Reactive Power Performance Requirements for Wind and Solar Plants

A. Ellis, *Senior Member, IEEE*, R. Nelson, *Member, IEEE*, E. Von Engeln, R. Walling, *Fellow, IEEE*, J. MacDowell, *Member, IEEE*, L. Casey, *Member, IEEE*, E. Seymour, *Senior Member, IEEE,* W. Peter, *Member, IEEE,* C. Barker, *Member, IEEE,* B. Kirby, *Senior Member, IEEE,* J. R. Williams, *Member, IEEE*

***Abstract*—A current challenge faced by the electric utility industry is to determine how variable generation plants (wind and solar) should contribute to the reliable operation of the electric grid, especially as penetration of these resources continues its upward trend. Traditionally, bulk system voltage regulation has predominately been supplied by synchronous generators, and this is reflected in the language of industry requirements. Where variable generation is concerned the requirements are vague and unclear. The technology used in variable generation plants are capable of providing voltage support, but will require a shift from how these plants are traditionally operated.**

This paper discusses the capability of wind and solar plants to provide voltage regulation. It also examines the deficiencies in existing standards and provides recommendations to improve upon existing requirements in order to clearly define the role of variable generation in providing voltage support to the bulk electric grid.

***Index Terms*— interconnection requirements, reactive power, solar, variable generation, voltage regulation, wind.**

I. Introduction

Voltage on the North American bulk system is normally regulated by Generator Operators, which typically are provided with voltage schedules by Transmission System operators. In the past, variable generation plants were considered very small relative to conventional generating units, and were characteristically either induction generator (wind) or line-commutated inverters (PV) that have no inherent voltage regulation capability. Bulk system voltage regulation was provided almost exclusively by synchronous generators. However, the growing level of penetration of non-traditional renewable generation – especially wind and solar – has led to the need for renewable generation to contribute more significantly to power system voltage and reactive regulation. For the most part, new wind plants use doubly-fed asynchronous generators or full-conversion machines with self-commutated electronic interfaces, which have considerable dynamic reactive and voltage capability. If needed to meet interconnection requirements, the reactive power capability of solar and wind plants can be further enhanced by the adding of SVC, STATCOMS and other reactive support equipment at the plant level. Currently, inverter-based reactive capability is more costly compared to the same capability supplied by synchronous machines. Partly for this reason, FERC stipulated in Order 661-A (applicable to wind generators) that a site-specific study must be conducted by the transmission operator to justify the reactive capability requirement up to 0.95 lag to lead at the point of interconnection [1]. For solar PV, it is expected that similar interconnection requirements for power factor range and low-voltage ride through will be formulated in the near future. Inverters used for solar PV and wind plants can provide reactive capability at partial output, but any inverter-based reactive capability at full power implies that the converter need to be sized larger to handle full active and reactive current.

Nonetheless, variable generation resources such as wind and solar PV are often located in remote locations, with weak transmission connections. It is not uncommon for wind parks and solar PV sites to have short circuit ratios (i.e., ratios of three-phase short circuit mega volt-amperes (MVA) divided by nominal MVA rating of the plant) of 5 or less. Voltage support in systems like this is a vital ancillary service to prevent voltage instability and ensure good power transfer.

Voltage regulation in distribution systems is normally performed at the distribution substation level and distribution voltage regulation by distributed resources is not allowed by IEEE 1547 [2]. Normally, distributed resources operate with fixed power factor with respect to the local system. Currently, the IEEE 1547 working group is addressing issues of high penetration of variable generators on distribution systems. The main focus of this paper is the interconnection of variable generators on the bulk transmission system. Section II discusses the reactive capability of synchronous generators, as reactive power requirements where historically tailored to these type of machines. Section III and IV discusses the reactive ability of wind and solar generators, as these machines and the power plants they are employed in have different topologies than conventional plants their ability to provide reactive power support will be different than a synchronous machine. Section V discusses the difference

This work was supported in part by the U.S. Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Abraham Ellis and Joseph Williams are with Sandia National Laboratories, Albuquerque.

Robert Nelson is with Siemens Wind, Orlando, FL.

Edi Von Engeln is with NV Energy, Reno, NV.

Reigh Walling and Jason MacDowell are with GE Energy, Schenectady, NY.

Leo Casey is with Satcon Technology Corporation, Boston, MA.

Eric Seymour is with Advanced Energy Industries, Fort Collins, CO.

William Peter is with SunPower Corporation, Richmond, CA.

Christopher Barker is with BEW Engineering, San Ramon, CA.

