Grid Connection of Renewable Energy

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Abstract—The paper will consider various techniques that have been used to help renewable generation connect to the grid. The first is the use of STATCOM technology for the supply of voltage and power factor control by supplying fast var’s to meet the reactive requirements of the grid code and also to support installations which are connecting to a weak grid. The second part will consider the role that energy storage has to reduce local intermittency and to participate more profitably in the local supply and ancillary service market.

I. INTRODUCTION

To meet the renewable and carbon reduction targets set by governments around the world technology changes have been required. S&C Electric has been actively involved in multiple projects around the world that allows grid connection of intermittent renewable sources to grids. This paper also draws on examples of other companies S&C have worked with.

A. Grid Code

There are many different grid codes in operation around the world and these vary depending on the requirements of the local grid operators and the condition of the grid that they are connected to. Modern wind turbine generators (WTGs) have capabilities to dynamically control the power factor or voltage at the terminals of the generators. Grid codes typically require wind power plants to be able to vary their power factor to meet system operating conditions and not all turbines are capable of this. In this case the use of voltage source inverter technologies using pulse width modulation techniques to synthesize a voltage either greater than or less than the bus where the inverters (DSTATCOM) are connected, are now widely used in wind power plants for power factor or voltage control. Most recent developments are that WTG act as the “master” and the additional requirements are provided by the DSTATCOM operating in a “slave” mode.

Due to economics normally one of the most cost effective solutions is the use of a substation based hybrid reactive power compensator solution which can be used to dynamically control the power factor at the Point Of Connection (POC) with response times dictated by intentional delays associated with the switching of Switched Shunt Devices (SSD). Through local collector bus voltage and current sensing and “slow” feedback of voltage and current at the POC through SCADA, the DSTATCOM can dynamically control the power factor at a remote POC using a line drop compensation algorithm. Figure 1 shows the actual measurements associated with a hybrid reactive power compensator for a 90 MW wind power plant where the POC is at 345 kV, 37 km away from the collector substation. In this case the compensator is controlling the power factor at the POC at unity (i.e., zero net Mvar at the POC).

Fig 1 – Measurements of a wind farm

A hybrid reactive power compensator offers several advantages relative to additional switched power factor correction capacitors applied at the WTG low voltage terminals:

- The power factor of the wind power plant can be dynamically controlled without changing the power factor set points of individual WTGs, increasing the overall speed of response.
- The power factor at the WTG terminals can be independently controlled at or near unity power factor, thereby minimizing reactive current flow through the WTG step-up transformers and the collector system. This effectively reduces active and reactive power losses in the wind power plant.
- A wind farm management system is not required to control reactive power in the wind power plant.
- The available reactive power from the compensator can be utilized at all power output levels of the wind power plant, compensating for collector cable charging (capacitive)
reactive power at zero and low power output levels or providing reactive power.

Compared to using only mechanically-switched capacitor banks in the collector substation, the hybrid reactive power compensator offers the following advantages:

- The power factor at the POC can be controlled more precisely over the entire output range of the wind power plant.
- The number of switching events of capacitor banks is reduced due to the dynamic reactive power range of the inverters, thereby increasing the life of the capacitor bank switching devices.
- The dynamic compensator control algorithm distributes the number of switching operations of any single capacitor bank based on historical number of switching operations, resulting in more even wear on capacitor switching devices and prolonged life in multiple capacitor bank applications.
- The severity of the capacitor-switching transients associated with the energisation of the capacitor banks can be reduced slightly by the inverter control action.

As in any situation where shunt capacitor banks are applied, the application review of the hybrid reactive power compensator must include a review of potential harmonic resonance conditions this is particularly relevant where the wind farm is connected to a grid with a low available short circuit level. The review will typically include detailed harmonic resonance analysis, including impedance frequency scans for various operating conditions of the wind power plant and harmonic distortion analysis based on representative “ambient” harmonic levels (i.e. harmonics present in the system without the wind power plant) or harmonic currents injected by WTGs. In cases where WTGs with power factor correction capacitors are involved, careful attention must also be paid to any potential resonance conditions caused by the WTG capacitors. In cases where resonance conditions with high local impedances at characteristic harmonic frequencies (i.e. 5\text{th}, 7\text{th}, 11\text{th}, 13\text{th}, etc. harmonics) are identified, capacitor banks in the hybrid reactive compensation system can be converted to harmonic filter banks. In wind power plants using WTGs with power factor correction capacitors where resonance conditions are caused by the WTG capacitors, a damped C-type filter is commonly used to lower the local impedance of the wind power plant over a wide range of frequencies. In wind power plants utilizing WTGs with doubly-fed induction generators (DFIG) or full-converter WTGs with appreciable levels of harmonic current injection, it is sometimes necessary to apply a high-pass filter to prevent some of the harmonic currents from flowing into the system and causing high levels of harmonic voltage and current distortion. If a hybrid compensator is applied in this situation, one or more of the capacitor banks can be converted to high-pass filters to address this issue.

The short term capability of 264\% of the DSTATCOM means that it can compensate for the longer response times for reactive power command, of some turbine manufacturers. This has the ability to reduce the size of the system solution as the turbine capabilities can then utilised to ensure the most economic solution by the WTG acting as a “master” and the DSTATCOM as a “slave”. In addition, it is possible to use the short term rating capability to supplement any shortfall in the turbine LVRT capability.

