INTEGRATING INTERMITTENT WIND POWER ON DISTRIBUTION NETWORKS USING DYNAMIC REACTIVE POWER AND ENERGY STORAGE

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ABSTRACT

The role and application of energy storage and dynamic reactive power support for integrating wind power plants on distribution feeders are discussed in this paper. A well-engineered energy storage plant can help alleviate some of the problems encountered with the integration of intermittent wind resources and at the same time make the wind power plants more cost effective and dispatchable in existing distribution system.

The intent of this paper is to demonstrate these features by means of a planned application of a D-STATCOM and Battery Energy Storage System (BESS) in a region with high penetration levels of wind. Firstly, the paper describes the integration challenges of integrating intermittent wind power, followed by possible mitigation measures. Thirdly, a specific application of a D-STATCOM with a BESS is included, the different possible revenue streams are calculated, and a plan to measure the field performance of the device is described.

INTRODUCTION

USA utilities are confronted with high Renewable Portfolio Standards (RPS) proposed by the different states. RPS levels, based on renewable energy production of 15 – 30% are required in most USA states by 2020. There is a trend to interconnect large utility scale wind projects as distributed renewable energy resources (DRER) on the distribution network to meet these standards. However, similar to other renewable energy sources, wind energy tends to be unsteady because they are influenced by natural and meteorological conditions [1]. Moreover, high penetration of intermittent renewable resources can introduce technical challenges including grid interconnection, power quality, reliability, protection, generation dispatch, and control [2]. Therefore, the industry will need to confront the challenges associated with higher levels of penetration [3].

As an example, the power output from a 60 MW wind farm is monitored over several months and some of the individual days are presented in the Figure 1. This wind farm is curtailed typically on a daily basis when local load is too low during the night time, or a contingency exist. The wind farm is also not dispatchable and lacks voltage ride-through capability.

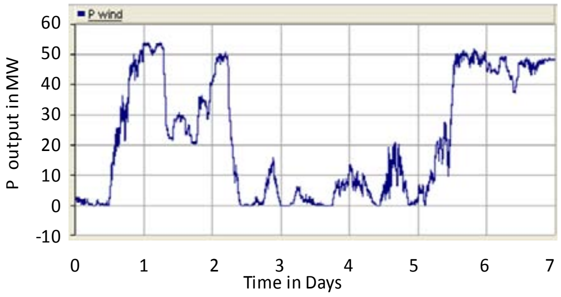


Figure 1: Wind farm generation profiles during seven days.

The next section will describe the integration challenges of integrating intermittent wind power, followed by a specific application of a D-STATCOM with a BESS. Finally, the result of economic analysis for D-STATCOM with a BESS is presented.

CHARACTERIZATION OF WIND ENERGY INTEGRATION PROBLEMS

This section includes a general description of the integration issues of wind at high penetration levels. Typical distribution system related problems include [4], [5]:

- Capacity factors in the range of 25 – 40 %
- No wind farm dispatch capability
- Minimum reactive power support capability, especially in areas with older Type 1 and Type 2 wind turbines.
- Absorb reactive power from system
- No Low-Voltage-Ride-Through (LVRT) capability
- Non-compliant with FERC – Large Generator Interconnection Procedure (LGIP)
- Common wind farm curtailments
- N-1 contingencies are sometimes resulting in wind curtailment
- Voltage collapse may occur due to long remote lines during line trips
- Lack of coordination control of existing reactive power support

APPLICATION OF D-STATCOM WITH ENERGY STORAGE

One of the most promising solutions to mitigate these integration issues is by implementing a hybrid fast-acting energy storage and D-STATCOM solution [6],[7]. Several fast energy solutions are currently available on the market, including NaS, Li-Ion, VRB, etc. battery technologies and flywheels [7],[8],[9]. For mitigating the mentioned wind integration problems, the energy storage device needs to be fast acting and to have a storage capability of typical of 15 min – 4 hours and a D-STATCOM that is larger than the battery power requirements to have adequate dynamic reactive power capabilities. Figure 2 shows a D-STATCOM – BESS application for mitigating the wind farm related integration issues [5].