Brendan Kirby is a private consultant, Palm City, FL.

between fast acting dynamic and slower static reactive capability and the difference in equipment needed to supply one or the other. Section VI discusses different modes of reactive power support that can be employed depending on operational considerations. Sections VII, VIII, and IX provide recommendations to clarify and or change reactive power requirements that would assist industry in standardization the reactive capability of variable generation plants.

II. Reactive Capability of Synchronous Generators

Customarily, when reactive capability of variable generation resources is specified for transmission interconnections, it is done at the Point of Interconnection (POI), which is the point at which power is delivered to the transmission system. This is often (but not always) at the high side of the main facility transformer. A typical requirement would be 0.95 power factor "lag to lead at the POI," meaning that the machine should be capable of providing (lagging pf) or absorbing (leading) approximately 1/3 of its active power rating (MW) in reactive power (MVAr). This "lag to lead" specification originated from FERC Order 2000 (Large Generator Interconnection Agreement) and was suggested by NERC as a representative synchronous generator capability [3]. In reality, synchronous generators are almost always applied with power factor measured at the terminals, not at the POI. Conventional synchronous generator reactive power capability is typically described by a "D curve" that covers the range from zero to rated output. However, it should be noted that synchronous generators are limited by the minimum load capability of the generating plant. Some conventional generators are designed to operate as synchronous condensers, allowing them to provide reactive power at zero load, but they still cannot operate between zero and minimum load. The ability to provide reactive power at zero load must be designed into the plant and it is not possible with many larger plant designs. The significance of the discussion above is that the practical reactive power capability of a typical synchronous generator is more limited than the typical "D curve" shows (see Fig. 1).

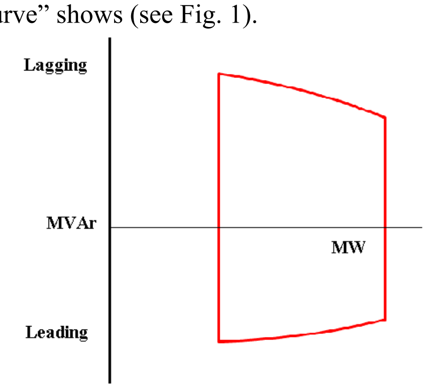

Fig. 1. Example of reactive power capability of a synchronous generator considering plant minimum load.

Assuming negligible auxiliary load, the corresponding power factor at the transmission interface can be easily calculated given the generator power factor at the terminals and the reactance of the generator step-up transformer. Generally, a generator with a reactive capability of 0.9 lag, 0.983 lead (measured at the generator terminals) connected to the transmission system through a transformer with a leakage reactance of 14% on the generator MVA base can provide 0.95 lag to lead at the transmission interface if the transmission system is at nominal (i.e., 100%) voltage.

Typical specifications for synchronous generators require 0.90 lagging and 0.95 leading at the machine terminals in order to allow voltage regulation at a transmission voltage range of 90% to 110%. Synchronous generators have maximum continuous voltages of 105%, and minimum voltage of 95%. Depending on the system voltage and generator output level, these limits may come into play, in which case the reactive power capability would be reduced.

A specification of "0.95 lead to lag at full power" is commonly stipulated for variable generation. However, terminal voltage limitations also affect reactive power capability of variable generators; therefore, to capture this effect, the reactive power versus voltage characteristic should be specified separately from the reactive range. For example, in addition to a "0.95 lead to lag" reactive range requirement, the chart shown in Figure 2 could be used to specify the reactive power capability versus voltage characteristic.

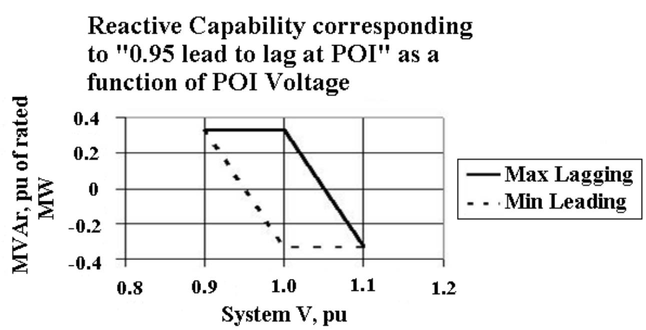

Fig. 2. Illustration of reactive power requirements as a function of POI voltage.

