Wind Parks as Power Plants

By Steven W. Saylors, P.E.

The North American experience in wind park construction tends to large installations, with numerous turbines aggregated in tens, to hundreds, of megawatts. This approach differs significantly from the European experience, where small clusters of only several turbines are more uniformly dispersed over the landscape. The reasons are as fundamental as North America (NA) having the wide-open spaces, with its better wind regime sites being in locales that tend to be remote from its load centers.

The consequence of integrating more wind power with other generating resources is that within the last few years the wind park has, by necessity, become regarded by power system operators as needing to meet similar, if not the exact same, operating constraints as their more conventional counterparts. Issues related to voltage and frequency regulation, real/reactive power control, improved operational condition monitoring and report generation, and the opportunity for more intimate grid operator control are challenging wind turbine manufacturers to provide innovative solutions that are revolutionizing the wind industry. The fact that the vast majority of North American installed wind turbines employ induction generators, albeit with varying fundamental control topologies, makes wind different from most other generation resources that use synchronous generators that have the ability to control turbine input energy and field excitation. Efforts to provide standardized interconnection requirements for wind's induction generators have gained momentum across the US and Canadian markets, providing turbine manufacturers benchmarks for present and future designs.

History of Interconnection Requirements

Interconnection requirements for wind have seen a dramatic change over the last five years. Turbine development and wind park design have had to evolve to remain compliant with these changes.

Pre 2000

For the first twenty years of wind power in NA, prior to around 2000, few interconnection requirements were pressed upon the industry because wind did not represent a significant contribution to the overall generation mix. Other resources providing power to the transmission grid could sufficiently provide for aspects such as voltage regulation and frequency control. The system operators only asked that the reactive power draw of the wind turbine's induction generator be compensated (with switched capacitors at the turbine or wind park substation) to prevent excessive voltage drop and line loss.

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Since 2000

With the recent exponential increase in MW from wind, due to larger turbines, larger and more numerous wind parks, and the potential for a sustained growth in the market it has been demanded by system operators that the manner in which wind parks interact with the rest of the transmission system become more sophisticated. Standards specifying Low Voltage Ride-Through, reactive power (VAR) control for voltage regulation, real power (Watt) control for frequency regulation and ramp rate control have become commonplace, with the intent that wind parks be viewed simply as just another power plant from the vantage point of the grid operator. It should be noted that these requirements are for larger parks connected to the bulk high-voltage transmission system as identified within such documents as FERC Order No. 2003-A; smaller parks or single turbines connected to utility distribution systems are not being asked to actively participate in grid control per standards such as IEEE 1547.

Evolution of turbine designs

Until the mid-nineties most turbines used simple induction generators (SIG) with fixed slip characteristics. Known as fixed speed turbines, these machines used internal or external static [*electro-mechanically switched*] compensation capacitors to improve the overall power factor (PF) of the park to the grid. The machines had rather tight voltage and frequency protection settings to protect the turbine by taking it off-line when system disturbances might jeopardize its operability. In the last ten years two other induction generator topologies have also been introduced that provide for variable slip which among other things tends to provide for smoother power output: the asynchronous generator with variable rotor resistance, and the double-fed asynchronous generator (commonly referred to as DFIG). The former employs reactive compensation capacitors, similar to the SIG to maintain a high PF; whereas, the DFIG utilizes power electronic switching in the rotor circuit to vary the magnitude and phase angle of the rotor current to control output reactive power within the design capability of the generator.

Recent interconnection requirements have mandated that the turbines now “ride-through” abnormal system events from transmission line faults, switching events, and generation/load loss. Commonly called Low-Voltage Ride-Through (LVRT) designs, these turbines must actually be capable of not disconnecting for low and high voltage excursions as well as frequency extremes. Turbine manufacturers have been challenged in the last three years to provide turbines that remain connected to the grid during and after such events to aid in grid stabilization.

Evolution of Wind Park designs

Park design has also advanced with these goals in mind. Meeting LVRT and/or reactive power control requirements often requires the combination of the turbine solutions discussed above plus park substation solutions. Since a high number of NA parks are located on electrically weak transmission systems, characterized by low Short Circuit Ratios (SCR) [*the short circuit power contribution of the grid at the Point of Interconnection (POI) in relation to the rated output power of the wind park*], dynamic power electronic devices such as SVCs and Statcoms providing smooth, step-less compensation have become increasingly incorporated in the park substation. Usually positioned on the medium-voltage collection bus, these devices supplement the turbine and other static device capabilities to fully satisfy requirements such as those posed by the Alberta Electric System Operator (AESO), shown in Figures 1 and 2.

