GE Wind Plant Dynamic Performance for Grid and Wind Events

Nicholas W. Miller*, Kara Clark, Mark E. Cardinal, Robert W. Delmerico
GE Energy, Schenectady, NY USA

Abstract-- **Grid integration of wind power plants is complicated by wind variability and the technical characteristics of wind generators. This paper describes an advanced wind plant controller designed to coordinate the real and reactive power response of multiple wind turbines to make the plant function as a single "grid friendly" power generation source.**

The real power controls include active power regulation, frequency or governor response, power ramp rate limiter, start up/shut down sequencer, and inertial control.

The reactive power controls include voltage regulation with or without active power production, reactive power or power factor control, and various fault ride-through capabilities.

These controls result in major grid performance and reliability benefits, especially in weak grids. The paper presents concepts and characteristics of this integrated control, and provides quantitative examples of enhanced grid performance.

Index Terms—Wind Generation, Reactive Power Supply, Voltage Regulation, Low Wind Conditions, Active Power Control, Inertial Response.

I. Introduction

This paper describes an integrated wind plant control system that addresses many of the grid integration issues confronting wind generation, and allows a wind plant to perform more like conventional generation. The control system coordinates the behaviors of the individual wind turbines to achieve the grid support requirements, usually without the need for supplemental equipment. Where supplemental equipment is needed, simple and relatively inexpensive shunt capacitor banks and reactors are often all that is required.

This wind plant control system governs both the wind turbines and the supplemental devices, if needed, to allow the wind plant to function as a single "grid friendly" power plant. These grid-friendly controls, which regulate both active and reactive power, have been successfully implemented in the GE WindCONTROL™ system and the paper focuses on field performance results.

A. Background

Grid integration of wind power plants is complicated by a number of issues, primarily related to wind variability and the electrical characteristics of wind generators. A typical wind plant appears to the grid as a substantially different generation source than a conventional power plant. The most significant difference is that the wind energy source is inherently uncontrollable. Also, the electrical characteristics of induction, doubly-fed, and full-conversion wind generators have disturbance responses and reactive output characteristics that naturally differ from that of conventional synchronous generators.

Historically, wind plants were allowed to produce real power that varied with the available wind, and were not required to participate in system frequency regulation, voltage regulation, or control of tie-line interchange.

Such uncontrolled real power output variations can have an impact on the grid, including voltage variations, frequency variations and increased regulation or ramping requirements on conventional generation resources. These are particularly significant issues in weak system applications, or in control areas where tie-line interchange is constrained.

In addition, a wind plant in which power output is not controlled inherently cannot participate in regulation of grid frequency. When wind generation displaces conventional generation, the burden of frequency regulation placed upon the remaining conventional generators is increased.

Historically, wind plants were also allowed to absorb reactive power from grids, or at best, maintain a prescribed power factor. This is a substantially different operating mode than is required of conventional power plants, which generally regulate their grid interconnection bus voltages. Without coordinated control of wind plant reactive power interchange with the grid, a typical wind plant provides no support or regulation of grid voltage. Furthermore, voltage variations caused by real power variations, as discussed above, cannot be mitigated.

With low penetrations of wind generation, these equipment characteristics and integration approaches did not have significant practical impact. However, wind generation is now reaching substantial penetration levels in many regions, and grid integration has emerged as a potential limit on further development of this environmentally friendly resource. Consequently, interconnecting utilities and regulatory agencies are imposing grid codes that demand performance from wind plants similar to that provided by conventional power plants, i.e., those using steam, gas, and hydro turbines with synchronous generators [1,2].

New features to address the grid impacts have been introduced in wind plant designs. Some designs require supplemental equipment, such as static VAR compensators, connected to the collection system in order to meet grid requirements. This equipment, however, adds cost and complexity to the wind plant.

B. Wind Plant Control System

The GE WindCONTROL™ system presented in this

* Nicholas W. Miller is with GE Energy, Schenectady, NY USA.
nicholas.miller@ge.com

paper regulates the net real and reactive power interchange of a wind plant with the grid. This allows the wind plant to regulate voltage magnitude of the grid, provide governor frequency response, and minimize rates of power change. The reactive capability can be achieved with or without sufficient wind velocity to operate the wind turbines. This is particularly useful for application in remote systems that may exhibit voltage problems, independent of the wind plant.

This wind plant control system is a hierarchical scheme that controls individual wind turbines in order to implement closed-loop regulation of grid parameters such as voltage or power, or grid-interface parameters such as power factor or net power output.

II. Wind Plant Control of Real Power

The advanced active power controls offered as part of the GE WindCONTROL™ system manage the electric power output.

A. *Governor Frequency Response*

One set of active power control functions offered as part of the GE WindCONTROL™ system is closely akin to governor controls for thermal and hydro generation. They respond to significant deviations in grid frequency, increasing or decreasing power output in response to low or high grid frequency events, respectively. To accomplish this, the controls alter the active power control reference targeted by the turbine controls.