III. Reactive Capability Requirements for Wind and Solar PV Generators

PV plants and some types of wind generators use power converters. The reactive capability of power electronic converters differ from those of synchronous machines because they are normally not power-limited, as synchronous machines are, but limited by internal voltage, temperature, and current constraints. The sections below discuss reactive power capability of individual wind turbine generators and solar PV inverters. Customarily, when reactive capability of variable generation resources is specified for transmission interconnections, it is done at the Point of Interconnection (POI), which is the point at which power is delivered to the transmission.

A. Wind Generators

Wind generators with converter interface are often designed for operation from 90% to 110% of rated terminal voltage. Lagging capability may diminish as terminal voltage increases because of internal voltage constraints and may diminish as terminal voltage decreases because of converter current constraints. Leading capability normally increases with increasing terminal voltage. Doubly fed and full-converter wind generators are often sold with a "triangular," "rectangular," or "D shape" reactive capability characteristic, shown in Figure 3. This represents the reactive power capability of individual wind generators or PV inverters. Reactive power capability at the plant level is discussed in Section IV.

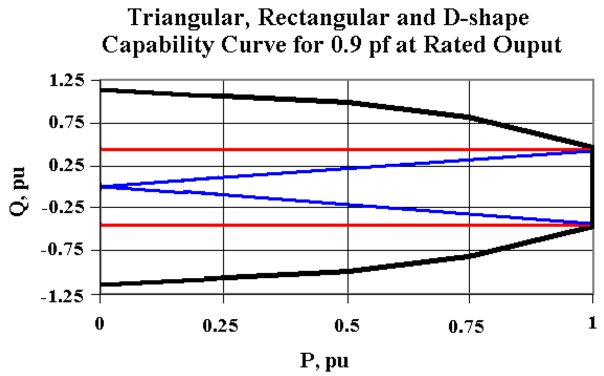

Fig. 3. Various reactive power capability curves for wind generators at nominal voltage.

Machines with a rectangular or D-shaped reactive capability characteristic may be employed to provide voltage regulation service when they are not producing active power (e.g., a low-wind-speed condition for a wind resource or at night for a PV resource, or during a curtailment) by operation in a STATCOM mode. However, this capability may not be available or may not be enabled by default. Unlike doubly fed or full-converter wind turbine generators, induction-based wind generators without converters are unable to control reactive power. Under steady-state conditions, they absorb reactive power just like any other induction machine. Typically, mechanically switched capacitors are applied at the wind generator terminals to correct the power factor to unity. Several capacitor stages are used to maintain power factor near unity over the range of output.

B. PV Inverters

PV inverters have a similar technological design to full-converter wind generators, and are increasingly being sold with similar reactive power capability. Historically, however, PV inverters have been designed for deployment in the distribution system, where applicable interconnection standards (IEEE 1547) do not currently allow for voltage regulation. Inverters for that application are designed to operate at unity power factor, and are sold with a kilowatt (kW) rating, as opposed to a kilovolt-ampere (kVA) rating. Furthermore, at low DC Voltages (MPP voltage) many PV inverters cannot provide full reactive power support (overexcited). With the increased use of PV inverters on the transmission network, the industry is moving towards the ability to provide reactive power capability. Some PV inverters have the capability to absorb or inject reactive power, if needed, provided that current and terminal voltage ratings are not exceeded. Considering that inverter cost is related to current rating, provision of reactive power at "full output" means that the inverter needs to be larger for the same plant MW rating, which comes at a higher cost compared to existing industry practice. In principle, inverters could provide reactive power support at zero power, similar to a STATCOM. However, this functionality is not standard in the industry. PV inverters are typically disconnected from the grid at night, in which case the inverter-based reactive power capability is not available. This practice could, of course, be modified, if site conditions dictate the use of reactive capability during periods when generation is normally off-line.

IV. Reactive Capability of Variable Generation Plants

Reactive power requirements for interconnection are specified at the POI. Between the POI and the generator terminals is a series of collection feeders designed to collect the output power of each generator. Given the spatial dispersion of the generators for a given system, the added impedance will impact the reactive power delivered at the POI relative to the generators reactive power contribution. This is an important consideration for wind and solar plants. First of all, it means that several technical options can be considered in the plant design to meet interconnection requirements. Technically, a plant with inverter-based wind or solar generators could rely on the inverters to provide part or all the necessary reactive power range at the POI. It may be more economical to use external static and dynamic devices such as a STATCOM, an SVC, or mechanically switched capacitors (MSCs). The additional amount of reactive support required depends on the reactive capability of individual wind generators of PV inverters and how it is utilized. Sometimes, external dynamic reactive support is required to assist with voltage ride-through compliance.