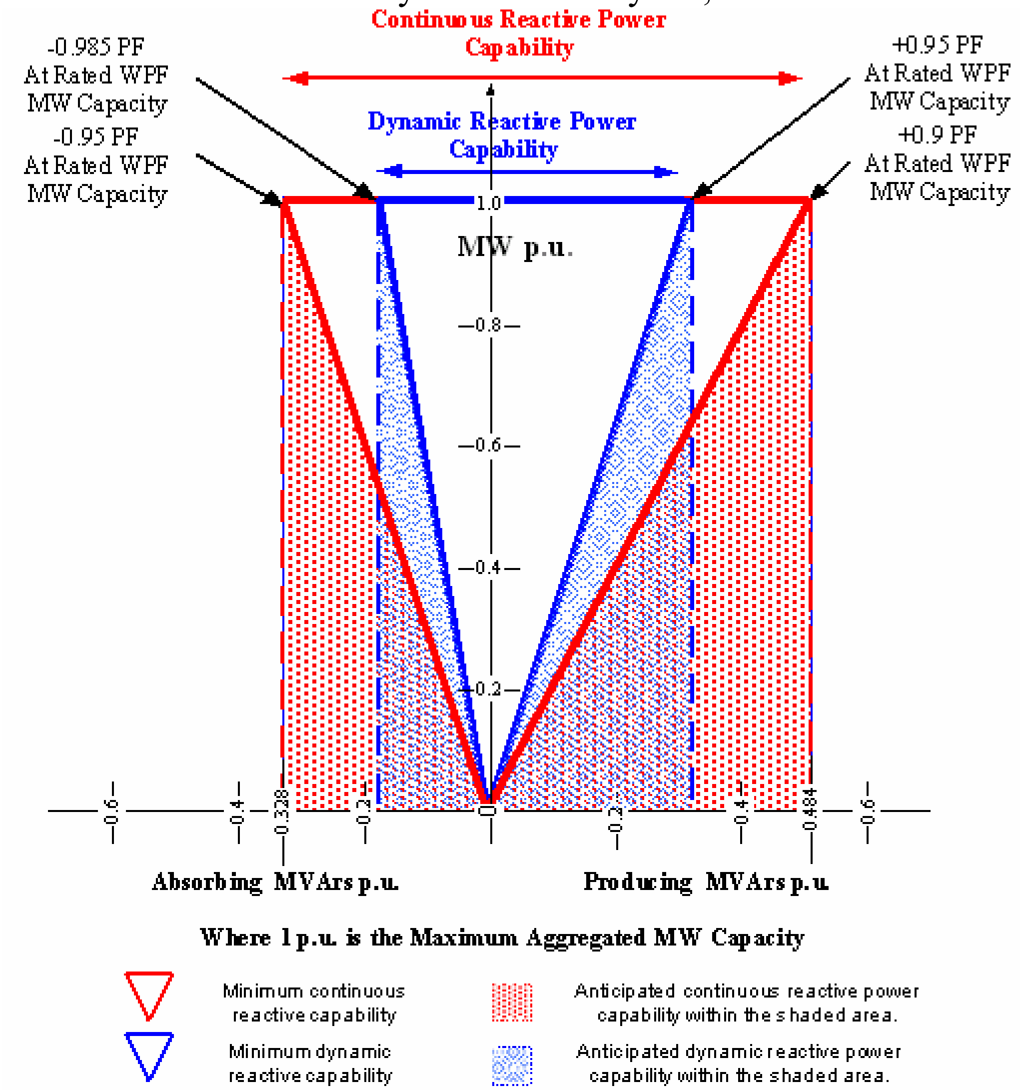

Figure 1: AESO Reactive Power Requirements

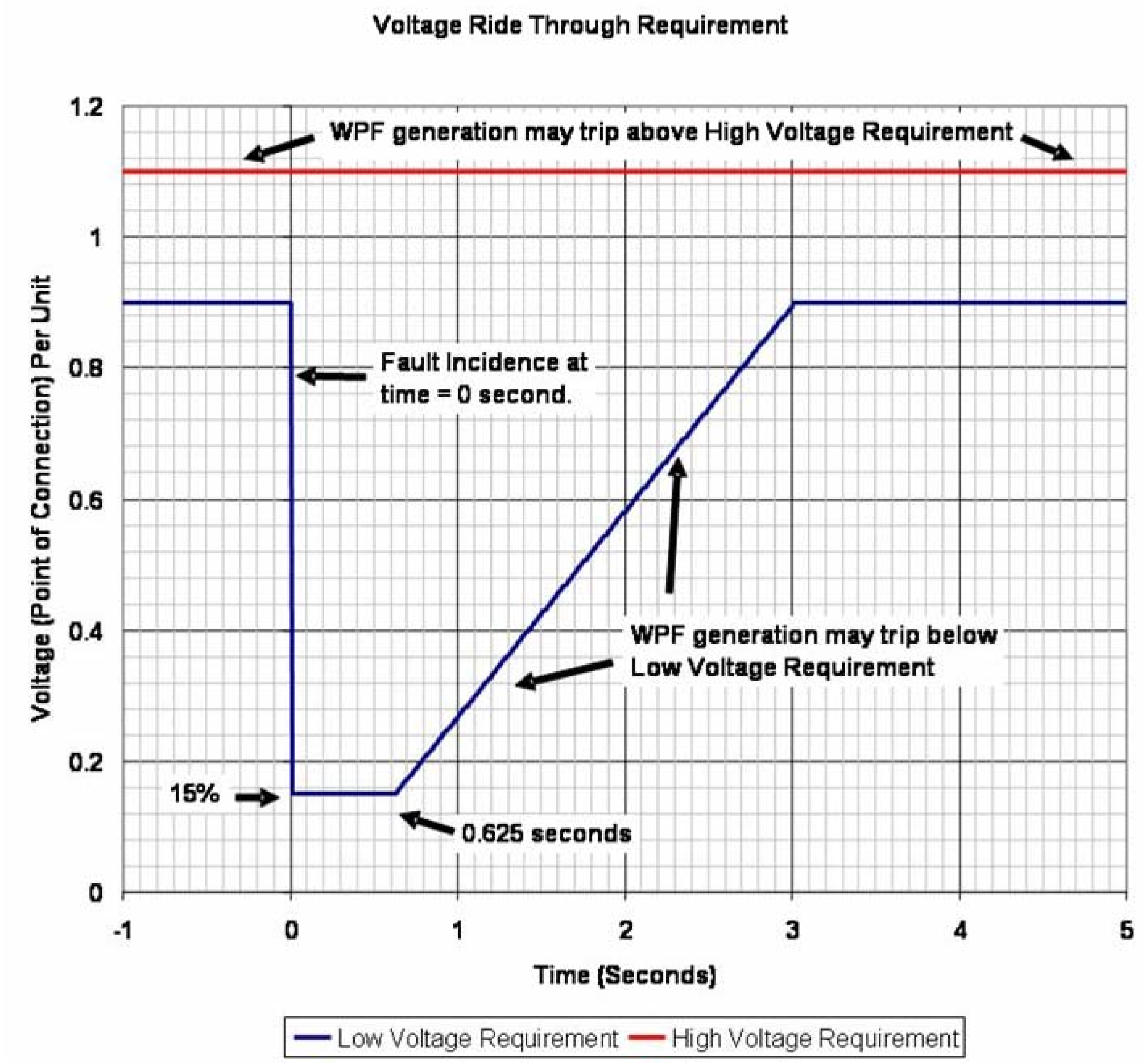

Figure 2: AESO Voltage Ride-Through Requirements

SCADA Server

In order to have the park act in concert as a single power plant, wind industry SCADA systems are evolving from just data collection and reporting units. Computerized data collection, report generation, and control functions have been standard equipment for many years. With advances in microprocessor memory and computing power, communication platforms, open protocol architectures, and Internet browsing capabilities these systems keep developing to provide the power industry with more flexibility to operate turbines and parks. The central server receives and transmits data to and from various elements of the overall wind park system (Figure 3).