Grid over-frequency events are stressful to power components. Further, temporary high frequency swings can present a reliability concern. For example, in one recent well publicized grid event [3], the high frequency backswing from a major grid disturbance caused power plant trips and aggravated an already severe event. When enabled, the response of the GE WindCONTROL™ will rapidly reduce power output for the duration of the over-frequency event. This behavior is similar to that of governor control on thermal generation, except that it is faster and allows deeper runback of power than is typical of conventional thermal generation..

The test results shown in the next three figures were obtained at a North American (60 Hz) site with forty operating 1.5 MW turbines. Each turbine is capable of delivering 1.5 MW at 0.95 power factor with a combined power plant rating of 60 MW and 19.7 MVAR. These tests were performed during the commissioning phase of the wind plant. During some portions of the tests, only 38 turbines were available for operation.

Figure 1 illustrates the power response of the wind plant due to a grid over-frequency condition. For this test, the controller settings correspond to a 4% droop curve and 0.02 Hz dead band. During this test, the site was operating unconstrained at prevailing wind conditions. It was producing slightly less than 23 MW prior to the over-frequency condition. The system over-frequency condition was created using special test software that injected a 2% controlled ramp offset into the measured frequency signal. The resulting simulated frequency increased at a 0.25 Hz/s rate from 60 Hz to 61.2 Hz. While the frequency is increasing the plant power is observed to drop at a rate of 2.4 MW/sec. After 4.8 seconds the frequency reaches 61.2 Hz and the power of the plant is reduced by approximately 50%.

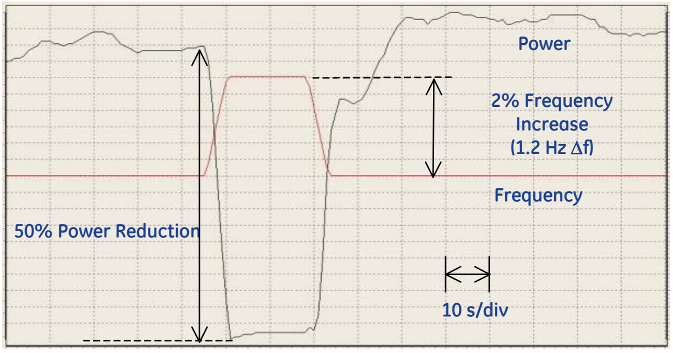

Figure 1 - Demonstration of over-frequency response.

The over frequency condition is removed with a controlled ramp down to 60 Hz at the same 0.25 Hz/sec rate. In response, the plant power increases to its unconstrained power level. This is slightly higher than the unconstrained level prior to the test, due to an increase in the wind speed. The droop and deadband settings for this test are typical values. These settings, which are deliberately asymmetrical between high and low frequency response, can be adjusted to meet specific grid and application requirements.

This control can also respond to under-frequency events. In order to allow for an increase of wind plant active power output in response to an under-frequency condition, some active power production must be kept in reserve [4]. Therefore, the maximum power production of the wind plant is constrained to a value less than that available from the wind. This amounts to a continuous loss of energy production and an intentional under utilization of the wind plant. It may be offset in certain applications by the value of the frequency regulation capability provided.

This feature can be scheduled to operate only at defined times of the day or year. Alternatively, it can selectively enabled according to overall grid operating conditions. The function is most likely to be valuable and economic under conditions of high wind and light power system load.

B. *Ramp Rate Control Response*

Figure 2 demonstrates the power ramp limiter maintaining a specified rate of change in power output. The power ramp limiter is able to track and limit to two simultaneous ramp rates that are measured and averaged over two different time frames. The two ramp rate limits allow targeting of different potential grid operating constraints. Specifically, a short window (typically 1-minute) ramp rate limit addresses possible limitations in system regulation capability. A longer window (typically 1-minutes) addresses possible limitations in grid load-following capability. As with the governor response discussed above, this functionality is most likely to be valuable and economic at times of high wind and light load.

In the figure, initially, the wind power plant is curtailed to 4 MW. Then the curtailment is released, and the plant is allowed to ramp up at a controlled rate of 5% per minute (3 MW/min or 50 kW/s) averaged and measured over a one minute interval. The second longer time frame ramp limit was set at 3.3 %/min (2 MW/min) and averaged and measured over a 10 minute interval (20 MW per ten minutes).

A unique limiting technique is used to maximize energy capture of the plant at the same time as enforcing an overall power ramp limit for the system. The ramp limiter does not impose a rate of change on any single power-producing turbine until the plant power rate of change approaches the limit. This technique enables each turbine to respond to local changes in wind conditions and allows each turbine to ramp its power independent of the other turbines. Only when the entire response of the collective plant approaches the ramp limit will the control enforce a ramp limit for the plant. The 20 MW/10 min ramp limit is not hit because the wind conditions prevented the output from increasing more than 18 MW/10 min.