During periods of low wind or solar resource, some generators in the plant may be disconnected from the grid, and the DC voltage for solar PV inverters may limit the reactive power capability of the inverters. This should be taken into consideration when specifying reactive power capability for variable generation plants. Below a certain output level, it makes sense for the specification to show a reduced power factor range, or a permissive MVAr range. Figure 4 shows several possible reactive power capability specifications for variable generation, applicable at the POI.

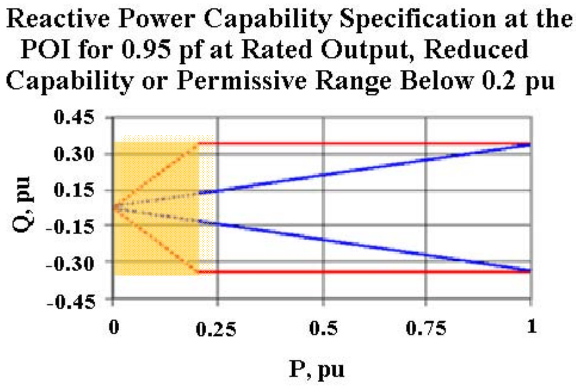

Fig. 4. Example of reactive capability specifications at the POI. At low output levels, as indicated by the shaded area, a permissive reactive range may be considered.

The interconnection requirements such as those shown in Figure 4 are often applied to transmission-connected wind power plants. In the case of PV, a requirement to maintain reactive power range at full output represents a change with respect to historical industry practice. This cost impact could be substantial if the PV plant relies on the PV inverters to provide a portion or all of the required plant-level reactive power capability. In order to achieve a power factor range of 0.95 lead or lag at the POI at rated plant output using only the inverters, the total inverter rating would have to increase by as much as 10%, considering reactive losses. It should be noted that both PV plants and inverter-based wind plants are technically capable of providing reactive capability at full kVA output. The difference is that such a requirement is new to the solar industry compared to the wind industry. In order to keep pace with the needs of the industry more inverter manufactures have "de-rated" their inverters and now provide both a kW and kVA rating.

In addition to the reactive capability versus output level discussed above, a complete specification should address the expected reactive capability during off-nominal voltage conditions, as illustrated in Figure 2.

V. Static vs. Dynamic Reactive Capability

Transmission Operators may specify both a dynamic range and a total range of reactive operation. Some Transmission Operators, for example, may specify a dynamic range of 0.95 lead to lag and a total range of 0.95 lead, 0.90 lag, indicating a need for smooth and rapid operation between 0.95 lead and lag, but allowing for some time delay for lagging power factors below 0.95. Dynamic reactive capability from converters can be provided almost instantaneously in a manner similar to that of synchronous machines, responding almost instantly (i.e., within a cycle) to system voltage variations, to support the system during transient events, such as short circuits, switching surges, etc. Fixed capacitors or reactors can be used to shift the dynamic reactive capability toward the lagging or leading side, respectively, as needed. If there is inadequate dynamic reactive capability available from the variable generation resources, it may be necessary to supplement the variable generation resources with an SVC or a STATCOM.

Non-dynamic reactive sources, such as supplemental mechanically switchable capacitors or reactors, can be installed to increase total (but not dynamic) reactive capability. Breaker times are in the range of cycles, not seconds. However, once disconnected, capacitors cannot be re-inserted without first being discharged (unless synchronous switching is used). Normally, discharge takes five minutes. Rapid discharge transformers can be applied to execute discharge in a few seconds. Good engineering practice requires that consideration be given to operation of switched reactive resources. For example, it is sometimes required that lagging reactive capability be placed in service as a function of variable generation output, irrespective of system voltage conditions. A Transmission Operator may require, for example, that capacitors be placed in service to compensate for transmission reactive losses whenever the output of a wind park exceeds 90% of rated capability. If the system voltage is high and the turbines are already operating at the leading power factor limit, placing capacitors in service may cause a high transient and steady-state overvoltage that can result in turbine tripping and other operational difficulties. It may be necessary to adjust transformer taps to bias turbine voltages in a safe direction if such operation is necessary.

