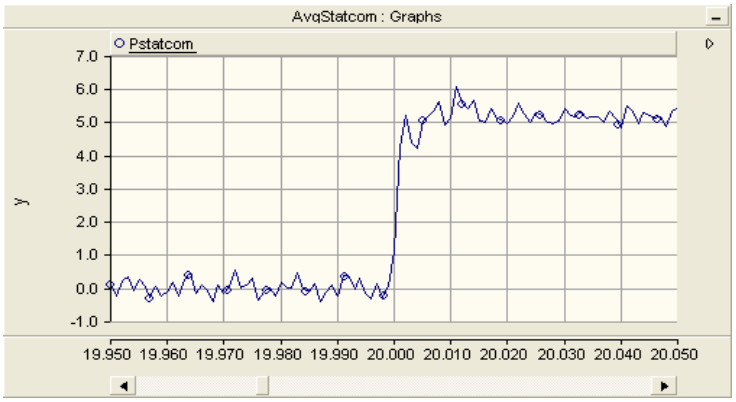

Figure 3: STATCOM-BESS response to a change in Id reference (y is power in MW, x is time in sec.)

Hence, we used this decoupled control scheme to smooth the power output of a wind farm. The amount of smoothing that the system can provide, however, depends on the power and energy capacity of the BESS. In this study, we considered smoothing short duration variations (within 10 min) and simulations were conducted to determine the proper BESS size needed for this smoothing option.

For the study, we had two-second wind farm power output data. Fig. 4 shows a sample of the power fluctuations from this data during a wind pick-up period. As the figure indicates, the power output of the wind farm fluctuates even at this time scale. Because the fluctuations are rather small, compared to the size/rating of the wind farm, using a BESS to smooth the fluctuations in the short-term is a feasible alternative.

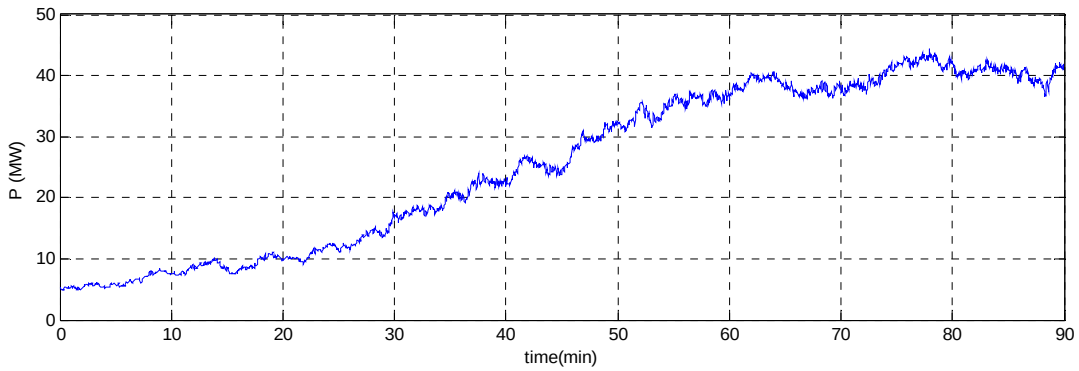

Figure4: Wind farm power *P* during a wind pickup period

In order for the STATCOM-BESS to provide smoothing, we needed to provide a reference signal to the outer power loop controller. A good choice for short term smoothing is to use a washout filter [2,8]. Another important constraint that we needed to consider was the state of charge (SOC) of the BESS. Hence, the controller adopted (as shown in Fig. 5) uses the SOC as the feedback signal, as proposed by *Yoshimoto, et al* [8].

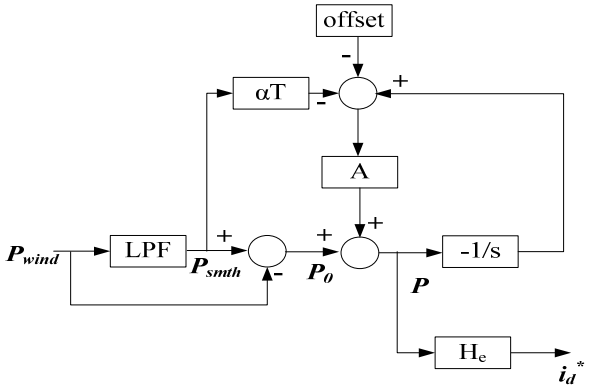

Figure 5: Control scheme for STATCOM with BESS using SOC feedback

By using this scheme, simulations have been performed using PSCAD/EMTDC. Because it is difficult to determine the size of the BESS needed for this scheme *a priori*, three different BESS sizes have been tried: 5, 10, and 15 MWh. Figure 6 shows the smoothed wind farm output with these three BESS sizes. As expected, the smoothing improves with the increased BESS size. From these results, it seems that the smoothing with 5 MWh BESS is not effective, the 10 MWh BESS provides acceptable smoothing and, because the difference between the 15 and 10 MWh BESS smoothing is not significant, the proper size for the BESS is 10 MWh.