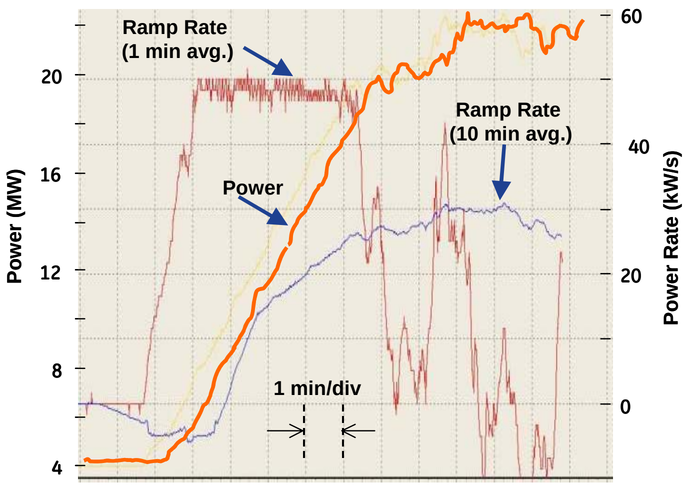

Figure 2 - Demonstration of power ramp-rate limitation.

Ramp-rate limits can be set to meet the requirements for specific grids and applications. Ramp-rate limits can be imposed for grid operating conditions that warrant their use, and need not be continuously enabled. The controller allows for switching in and out of ramp-rate control by either the plant operator or in response to an external command.

C. Start/Stop Response

Starting and stopping a large wind power plant can be disruptive to other generation equipment in a utility system when the wind is such that the plant is near its rated value. Loss of plant output when all the wind turbines are quickly disconnected from the system can create under frequency and power balance problems. Conversely, rapid start-up of a wind plant that has been shut down, for some reason other than lack of wind, can create over frequency and power balance problems.

GE WindCONTROL™ employs a configurable means to control the time a wind plant is shutdown and disconnected from the grid. An operator can send a shutdown signal to the plant controller initiating a controlled shutdown response. The control immediately interprets the shutdown command to begin reducing the power of the plant and start sequencing off turbines.

Figure 3 depicts a shutdown sequence for the site that had 38 available and operating wind turbines and was programmed to shut down over a five minute interval. It shows the power of the plant decreasing to zero over five minutes and the number of on-line generators.

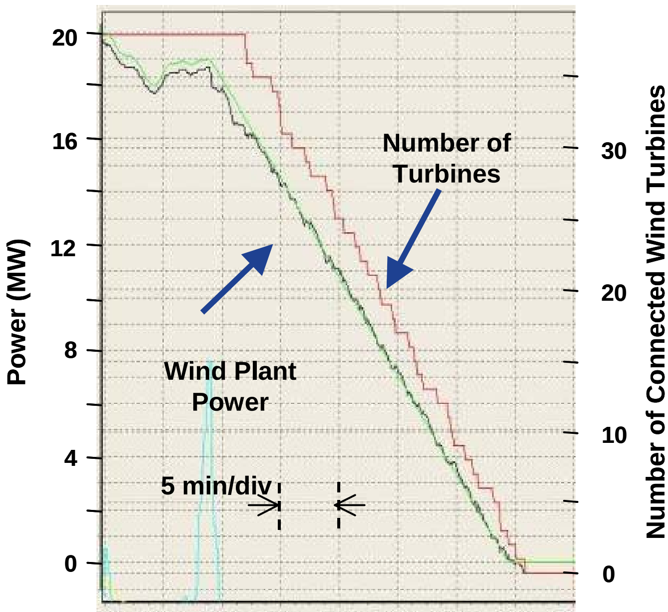

Figure 3 – Demonstration of wind plant shutdown sequence.

D. Controlled Inertial Response

The response of bulk power systems to system disturbances is of great concern to those responsible for grid planning and operations. System events that include loss of generation normally result in transient depressions of system frequency. The rate of frequency decline, the depth of the frequency excursion, and time required for system frequency to return to normal are all critical bulk power system performance metrics that are affected by the dynamic characteristics of generation connected to the grid.

Typically in the first few seconds following a loss of a large generating plant, the frequency dynamics of the system are dominated by the inertial response of the operating generation. The behavior of conventional synchronous generation is well understood, and is relied upon by the grid for secure operation [5]. These synchronous turbine-generators inherently contribute some of their stored inertial energy to the grid, reducing the initial rate of frequency decline, and allowing for slower governor actions to stabilize grid frequency. However, most modern MW-class wind generation does not exhibit this inertial response. This raises concerns that systems with high penetrations of wind generation will exhibit unacceptable frequency response.

Fortunately, an inertial response capability for wind turbines, similar to that of conventional synchronous generators for large under-frequency grid events, is now available.