VI. Operational Considerations

Reactive capability on transmission systems is typically deployed in voltage regulation mode. The transmission system operator provides a voltage schedule and the generator (conventional or variable generation) is expected to adjust reactive output to keep the voltage close to the set point level. Normally this is done by either regulating the resource's terminal voltage on the low side of the resource's main transformer. Another emerging practice is to adjust reactive output per a "reactive droop" characteristic, using the transmission voltage. Reactive droop in the range of 2% to 10% is typically employed. A typical droop of 4% simply means that the resource will adjust reactive output linearly with deviation from scheduled voltage so that full reactive capability is deployed when the measured voltage deviates from the scheduled voltage by more than 4%. A 1% deviation results in 25% of available reactive capability being deployed, etc. A voltage deviation less than the deadband limit would not require the resource to change reactive power output.

The specifications of the reactive droop requirement (e.g., the deadband of the droop response, together with the response time to voltage changes) may lead to requirements for dynamic reactive power support as well as potentially fast-acting plant controller behavior. Reactive droop capability has yet to be demonstrated in the field for solar PV plants, although there are no technical impediments to the implementation of such a control scheme. Individual wind generators and solar PV inverters typically follow a power factor, or reactive power, set point. The power factor set point can be adjusted by a plant-level volt/var regulator, thus allowing the generators to participate in voltage control. In some cases, the relatively slow communication interface (on the order of several seconds) of inverters limits the reactive power response time.

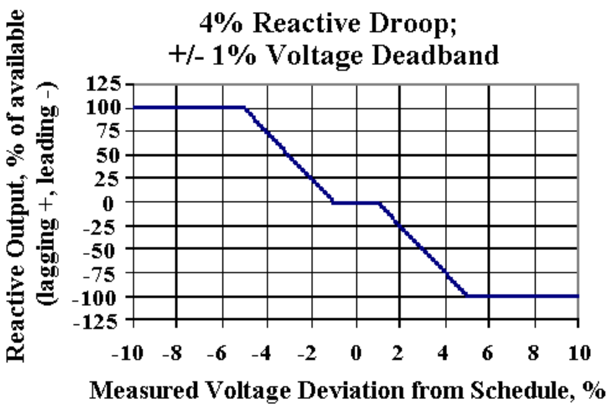

Fig. 5. Example of Reactive Droop control with Deadband

Reactive droops of less than 2% for voltage regulation on the transmission system are essentially "bang-bang" voltage controls that may introduce oscillations, cause excessively rapid voltage fluctuations, and deplete reactive reserves for contingencies. They may be necessary in some weak systems, but they should generally be avoided, if possible. For large plants connected to the transmission system, reactive power control (fixed Q) and power factor control (fixed ratio of Q to P) is not generally used because they can result in inappropriate response to system voltage fluctuations and they generally detract from local system voltage stability. However, it should be noted that reactive or power factor control may be desirable when connected to a very stiff bus relative to the plant size. Moreover, power factor control is generally required for distribution-connected systems.

VII. Recommendations for Modification of Existing NERC Standards

NERC should consider revisions to its Facility Design, Connections, and Maintenance (FAC) and Voltage and Reactive (VAR) standards to ensure that reactive power requirements for all generators are addressed in a technically clear and technology-neutral manner. As with all new or changing requirements, appropriate consideration should be given to the applicability to existing generators. Suggested updates are as follows:

• Consider adding a clarification to FAC-001 expanding R.2.1.3 or as an appendix, stating that interconnection standards for reactive power must cover specifications for minimum static and dynamic reactive power requirements at full power and at partial power, and how terminal voltage should affect the power factor or reactive range requirement (see Section IX for technical guidelines) [4].

• Consider modifying VAR-001 to include the term "plant-level volt/var controller" (in addition to "AVR"), which is more appropriate for variable generation. Specific recommended changes are underlined below [5]:

"VAR-001 R4. Each Transmission Operator shall specify a voltage or Reactive Power schedule at the interconnection between the generator facility and the Transmission Owner's facilities to be maintained by each generator. The Transmission Operator shall provide the voltage or Reactive Power schedule to the associated Generator Operator and direct the Generator Operator to comply with the schedule in automatic voltage control mode (AVR or plant-level volt/var regulator in service and controlling voltage)."

A large amount of variable generation, including most of the solar PV deployment, will be relatively small plants with capacity below the threshold specified in the existing NERC Registry Criteria, and connected at voltages below 100 kV. This includes residential and commercial systems, as well as larger plants connected to the distribution or sub-transmission system. To the extent that these systems, in aggregate, can affect the reliability of the bulk grid, the FAC and VAR standards should be extended or revised to accommodate them. A prospective NERC standard addressing reactive requirements for smaller plants should recognize that distribution-connected variable generation plants have traditionally been operated in power factor control mode.