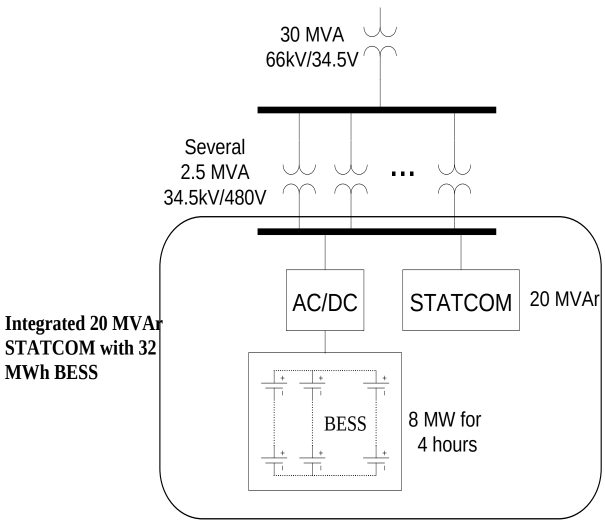


Figure 2: Basic Schematic of the D-STATCOM – BESS [5].

From Figure 2, the main technical characteristics are summarized below:

1. 8 MW/4hr Battery.

The charge/discharge profile for battery operation is weekday-only and the battery shall have an operational life of at least 10 years without capacity reduction. The battery should have a 20 year lifetime at a reduced capacity.

2. 20 MVAr D-STATCOM.

The D-STATCOM ratings in MVAr are dynamic, or short term overload ratings and shall last at least 4 seconds.

3. Control and HMI (Human Machine Interface) of D-STATCOM-BESS system. The BESS (with its AC/DC interface) can operate independently of the D-STATCOM.

4. Inverters

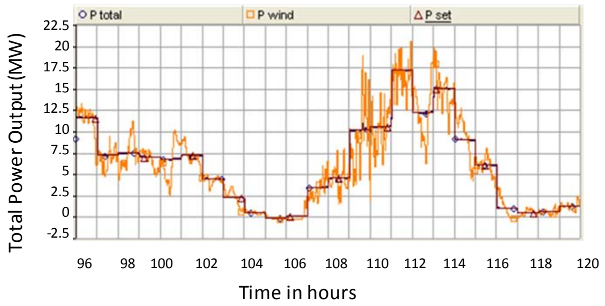
One or more inverters are used to build up the complete BESS and D-STATCOM system as long as the ratings are within the MVA requirements.

The control algorithm for the BESS system includes: 1) hourly dispatch of real power output; and 2) contingency support [5]. For the first control algorithm, the hourly dispatch at the individual wind farm, the battery can contribute to minimize the wind power variations and can control the wind farm power output within a pre-defined range. For the second control algorithm, or contingency support, the battery can contribute to absorb energy (up to 8 MW during four hours maximum) in order to minimize wind farm curtailments during times in which a transmission line is out of service.

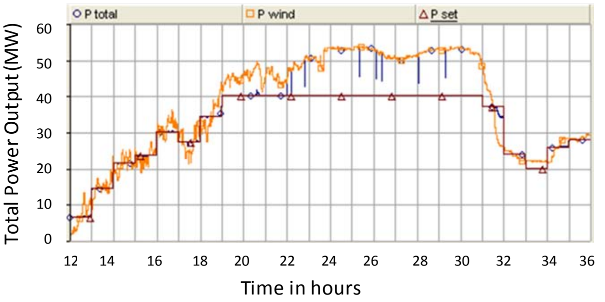
The BESS controls are set so that the battery modes of operation are as follows [5]:

- Battery regulates, based on hourly dispatch profile, when the wind farm maximum power output (Pmax) is less than 80% or other user defined value.
- When wind power output is more than 80%, the battery discharges at State of Charge (SOC) of 30% in preparation for a potential contingency. No hourly dispatch is done during the time Pmax is at 80% or more.
- If a contingency occurs, the battery absorbs energy to minimize wind farm curtailments and avoid transient instability during the time following the contingency on the system.
- If the contingency is fixed before the battery SOC is at 100% and Pmax is less than 80%, of the battery rating, it goes back to hourly dispatch.
- If the contingency is not fixed and the battery gets to 100% SOC, wind curtailments take place.