For large under frequency events, the GE WindINERTIA™ feature temporarily increases the power output of the wind turbine in the range of 5% to 10% of the rated turbine power. The duration of the power increase is on the order of several seconds. This inertial response is essentially energy neutral. Below rated wind, stored kinetic energy from the turbine-generator rotors is temporarily donated to the grid, but is recovered later. At higher wind speeds, it is possible to increase the captured wind power, using pitch control, to temporarily exceed the steady-state rating of the turbine. Under these conditions, the decline in rotor speed is less and the energy recovery is minimal.

The GE WindINERTIA™ feature utilizes the energy stored in the rotor to provide an increase in power only when needed. Hence, this feature does not adversely impact annual energy production.

Unlike the inherent response of synchronous machines, inertial wind turbine generator (WTG) response is dependent on active controls. Further, the response is shared with controlled variations in active power necessary to manage the turbine speed and mechanical stresses. These stress management controls take priority over inertial control. Turbulence may mask the response for individual turbines at any instant in time, but overall plant response will be additive. The design has sufficient margin over the turbine operating range to meet the equivalent energy (kW-sec) contribution of a synchronous machine with 3.5 sec pu inertia for the initial 10 seconds.

Overall, the GE WindINERTIA™ control is designed to provide similar functional response to that of a synchronous machine. Unlike the inherent response of a synchronous machine, the response is not exactly the same under all operating conditions.

A simple representation of the critical elements is shown in Figure 4. Frequency error is simply the deviation from nominal. A positive frequency error means the frequency is low and extra power is needed. The deadband suppresses response of the controller until the error exceeds a threshold. This limits the response to large events. The continuous small perturbations in frequency that characterize normal grid operation are not passed through to the controller.

The Power Shaping block produces a driving power response signal. This signal is further filtered and coordinated with other WTG controls, particularly the generator power order, in the Power Coordination block. Finally, the inertial response signal is limited, and sent to the turbine control that alters the generator power order. This net command is implemented by the WTG converter controls, ultimately resulting in power delivered to the WTG terminals.

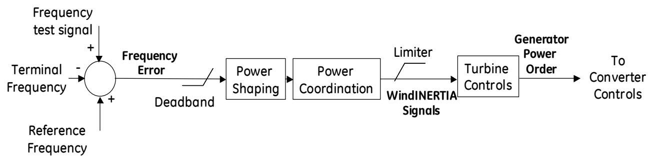

Figure 4 - Functional diagram of the GE WindINERTIA™ control.

Field test results of the GE WindINERTIA™ for various wind speeds on a single wind turbine are shown in Figure 5. The field data was generated by repeated application of a frequency test signal to the control. The results, at various wind speeds, were then averaged and plotted. Below rated wind speed (<14m/s) the results clearly demonstrate the inertial response and recovery. Above rated wind speed the inertial response is sustained by extracting additional power from the available wind.

The greatly simplified representation of Figure 4 illustrates a number of differences between this controlled inertial response, and the inherent inertial response of a synchronous machine. First, and most important, the control is asymmetric: it only responds to low frequencies. High frequency controls are handled separately, by a different controller (GE WindCONTROL™), as discussed above. Second, the deadband ensures that the controller only responds to large events – those for which inertial response is important to maintain grid stability, and for which seriously disruptive consequences, like under frequency load shedding (UFLS), may result. Finally, a controlled inertial response means the speed is a function of the control parameters. In the example shown, the response was tuned to provide good coordination not only with inertial response of other generation on the system, but with governor response of conventional generation as well.

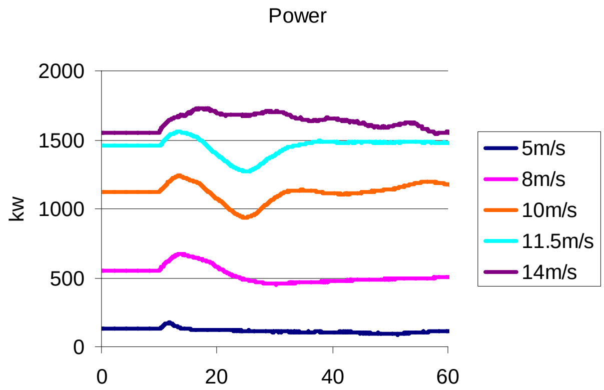

Figure 5 – Field demonstration of the GE WindINERTIA™ response.

The GE WindCONTROL™ active power control discussed in the previous subsection, if enabled, will also respond to significant under-frequency events. The command for this response emanates from the wind plant level, and is delivered to each individual WTG. In order to increase active power, the plant must be partially curtailed, so that additional power can be extracted from the available wind. This incremental power order signal will add to that from GE WindINERTIA™, which is local to the individual WTG. The total response of the WTG to these two signals is coordinated to respect the physical capabilities of the WTG.

Ultimately, grid codes may be modified to include some type of inertial response requirement. The development of the GE WindINERTIA™ feature shows that such functionality is, indeed, possible. However, it also shows that inertial response identical to that of synchronous generation is neither possible nor necessary. Inertial response of wind generation is limited to large under-frequency events that represent reliability and continuity-of-service risks to the grid. The crafting of new grid codes should therefore proceed cautiously and focus on functional, systemic needs.