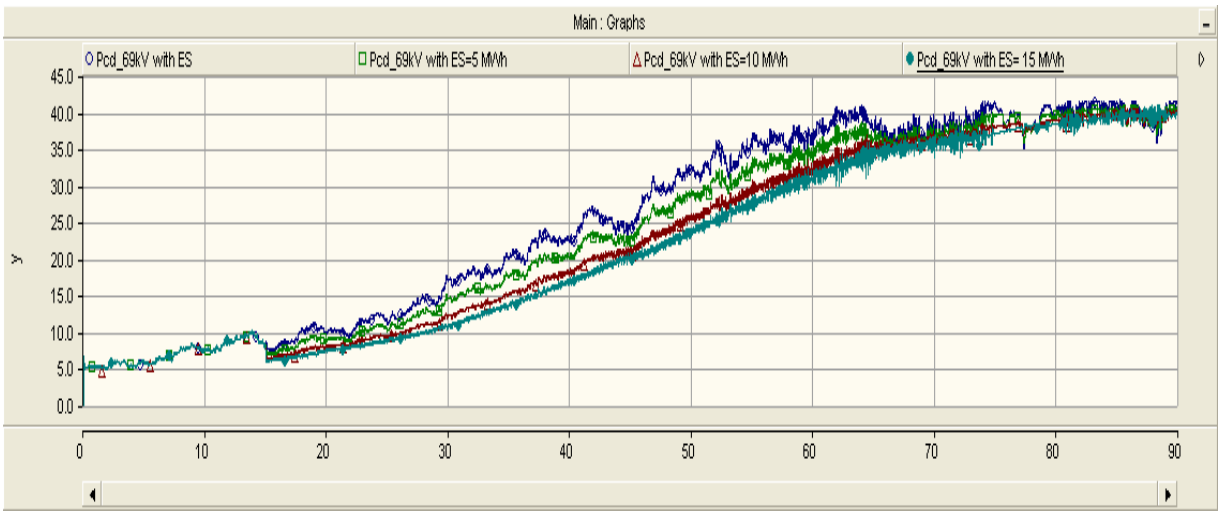

Figure 5: Smoothing provided by the washout filter based STATCOM-BESS with three different sizes (blue: wind farm output, green: 5 MWh, red: 10 MWh, mag.: 15 MWh BESS)

References

[1] BPA Report, "Renewable Energy Technology Roadmap (Wind, Ocean Wave, In-Stream Tidal & Solar Photovoltaic)", 2006.

[2] C. Han, A.Q. Huang, W. Litzenberger, L. Anderson, A.-A. Edris, M. Baran, S. Bhattacharya, A. Johnson, "STATCOM Impact Study on the Integration of a Large Wind Farm into a Weak Loop Power System," IEEE PES, pp. 1266 – 1272, Oct. 29-Nov. 1 2006.

[3] C. Han, Z. Yang, B. Chen, W. Song, A. Q. Huang, A. Edris, M. Ingram, S. Atcitty, "System integration and demonstration of a 4.5 MVA STATCOM based on emitter turn-off (ETO) thyristor and cascade multilevel converter ", in Proc. IEEE-IECON, pp.1329-1334, Nov 2005.

[4] S. Sirisukprasert, A. Q. Huang, J. S. Lai "Modeling, analysis and control of cascaded-multilevel converter-based STATCOM," IEEE PES general meeting, vol. 4, pp. 2561 - 2568, July 2003.

[5] C. Schauder, H. Mehta, "Vector analysis and control of advanced static VAR compensators," IEE Proceedings of Generation, Transmission and Distribution, Volume 140, Issue 4, pp. 299 – 306, July 1993.

[6] Electricity Storage Association
http://electricitystorage.org/tech/technologies_comparisons.htm

[7] Z.M. Salameh, M.A. Casacca, W.A. Lynch, "A mathematical model for lead-acid batteries," IEEE Transactions on Energy Conversion, Volume 7, Issue 1, pp. 93 – 98, March 1992.

[8] K.Yoshimoto, T.Nanahara, G.Koshimizu, "New Control Method for Regulating State-of- Charge of a Battery in Hybrid Wind Power/Battery Energy Storage System," IEEE PES, pp. 1244 – 1251, Oct. 29-Nov. 1 2006.

[9] PSCAD/EMTDC, *Power Systems Computer Aided Design*, Manitoba HVDC Research Centre, Manitoba CA; http://pscad.com.