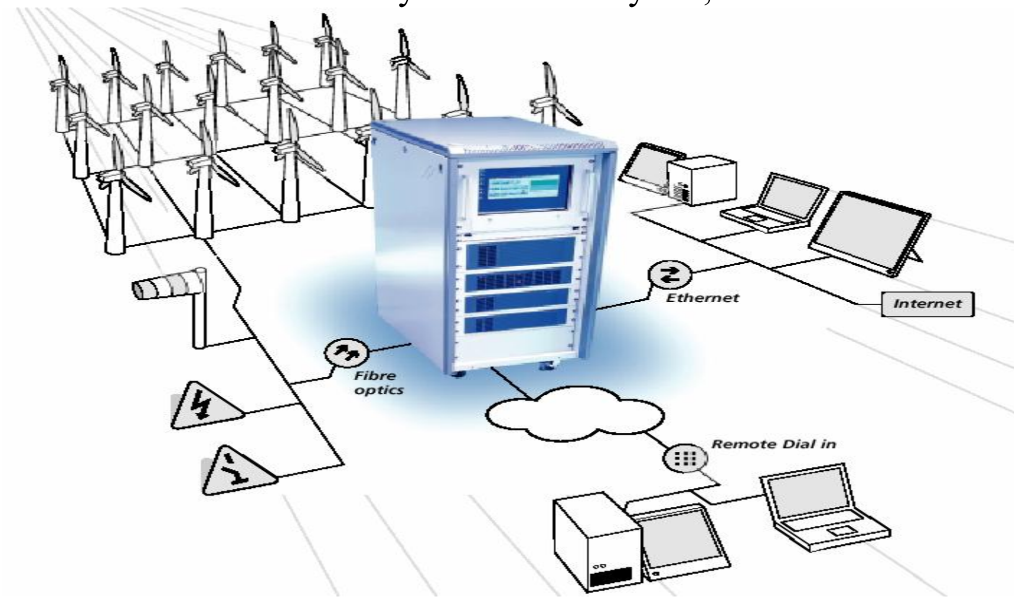

Figure 3: Wind Park Supervisory Control and Data Acquisition system

Either through Dial-In or Internet user stations, remote data transmittal and control functions becomes available to various interested entities. The wind farm SCADA server, housed within the substation control building, permits turbine, met tower and substation data to be collected for review and report making. It can also take inputs to change aspects of park operation for such parameters as voltage or frequency regulation. DFIG turbines can have their reactive power operate in a leading or lagging function, thus controlling turbine power factor. The SCADA server can integrate turbine VAR control with substation based reactive power devices to provide for precise setpoint control at the PCC. By accepting a varying signal from Dispatch, the SCADA system can then operate similar to traditional AVR in helping to regulate voltage continuously on the grid.

Real Power and Frequency Control

In a manner similar to voltage control, SCADA could be asked to have a real power setpoint varied to allow for frequency regulation through turbine ramping and scheduling. This capability is just beginning to be discussed within the industry as the next desirable feature for wind parks. SCADA has the ability for individual turbine pitch control and Pause/Run logic, to provide exact production levels if curtailment of output is needed for transmission operability. Turbine run times are polled to ensure all units in the park maintain uniform average connectivity. One frequency control concept that is already being asked for is Megawatt Ramp Rate Control

(Figure 4). This feature ensures system over frequency does not exceed operational limits by controlling how much real power can be delivered to the grid from the park over a short time period of seconds or minutes. While being especially effective during ramping up events due to oncoming weather fronts, it can also apply for ramp down situations such as when wind speeds exceed turbine Cutout conditions and there is concern for losing the entire park's output at once. Also being built into SCADA systems is the ability to limit maximum park output by clipping power peaks caused by high-speed wind gusts.

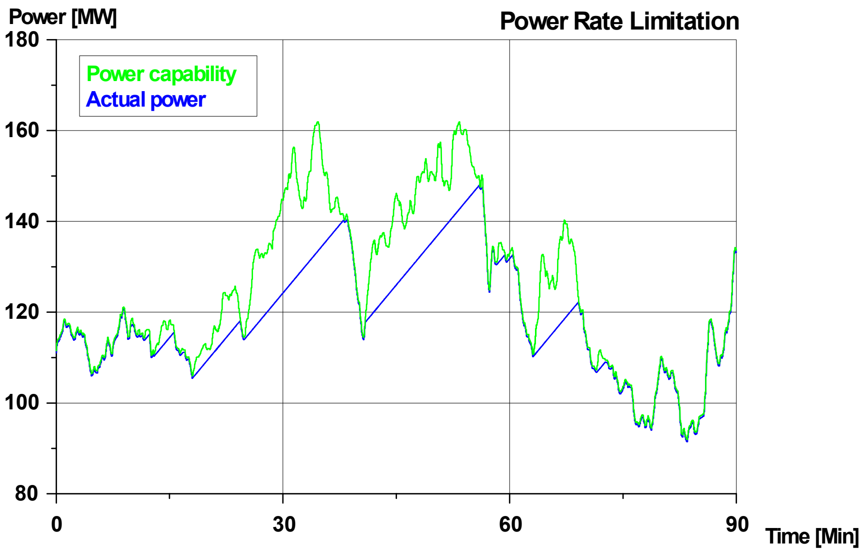

Figure 4: SCADA Control Functions for Improved Grid Operations - Ramp Rate Control

Even the potential for providing spinning reserve margin can be achieved through SCADA by purposefully ramping back a specified percentage of real power (Figure 5). Along with improved wind forecasting capabilities for day-ahead and hour(s)-ahead predictions the wind farm is moving to take its place with other regional resources for economic dispatch.