III. Wind Plant Control of Reactive Power

For many wind plants, especially large remote projects, traditional approaches to managing reactive power are no longer acceptable. A large wind plant may consist of a hundred or more individual wind turbines, separated by tens or even hundreds of kilometers of electrical collector system. However, the power system needs are dictated at the point of interconnection with the host grid. GE WindCONTROL™ control system achieves improved voltage/VAR control by using the inherent VAR capabilities integrated into each GE wind turbine and precisely controlling the turbine's VAR output to maintain voltage at the point of interconnection. This coordinated control system senses AC system conditions and instructs the individual turbines within a plant to adjust their local control objectives to meet system needs. The control system provides tight closed-loop regulation of utility system voltages. This hierarchical control minimizes voltage flicker, improves system stability, reduces the risk of voltage collapse, and minimizes the impact of system disruptions. This provides two major benefits. First, the impact of active power fluctuations from wind variation on the grid voltages is minimized. Second, the fast and precise voltage control effectively strengthens the grid, improving the overall power system's resilience to large disruptions.

The control system can also control VARs at a point of interconnection a distance away from the wind plant, coordinate additional capacitor/reactor banks, and control the startup and shutdown sequence of the wind plant.

A. *Voltage Regulation*

Figure 6 shows the response of a wind plant, consisting of 108 GE 1.5 MW wind turbine generators, to sixty minutes of highly variable wind speed. This wind plant is connected to the grid by a dedicated 75 km 230 kV transmission line. The short circuit capacity at the remote point of grid interconnection is quite low compared to the rating of the wind plant, approximately 670 MVA, which is a short-circuit ratio of approximately 4.1. At the wind plant collector system, the short circuit ratio is much lower, less than 2.5.

The specifications of this particular system required regulation of the voltage at a remote point of grid interconnection. To avoid dependence on telecommunications, the GE WindCONTROL™ line drop compensating feature was used to synthesize the voltage at the point of interconnection, 75 km from the measurement points at the wind plant substation.

Despite the challenges of a very weak grid and the requirement of regulation of a remote voltage, performance of this system has been excellent. The upper chart of Figure 6 shows the wind plant voltage and the voltage at the point of grid interconnection. The wind velocity is also shown, but without a scale. In the lower chart of Figure 6, the same wind velocity is shown, along with the wind plant power output. Despite rather large variations in generated power, the voltage at the interconnection bus is quite invariant. The voltage flicker index, P_{st}, is less than 0.02 for this high stress condition – well within industry expectations. Most of the voltage variations are within a few hundred volts on the 230kV system.