VIII. General Recommendations for Standards Development and Reconciliation

For the most part, existing NERC and FERC interconnection standards were developed with a class of equipment in mind (synchronous generators), and do not fully define performance requirements for reactive power support. This has resulted in unclear, inconsistent, and sometimes inappropriate interconnection reactive power requirements for generators, especially variable generation. Specific recommendations are as follows:

• NERC should promote greater uniformity and clarity of reactive power requirements contained in connection standards that Transmission Operators have issued pursuant to FAC-001. NERC, FERC, and other applicable regional standards should be reconciled.

• NERC should consider initiating a Standards Authorization Request (SAR) to establish minimum reactive power capability standards for interconnection of all generators, and provide clear definitions of acceptable control performance (see Section IX below for technical guidelines).

IX. Technical Guidelines for Specification of reactive Power Requirements

Variable generation technologies are technically capable of providing steady-state and dynamic reactive power support to the grid. Based on a review of best practices and operating experience, we offer the following technical guidelines for specification of reactive power capability and control requirements for interconnection of generating plants to the transmission system:

A. Applicability

Generator interconnection requirement for reactive power should be clearly established for all generator technologies. NERC adheres to the notion of technology neutrality when it comes to reliability standards; however, certain unique characteristics of variable generation may justify different applicability criteria or appropriate variances. Technology differences were considered in nearly all international interconnection standards for wind generation [6]. A key consideration is whether reactive power capability should be a baseline requirement for all variable generation plants, or if it should evaluated on a case-by-case basis. The later approach was adopted in FERC's Order 661-A. A thorough analysis to establish the need for reactive power support necessitates the establishment and application of clear and consistent criteria for reactive planning that takes into account system needs such as steady-state voltage regulation, voltage stability, and local line compensation requirements under normal and contingency conditions. Without consistent application of a set of planning criteria, establishing the "need" for reactive power can become a complicated process considering that multiple transmission expansion plans and generator interconnection requests that may be under evaluation. Application of a baseline requirement for reactive power to all generators would address this concern to a large extent. However, in some situations, additional reactive power from variable generation plants may not contribute appreciably to system reliability. NERC should consider giving transmission planners some discretion to establish variance based on the characteristics of their transmission system.

B. Specification of Reactive Range

The reactive range requirement should be defined over the full output range. A Q versus P chart should be used for clarity. A baseline capability of ±0.95 lead/lag at full output and nominal voltage should be considered. Unlike most conventional generators, variable generation plants routinely operate at low output levels, where it is difficult and unnecessary to operate within a power factor envelope. All or a portion of the generators in a wind or solar plant may be disconnected during periods of low wind or solar resource, which means that reactive power capability may be considerably reduced. For these reasons, it makes technical sense to allow variable generation to operate within a permissive reactive power range (as opposed to a power factor envelope) when the active power level is below a reasonable threshold such as 20% of plant rating.

C. Impact of System Voltage on Reactive Power Capability

It should be recognized that system voltage level affects a generating plant's ability to deliver reactive power to the grid and the power system's requirement for reactive support. A Q versus V chart could be used to describe the relationship between system voltage and reactive power. A reduced requirement to inject vars into the power system when the POI voltage is significantly above nominal and a reduced requirement to absorb vars when the POI voltage is significantly below nominal should be considered.

D. Specification of Dynamic Reactive Capability

The standard should clearly define what is meant by "Dynamic" Reactive Capability. The standard could specify the portion of the reactive power capability that is expected to be dynamic. For example, the baseline requirement could be that at least 50% of the reactive power range be dynamic. Alternatively, the definition of control performance (e.g., time response) can be used to specify the desired behavior.

E. Definition of Control Performance

Expected volt/var control performance should be specified, including minimum control response time for voltage control, power factor control, and reactive power control. For example, a reasonable minimum response time constant for voltage, power factor, or reactive power control may be 10 seconds or comparable to a synchronous generator under similar grid conditions. Consistent with existing VAR-002 [7], voltage control should be expected for transmission-connected plants; however, as previously discussed, power factor control is a technically reasonable alternative for plants that are relatively small. An interim period for the application of precisely defined control capabilities should be considered.

F. Effect of Generator Synchronization on System Voltage

Synchronization of generators to the grid should not cause excessive dynamic or steady-state voltage change at the point of connection. A 2% limit may be considered as a baseline.