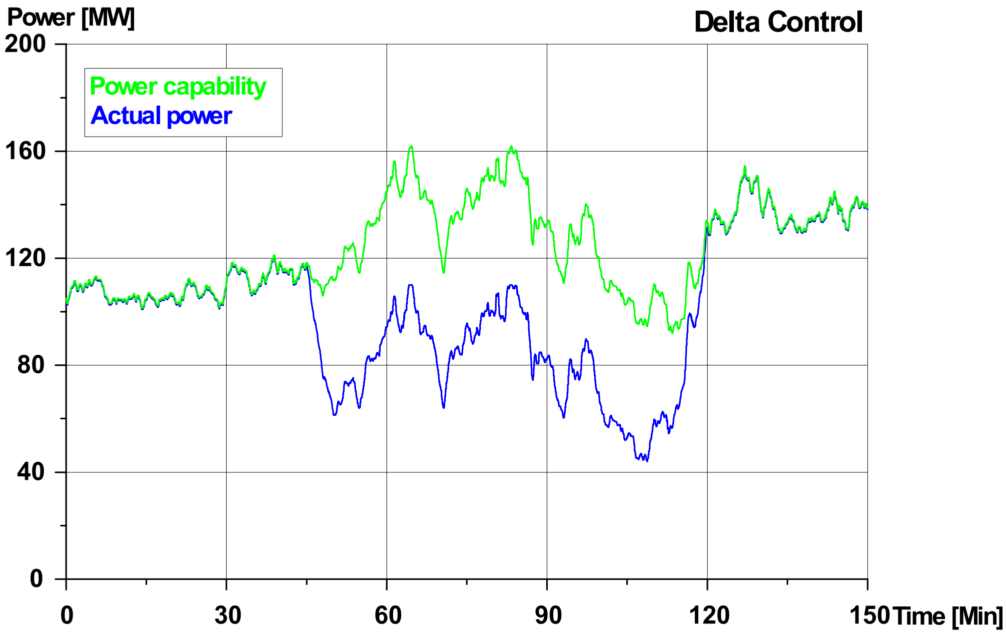

Figure 5: SCADA Control Functions for Improved Grid Operations - Spinning Reserve Margin

Power Plant Controller

Recent advances in park control also include the use of a Power Plant Controller (PPC) that is independent of the SCADA server. Having all the functionality of the server, the PPC not only provides redundancy but yields further capabilities for park operation. The PPC assists the server with offering a rugged, reliable, expandable power plant regulator and IO controller fitting into the network infrastructure defined by the SCADA system. In short, the PPC regulates the turbines by means of preconfigured rules which as a whole, or in clusters, handle data and event logging for SCADA and maintenance. It is an interface unit for a large set of digital/analog input and output signals. Among other functions it can provide for grid and substation monitoring/control/protection, as well as circuit breaker monitoring/switching/ tripping functions. PPC can also provide for flicker, noise and cut-in management schemes.

Summary

As wind parks grow in nameplate capacity, and wind energy becomes an increasingly greater proportion of the total bulk transmission mix, the power industry is now beginning to view the wind park as a single power plant with operational capabilities similar to traditional power plants powered by steam, hydro or gas sources. Wind park design has evolved within the last

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several years in an effort to become more acceptable as a generating resource by operating more analogously to large synchronous units. Although previously allowed to disconnect from the grid when voltage and frequency operated out of grid contingency conditions, wind parks are now being asked to remain connected to aid with system recovery along with their more conventional counterparts. Additionally, they are becoming required to help with voltage and frequency regulation during normal and contingency operation. To accomplish these capabilities, the turbines themselves are being redesigned to provide dynamic reactive power control and Fault Ride-Through features. When interconnection requirements go beyond what the individual turbines can presently deliver, collection system/substation solutions can by engineered using equipment such as static and/or dynamic switched reactive elements to assuage operators' reliability concerns. Features such as Ramp Rate Control, Maximum Power Limitation and Reserve Margin will allow the wind park to contribute to grid frequency regulation in a manner not seen in the past from wind. Modern park SCADA systems are being improved to not only allow for these capabilities, but also make them available to system Dispatch personnel, when desired, for direct control of the grid operation.

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