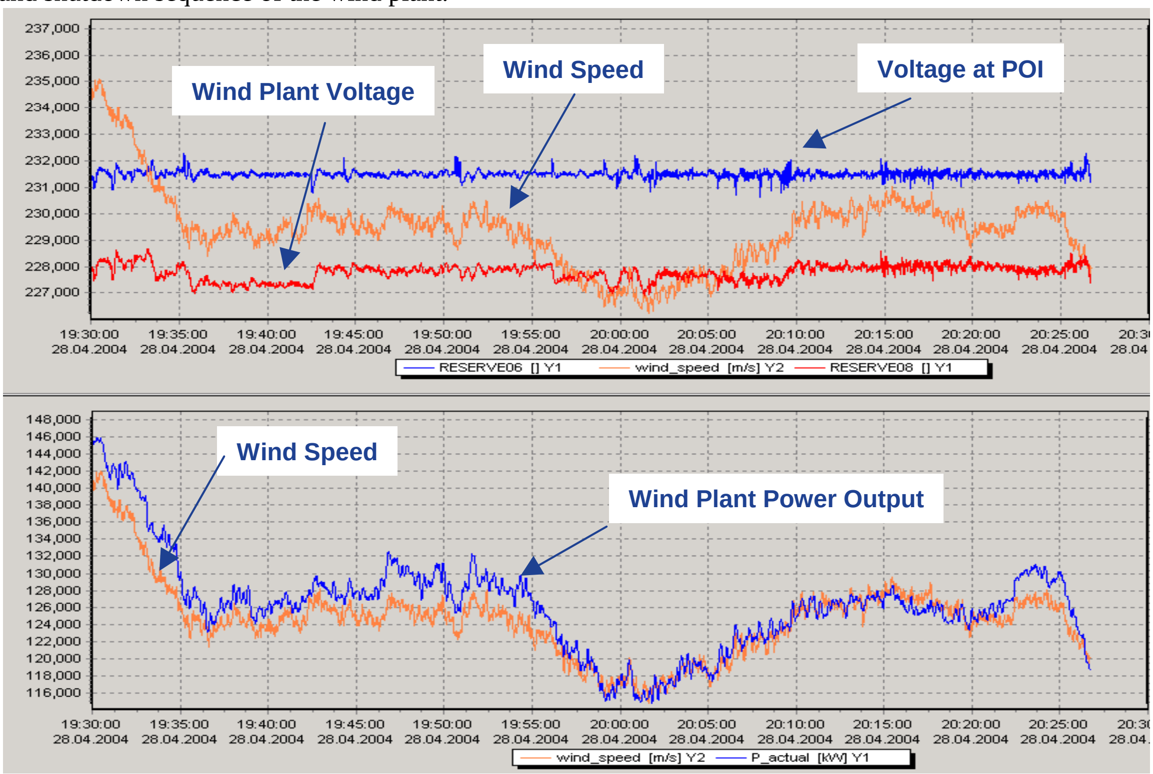

Figure 6 - Demonstration of voltage regulation performance during variable power output conditions.

B. *WindFREE™ Reactive Power Control*

The latest advancement in wind turbine generator technology provides control of reactive power output even when the wind turbine is stopped. Currently, all MW-class wind turbines stop in response to sustained wind speeds below a minimum threshold or when wind exceeds a high speed cut-out. They may also be disconnected from the grid in response to severe system disturbances. Under such conditions, both real power to serve load and reactive power to support system voltage are lost.

GE's wind turbine generators, equipped with the new GE WindFREE™ reactive power control, provide smooth fast voltage regulation by delivering controlled reactive power even when the wind turbines are not generating active power. Such a function cannot normally be provided by conventional (e.g., thermal, hydro) generation, since production of reactive power from these generators requires that the generator (and therefore the turbine) continue to spin at synchronous speed. Continuous voltage support and regulation provides a major grid performance and reliability benefit.

From a systemic perspective, the reactive power capability is similar to that provided by various dynamic reactive devices (e.g., synchronous condenser, SVC, STATCOM [6]), that are used for grid reinforcement where dynamic voltage support is required. These devices are quite expensive, but are sometimes required to maintain voltage and stability in stressed systems [7,8]. GE wind plants do not require these devices.

The most significant benefits are observed for systems with substantial dynamic reactive power requirements. This includes very large projects, projects that are physically remote with electrically weak connections to the grid, and projects in areas with heavy and variable loads. Wind power plants equipped with this feature will provide effective grid reinforcements by providing continuous voltage regulation.

GE's wind turbine generators use large power converters. This decouples the generator speed from the power system frequency and allows for a wide operating speed range. The power converters rely on two major components: the generator side converter and the line side converter, which connects to the grid. It is important to recognize that the line side inverter is self-commutating. This provides the capability to independently deliver active and reactive power. When there is no active power available from the turbine, the converter can continue to deliver or absorb reactive power.

Test results for a single wind turbine operating with the GE WindFREE™ control are shown in Figure 7. Initially, the real power output is zero, while the reactive power output is about 1100 kVAr. Then, the wind picks up (at about 527 seconds) and the real power increases, while the reactive power remains constant.

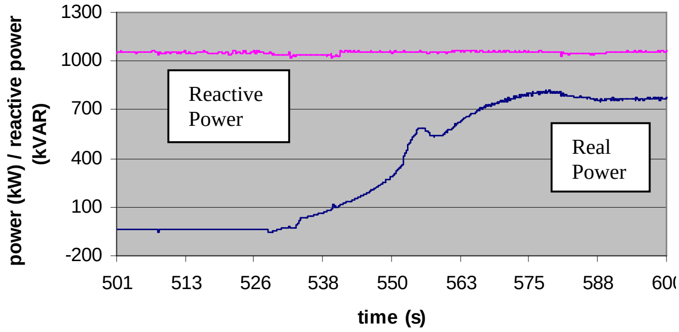

Figure 7 - Demonstration of WindFREE response.

IV. FAULT TOLERANCE

Low voltage ride-through (LVRT) capability became a common requirement for wind plant interconnection due to both increasing plant sizes and greater wind generation penetration [9]. Zero voltage ride through (ZVRT) requirements are now standard in much of the world, including most North American systems [10,11,12,13]. As an example, some ZVRT standards require wind plants to remain in-service during normally cleared system faults with 0 pu voltage at the point of interconnection for up to 9 cycles.

The GE WindRIDE-THROUGH™ features meet these fault tolerance requirements. Since staging faults on operating grids is expensive, risky, and disruptive, testing is usually performed in a more controlled environment. The following test results were provided by WINDTEST K-M-K GmbH, an independent testing group, for an operating 1.5 MW wind turbine generator. A 200 msec, 3-phase fault-to-ground was applied to the medium voltage bus. Figure 8 shows the rms voltages for each phase of the faulted bus. Figure 9 shows one of the voltages again, as well as the real power delivered to the medium voltage bus. The wind turbine remains in service during the fault, and power output recovers to the pre-disturbance level in under 200 msec.