G. Special Considerations

NERC should investigate whether transmission operators can, under some conditions, allow variable generating plants to operate normally or temporarily at an active power level where dynamic reactive capability is limited or zero. If needed for reliability and upon command from the system operator, these plants could temporarily reduce active power output to maintain a reactive range. Such an approach could make sense depending on the size of the plant and its location on the system. The possibility of operating in this manner could be considered as part of the interconnection study.

H. Technical Alternatives for Meeting Reactive Power Capability

The reactive power requirements should be applicable at the point of interconnection. Technical options to meet the interconnection requirements should not be restricted. For example, reactive power support at the point of interconnection need not be provided by inverters themselves; they could be provided by other plant-level reactive support equipment.

I. Commissioning Test

Commissioning tests, which are part of the interconnection process, often include a test to demonstrate plant compliance with reactive power capability requirements. Commissioning tests often include verification of reactive power capability at rated power as a condition to allow operation at that level of output. An alternative approach should be used for variable generation plants, considering that the output cannot be controlled. For example, PV plants may be designed such that maximum output is reached only during certain months of the year, and it may not be possible to conduct a commissioning test at rated power output for several months.

X. Conclusion

As variable generation continues to grow in capacity on the electric utility grid it is necessary to transition from the operational practice of reactive support being solely provided by synchronous generators. Advances in the technology used for variable generation has now provided them with the ability for voltage regulation and reactive support, compared to the older induction generators and line commutated devices. This paper presented an overview of the existing practices for reactive power support in the electric grid and provided a set of recommendations to changes in these practices that can be used by industry in order to transition variable generation from being a non-entity in reactive power support to being a contributor to enhanced grid reliability.

XI. References

[1] *FERC Order No. 661-A*, December 12, 2005. [Online]. Available: www.ferc.gov/EventCalendar/Files/20051212171744-RM05-4-001.pdf

[2] *Standard for Interconnecting Distributed Resources with Electric Power Systems,* IEEE 1547-2003, June 2003.

[3] *FERC Standard Large Generator Interconnection Agreement (LGIA)*, June 16, 2005. [Online]. Available: www.ferc.gov/industries/electric/indus-act/gi/stnd-gen/2003-C-LGIA.doc

[4] *NERC Standard FAC-001-0 Facility Connection Requirements,* February 8, 2005. [Online]. Available: www.nerc.com/files/FAC-001-0.pdf

[5] *NERC Standard VAR-001-2 Voltage and Reactive Control,* August 5, 2010. [Online]. Available: www.nerc.com/files/VAR-001-2.pdf

[6] *EWEA Generic Grid Code Format for Wind power Plants,* November 29, 2009. [Online]. Available: www.ewea.org/fileadmin/ewea_documents/documents/publications/091127_GGCF_Final_Draft.pdf

[7] *NERC Standard VAR-002-1.1b Generator Operation for Maintaining Network Voltage Schedules,* February 10, 2009. [Online]. Available: www.nerc.com/files/VAR-002-1_1b.pdf

XII. Biographies

Abraham Ellis (SM'02) is a Principal Member of Technical Staff at Sandia National Laboratories in Albuquerque, New Mexico, where he leads the PV grid integration program area. Prior to joining Sandia, he worked in the Transmission Planning and Operations at Public Service Company of New Mexico, where he was responsible for transmission expansion and generation interconnection studies. He has served as Chairman of the IEEE Dynamic Performance of Wind Power Generation Working Group, and currently chairs the WECC Renewable Energy Modeling Task Force (REMTF). Abraham received a MSEE and Ph.D. degrees in Power Systems from New Mexico State University in 1995 and 2000, respectively. Abraham is a registered Professional Engineer in New Mexico.

Robert Nelson (M'84) received his Master of Engineering in Electric Power Engineering from Rensselaer Polytechnic Institute. He has been with Siemens since 1999 when Siemens purchased Westinghouse Power Generation; prior to that he was with Westinghouse, starting in 1989. Prior to joining Westinghouse, Mr. Nelson worked as a bulk system planning engineer for Boston Edison, an operations engineer for the Florida Municipal Power Pool, and as a consulting engineer for RW Beck. Mr. Nelson has over 30 years of experience in transmission and generation operations and design. He has over 20 patents in various aspects of power generation and flexible ac transmission and he is the author of over 25 technical papers on power generation and transmission.