As the penetration of wind increases there has been a trend in the UK to connect to networks where there is a low available fault level which means that voltage fluctuations are higher between maximum generation and no generation. Even full converter WTG has problems with this and a substation based solution will keep voltage within statutory limits. Figure 2 illustrates the use of a single DSTATCOM to provide voltage control for a single 850kW turbine.

**Fig 2 – Voltage control performance on a weak grid**

![Voltage control performance on a weak grid](image)

### B. The Electronic Shock Absorber

The Electronic Shock Absorber (ESA) is basically the DSTATCOM with energy storage added. This allows wind farms to control real power outputs and ramp rates. The ESA was developed in conjunction with the Hawaiian Electric Company (HECO) as a demonstration unit and is used with very early models of wind generators that have limited basic control functions. The problem that HECO faced is that due to the large penetration of wind on an island system, the variations in wind speed caused both voltage regulations problems and frequency variations. The ESA has demonstrated the ability to modify the net output of the wind farm/ESA into the utility system to meet all the local requirements. The following graphs show the ESA performance against performance parameters set by HECO as part of local Power Purchase Agreements.

The ESA power graph shows the performance of the ESA as it compensates for the variations in each of the three parameters which it is monitoring. For this sample, the average power does not go outside of its limits so the ESA does not need to react to compensate. The Ramp Rate reaches its lower limit and the ESA compensates for this by injecting energy into the system. This is most noticeable around the 70 second area. The
instantaneous power hits its upper limit at 90 seconds and the ESA absorbed energy at that point.

**Fig 3 – Performance of the ESA.**

It should be noted that the ESA, whilst performing these functions, can also provide voltage and/or power factor control plus it can assist with LVRT requirements.

**C. Utility Scale Energy Storage.**

As more Distributed Generation (DG) schemes are introduced closer to the load, there is a desire to provide energy when needed. Typically, a 100MW wind farm will only average 30 to 40MW, resulting in a network utilization of up to 40%.

The other area where renewable energy suffers is the lack of ability to dispatch it when it is needed. The Economic Research Council [1] argues that often wind is generated at night when demand is low, and does not have a mechanism to balance or store the energy to meet demand when needed, so the energy tends to be lost. The UK Department of Trade and Industry (DTI) [2] stated that 6-10 hours of energy storage can increase the dispatch reliability up to 95%, and that depending on the power purchase agreement, could increase revenue between 2 to 35%, or more. Additional work in the UK has shown that 1MW of energy storage could be used to remove 3MW of transmission and distribution capacity constraint.

S&C has the ability to integrate multiple energy storage technologies but due to commercial reasons the largest number of projects has been with NGK’s NaS technology. The NaS battery based long term energy storage offered by S&C uses the DSTATCOM as the Power Conditioning System. This means that the DSTATCOM can provide the voltage and power factor control plus assisting LVRT, with the added benefit of controlling the power fed into the utility system versus the power fed into charging or discharge the energy storage. The following discusses some of these in relation to the S&C demonstration unit in American Electric Power (AEP) Charleston, West Virginia and other NGK NaS applications.

The first system installed at AEP has the ability to provide 7 MWh of storage. This storage helps in a number of ways and has been discussed by the DTI [3]. The most obvious is the ability to provide the storage to meet demands. The system is charged at night and is used during the daytime near peak hours to shave the peak demand. It could also be used to improve the dispatch reliability if it was connected and charged by a renewable energy source. One of the attractions for AEP was the deferment of asset upgrades. With T&D congestion and the ability to obtain upgrades for transmission assets means that this has significant benefits for the renewable industry. The modularity of the units means that they can be relocated at various points in the system where it is needed. Several other systems are now connected and they include projects connected to renewable sources.

**Fig 4 – Charge / discharge cycles.**

Japan Wind Development [4] has installed a project that uses 34MW of NaS energy storage for a 51 MW wind farm. The use of such a large amount of energy storage in this instance allows for a much higher level of energy trading and also allows significant peak shaving, the economics of which are driven by storing energy at night and selling at peak times when the rate per kWh is better.

The recently published report by Xcel Energy [5] covering the use of NaS batteries in wind applications concludes that energy storage not only has the ability to move peaks but can
also provide economic dispatch, frequency control, wind leveling and smoothing.

NGK has also demonstrated NaS technology for load smoothing at TEPCO Demonstration at Hachijo-Jima Island. Here the NAS battery is used in a constant state of charge and discharge to provide a smooth output from the wind farm.

In conclusion, with multiple installations now operating around the world then the technology is now proven and can be delivered on a commercial scale to help Europe achieve both their 2020 Renewable targets and their 2050 carbon reduction targets.

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III. REFERENCES


IV. BIOGRAPHIES

Andrew Jones was born in Wales in the UK in 1963. He completed his mechanical engineering studies at Swansea and his MBA at Sheffield, UK. He is a member of the UK IET.

His employment experience included the Alcan, CCL Systems and Mosdorfer before his current employment at S&C Electric, where he is currently Managing Director of their European operation.