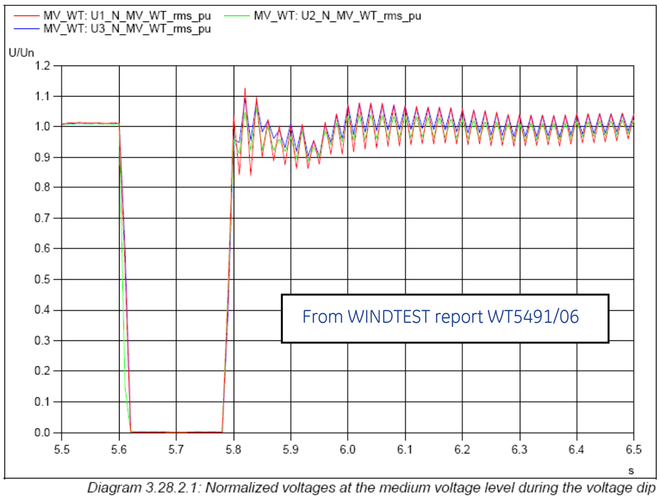

Figure 8 – Demonstration of 1.5 MW ZVRT capability (voltage).

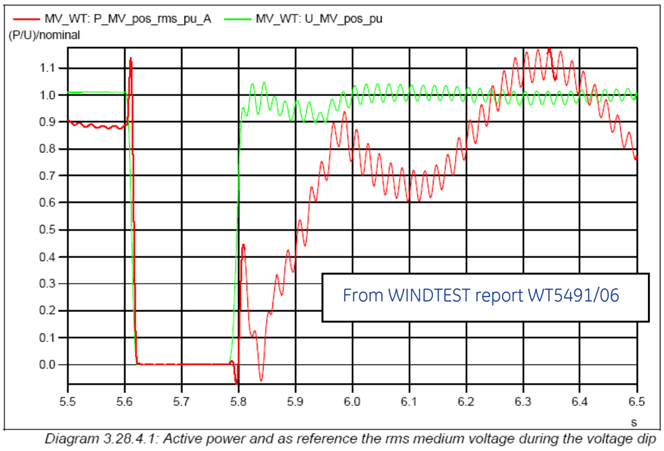

Figure 9 - Demonstration of 1.5 MW ZVRT capability (power and voltage).

Similar ZVRT performance is provided by GE's 2.5 MW, full converter wind turbine generators. Test results demonstrating this capability are shown in Figure 10 and Figure 11. Figure 10 shows the machine is initially operating at near rated power output and near zero reactive power output. A 3-phase fault to ground is then applied for 200 msec, as shown in Figure 11. The wind turbine rides through this fault and returns to normal operation after the fault is removed.

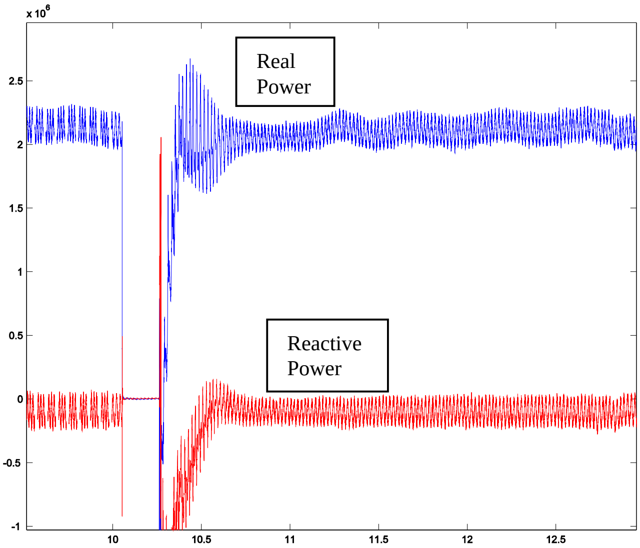

Figure 10 - Demonstration of 2.5 MW ZVRT capability (real and reactive power).

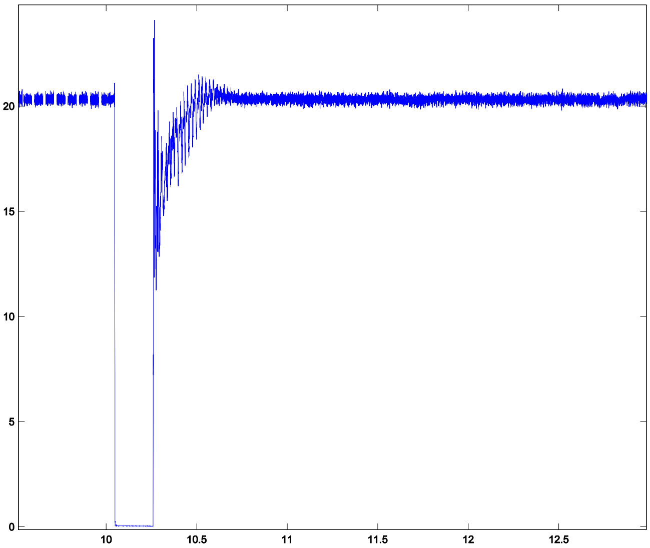

Figure 11 - Demonstration of 2.5 MW ZVRT capability (voltage).