One of the wind integration mitigation applications of the hybrid D-STATCOM and BESS is to provide 1 hour dispatch of a local wind farm. Assuming that the average wind power output for the next hour can be forecasted with a 10% mean absolute error of the individual wind farm (50-52 MW peak power) [10], the BESS will compensate the differences between the hourly dispatch level through Pset, which comes from the forecast, and the wind farm power output, Pwind. The power at the battery, Pbess, can be expressed as Pbess=Pset-Pwind. The results of dispatching the wind farm are shown in Figure 3 (a) for low wind generation and Figure 3 (b) for high wind generation study cases.



(a)



(b)

Figure 3: Dispatching of wind farm power with BESS; Pset: desired set point, Pwind: wind power, Ptotal: net injected power (Pwind + Pbess, in MW) (a) During low wind generation (b) During high wind generation.

It is seen from Figure 3 (a) that the system can dispatch the wind power with the help of the BESS during low wind generation. From Figure 3 (b) the BESS can also help to absorb the excess generation when wind power is high as long as the SOC of the BESS is within its limits.

The other applications of D-STATCOM-BESS include:

- Contingency support in terms of MW and MVAr. The D-STATCOM-BESS system prevents the system from collapsing for the critical contingencies.
- Voltage regulation support. With the D-STATCOM-BESS system the voltage recovery is improved with about 10-15%.
- Improved fault ride-through (LVRT) support is provided on mostly Type 1 wind farms.
- Regulation ancillary services are provided
- Large transmission upgrades to the wind facility can be postponed for several years.
- Curtailments of the wind farm are minimized for up to 4 hours

These applications are discussed in more detail in reference [5].

D-STATCOM-BESS CASE STUDY

The D-STATCOM-BESS applications for ROI calculation can be summarized as follows:

- Electric energy time shift
- Load following
- Frequency regulation
- Reserve capacity
- Congestion relief
- Avoided cost for delay in line upgrade
- Electric service reliability
- Wind capacity firming
- Wind generation grid integration
- Voltage Support
- Decreased Transmission Losses
- Power Quality

Adding all the yearly avoided costs for the value streams mentioned above with respect to a possible $30 M investment in a hybrid D-STATCOM - BESS application, a return on investment (ROI) of about 10% is obtained.

FIELD INSTALLATION

As a result of a series of analysis performed by the authors of this paper in conjunction with a USA based utility, the field installation of a D-STATCOM - BESS system similar to the one described in this paper is underway. This demonstration project is co-sponsored by the US Department of Energy, a large US Utility and a battery manufacturer. An implementation plan to evaluate the performance of such a utility scale lithium-ion battery technology in improving grid performance and integrating more wind generation has been proposed. The plan is to work during a three year period to measure and monitor the performance of the D-STATCOM and BESS system that includes: 1) the development of the energy storage device specification, commissioning and integration; 2) the development of key performance indicators (KPIs), develop a measurement and verification plan for the energy storage device; and 3) monitoring of the energy storage device performance during the measurement and verification phase.

The energy storage device specification includes detailed technical characteristics for the energy storage system (ESS), the power conversion system (PCS) dynamic reactive power support device, communication, control and HMI (Human Machine Interface) of the system and inverters. The key performance indicators include frequency and history of operation based on identified tasks, type of events and amount of energy stored during specific time periods. These indicators are to be monitored and are expected to capture the device benefits from three main fronts: 1) transmission/distribution use (voltage support, load shed deferral, among others); 2) system use (capacity/resource adequacy, shift generation output, among others); and 3) ISO Market use (frequency regulation, spin/non-spin replacement reserves, among others). The monitoring of the energy storage device performance during the measurement and verification phase will last three years.

CONCLUSIONS

This paper has presented the mitigation options and associated value of utilizing dynamic reactive power support and fast acting energy storage to help alleviate some of the problems encountered with integrating intermittent wind on transmission systems, especially in regions with high penetration levels. The paper has characterized a number of integration issues where there is abundant wind generation. The benefits of the application of a hybrid 8 MW/4 hours Battery Energy Storage System (BESS) and 20 MVAr D-STATCOM to address the problems at a wind power generation rich area are presented. For this application, the ROI is calculated for the different value streams at above 10%. A plan to evaluate the performance of the D-STATCOM – BESS system in improving grid performance and integrating wind generation has been described.

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