Edi Von Engeln received a BSEE from Colorado Tech in 1992. He has worked in various sectors of the power industry from electrical testing to commercial and light industrial design. Mr. von Engeln was involved in the design and commissioning of several combined cycle power plants and protective relaying systems while at Utility Engineering, a former subsidiary of Xcel Energy. Mr. von Engeln completed a Masters in Engineering, with a Power Systems emphasis in 2005 at the University of Colorado at Denver. He is now a Staff Engineer in Transmission Planning with NV Energy in Reno NV. Mr. von Engeln is a registered Professional Engineer in Colorado, California and Nevada.

Reigh Walling (F'05) is a Director of Energy Consulting for GE Energy and provides his recognized expertise to solve a range of power system issues as a consultant to electric power industry clients. Mr. Walling's consulting practice includes utility distribution and transmission systems, as well as grid integration of solar and wind generation systems. Mr. Walling received his Bachelor's and Master's Degrees in Electric Power Engineering from Rensselaer Polytechnic Institute, and is a registered Professional Engineer in Minnesota. He is a Fellow of the IEEE, has published over seventy technical papers and articles, and has been awarded twelve patents. In 2009, Mr. Walling was awarded the IEEE Power and Energy Society's Excellence in Power Distribution Award.

Jason MacDowell is a Principal Engineer for GE Energy Consulting in NY. His current focus is on performance and interconnection of wind generation into the bulk transmission system, modeling and model validation of wind plants and power system protection, and has authored many technical papers on these subjects. He was chairman of IEEE std. 551-2006 (the Violet Book) and is a balloting member of NERC Generator Verification Standards Drafting Team (GVSDT). He has lectured and provided consultation on Wind Power interconnection to governments, grid companies and generation owners in North America and Asia.

Leo Casey (M'81) received his Doctorate from MIT and Bachelors of Engineering from the University of Auckland, coming to the US as a Fulbright Scholar. He is the EVP of Engineering & CTO of Satcon Corporation, a provider of utility-scale, grid-connected renewable energy solutions for distributed power markets. He is Chairman of the High-Megawatt Power Conversion Program organized by Industry, DOE and NIST. He is an editor of the IEEE PES's Energy Conversion Transactions, and serves on NREL's Solar Advisory Panel.

Eric Seymour is responsible for corporate technology research in the areas of high power energy conversion and renewable energy. He is also Advanced Energy's lead designer for photovoltaic inverters above 250kW. Prior to joining Advanced Energy in 1997, he worked as an engineer for Niagara Mohawk Power Corporation. Eric holds a master's degree from the University of Wisconsin-Madison and bachelor's degree from Clarkson University, both in electrical engineering.

William Peter (M'10) received his Doctorate in Electrical Engineering from Stanford University and his Bachelors of Engineering from Dartmouth College. He is a Systems Engineer for SunPower Corporation, providing support on interconnection and grid integration issues for solar PV generators. Prior to working for SunPower, William worked for Australia's electricity market operator and regulator, and later for Senergy Econnect, a UK based renewable energy consultancy.

Chris Barker received his Bachelors of Science in Electrical Engineering from Northeastern University in 2003 and received his professional engineering license in California in 2007. He currently works for BEW/DNV as a Power Systems Engineer providing consultant work for utilities and project developers. Prior to joining BEW, Christopher worked for SunPower for seven years first as a Project Engineer responsible for the execution of utility scale interconnected solar power plants and later manager of System Engineering.

Brendan Kirby (M'76, SM'98) is a private consultant with numerous clients including National Renewable Energy Laboratory, AWEA, Oak Ridge National Laboratory, EPRI, Hawaii PUC and others. He served on the NERC Standards Committee. He recently retired from the Oak Ridge National Laboratory's Power Systems Research Program. He has 36 years of electric utility experience and has published over 150 papers, articles, and reports on ancillary services, wind integration, restructuring, the use of responsive load as a bulk system reliability resource, and power system reliability. He has a patent for responsive loads providing real-power regulation and is the author of a NERC certified course on Introduction to Bulk Power Systems: Physics / Economics / Regulatory Policy. Brendan is a licensed Professional Engineer with a M.S degree in Electrical Engineering (Power Option) from Carnegie-Mellon University and a B.S. in Electrical Engineering from Lehigh University. Publications are available at www.consultkirby.com, e-mail kirbybj@ieee.org

Joseph Williams (M'05) received his Master of Engineering (in Electrical Engineering) from the University of Idaho. He currently works as a renewable integration engineer for Sandia National Laboratories. Prior to joining Sandia Labs Mr. Williams has worked as a transmission planning engineer for Western Farmers Electric Cooperative, and an Engineer for Northrop Grumman Shipbuilding. Mr. Williams is a registered Professional Engineer in the state of Oklahoma.