V. Summary and Conclusions

A. Summary

A commercially available wind power plant control system is capable of meeting many grid requirements. The GE WindCONTROL™ system demonstrates that wind power plants can be controlled to provide performance similar to that of conventional generating equipment.

The variability of wind power and the tendency for wind plants to be located in relatively weak electrical systems makes tight voltage and power regulation critical. These control capabilities enable higher penetration levels of wind power plants in a utility system by allowing for secure operation even in systems with marginal generation resources or low short circuit ratios.

The examples shown above illustrate the real power control capabilities of the GE WindCONTROL™ system – under and over frequency response, up and down power ramp rate limits, and the start/stop sequence.

In response to the growing penetration of wind power in grids around the world, GE is also offering the GE WindINERTIA™ feature, which enables the wind turbine to provide a short pulse of additional power in response to significant under-frequency grid events and therefore, to support restoration of the grid frequency to its nominal value.

The examples shown above also illustrate that wind turbines and wind power plants equipped with state-of-the-art reactive power and voltage regulation capability can provide superior voltage performance for weak systems. Systems can realize both increased security and improved economy from this capability.

Expanding reactive power and voltage regulation to zero-power operations greatly enhances this valuable system service, reaching performance benefits not possible with conventional generation. The GE WindFREE™ reactive power control provides tight voltage regulation under all conditions, increased system security for grid events, and security from system voltage disruptions due to wind-induced wind turbine generator tripping. It also provides more economic system operation by reducing or eliminating requirements for transmission reinforcement, and by reducing the requirements for local, must-run generation.

Fault tolerance has been widely identified as critical to system reliability. The GE WindRIDE-THROUGH™ low voltage ride-through (LVRT) capability has been extended to include zero voltage ride through (ZVRT) capability, allowing wind plants to remain in-service for normally cleared faults with zero voltage at the point of interconnection.

B. Conclusion

GE, with our 130 years of power systems experience and provider of 25% of the world's power generation capability, is committed to the continued development of grid-friendly wind power plants.

ACKNOWLEDGMENT

The authors would like to acknowledge the valuable support of the GE engineering team, especially Werner Barton, Vincent Schellings, Jason MacDowell, Michael Ginzburg, Minesh Shah, and Ron Brzezinski.

VI. REFERENCES

[1] "Interconnection for Wind Energy", U.S. Federal Regulatory Commission, Order 661-A, December 12, 2005, Available http://www.ferc.gov.

[2] "Grid Code, High and Extra-High Voltage", E.ON Netz GmbH, Bayreuth, Germany, April 1, 2006.

[3] FRCC Event Analysis Team (FEAT) Interim Recommendations Report, http://www.balch.com/files/upload/FRCC_Interim_Report_6_3_08.pdf

[4] Cardinal, M.E; N.W. Miller, "Grid Friendly Wind Plant Controls: WindCONTROL – Field Test Results"; proceedings WindPower 2006, Pittsburgh, PA.

[5] Kundar, P., Power System Stability and Control, 1994, McGraw-Hill, Inc., New York, ISBN 0-07-035958-X.

[6] Hingorani, Narain G.; Laszlo Gyugyi and Mohamed E El-Hawary, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems," New Delhi: Standard Publishers, 2001. xix, 432p. ISBN: 81-86308-79-

[7] Ackermann, Thomas, "Wind Power in Power Systems", Wiley; Sussex, UK, 2005.

[8] "Voltage Stability Assessment, Concepts, Practices and Tools," IEEE PES WG Publication, 2005.

[9] "Appendix G. Interconnection Requirements For A Wind Generating Plant", FERC, http://www.ferc.gov/industries/electric/indus-act/gi/wind/appendix-G-lgia.doc

[10] "PRC-024-WECC-1-CR – Generator Low Voltage Ride-Through Criterion," WECC, http://www.wecc.biz/documents/library/Standards/2008/WECC_Low_Voltage_Criterion_2-12-08_clean.pdf

[11] Erlich, W. Winter, A. Dittrich, Advanced Grid Requirements for the Integration of Wind Turbines into the German Transmission System, IEEE Power Engineering Society General Meeting, 2006

[12] J. Matevosyan, T. Ackermann, S. Bolik, L. Söder, Comparison of International Regulations for Connection of Wind Turbines to the Network, Technical Paper Presented At The Nordic Wind Power Conference, 1-2 March, 2004, Chalmers University Of Technology

[13] I. Garin, A. Munduate, S. Alepuz, J. Bordonau, Low and Medium Voltage Wind Energy Conversion Systems: Generator Overview and Grid Connection Requirements, C I R E D 19th International Conference on Electricity Distribution, Vienna, 21-24 May 2007