UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Principles for Efficient and Reliable Reactive Supply and Consumption	Docket No. AD05-1-000

COMMENTS OF THE
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL
ON COMMISSION STAFF REPORT

The North American Electric Reliability Council, a New Jersey nonprofit corporation ("NERC")[1], is pleased to present these comments in response to the issues raised regarding reactive power supply in the 58 sets of questions in the February 4, 2005 Federal Energy Regulatory Commission staff's report, "Principles for Efficient and Reliable Reactive Power Supply and Consumption."

NERC recognizes the importance of an adequate reactive power supply and its contribution to maintaining system voltages and stability for the reliable operation of the interconnected electric grid. It also compliments the Commission for its effort in bringing to the forefront the technical and economic aspects of reactive power. Before addressing the specific questions in the Commission staff's report, we will state three general comments:

[1] NERC was formed after the Northeast blackout in 1965 to promote the reliability of the interconnected electric systems in North America. Its mission is to ensure that the bulk electric systems that serve North America are adequate, reliable, and secure. It works with all segments of the electric industry as well as customers to "keep the lights on" by developing and encouraging compliance with rules for the reliable operation and adequacy of supply of these systems. NERC comprises ten regional reliability councils that account for virtually all the electricity supplied in the United States, Canada, and a portion of Baja California Norte, Mexico.

1. **Local nature of reactive power.** Reactive power does not travel far on the transmission system, and many electrical and physical requirements determine where the reactive resources need to be placed and how they are used.
2. **Static and dynamic reactive power sources.** Static and dynamic reactive power sources are not substitutes for each other in all cases. They both play important roles, but their operation and deployment are often very different.
3. **Economic, pricing, and investment issues**. NERC does not believe it is appropriate to address specific economic, pricing, and investment issues associated with reactive power. We do, however, believe it is appropriate to request that whatever market or compensation rules the Commission adopts will: a) help ensure that sufficient reactive power reserves are developed in the right places, and b) allow the system operators to deploy those reserves in real time to maintain system reliability.

The remainder of our comments address those questions in the Commission staff's report that the deal with specific technical issues related to reactive power and their impact in maintaining the reliability of the interconnected bulk electric systems. These technical comments are the product of several NERC Planning Committee and Operating Committee subcommittees whose expertise spans a wide range of reactive power concepts and principles.

General

Q1: Should transmission providers report the value of real and reactive power on their systems? Would this help make better locational investment decisions?

Response: Not applicable (assuming "value" means dollars and not megawatts and megavars).

Q2: By not properly pricing reactive power are we missing opportunities to further increase reliability and efficiency?

Response: Improper pricing of reactive could impact supply. Having said this, NERC does not believe it should discuss the "proper pricing of reactive power" concept as it relates to system supply and will reserve comments on this now and in future questions.

Reactive supply to maintain a reliable system can be adequate if providers follow and meet individual system and regional criteria and the NERC reliability standards.

Q3: Should reactive power reserves be differentiated by quality as are real power reserves? Should dynamic reactive power be differentiated from static reactive power?

Response: Yes. Dynamic and static reactive resources have different characteristics and different applications. System planners and operators must be aware of these differences for the proper application and use of these resources.

Quality can be differentiated by response time, and reactive output as a function of voltage. Quality can also be determined by the "firmness" or reliability of supply. Adequate differentiation is generally achieved by classification of reactive resources as static or dynamic. In addition, reactive quality should consider the amount, location, and deliverability of the reactive resource. In some cases, it is better to have dynamic reserves (synchronized) instead of static reserves (components switched in or out of service).

The split between the required dynamic and static reactive power has to be computed on a case by case basis because the requirements can vary by system as well as by location and the nature of the contingency. Several empirical methods exist to determine this split, but have proved inadequate during post-mortem studies of system blackouts.

Q4: What are the relationships and differences among standard transmission assets, e.g., capacitors, FACTS devices and generators in reactive power supplied? Where do FACTS fit in? What is the effect of different outage rates?

Response: Generators with automatic voltage regulators are dynamic reactive resources. Capacitors are manually switched reactive sources, and static var compensators (SVCs)/Flexible AC Transmission System (FACTS) devices are capable of supplying a degree of automatic voltage regulating response. The various reactive power components should be differentiated by these and other "quality" considerations.

Another quality consideration is that many dynamic reactive devices can, on demand, increase their output above the normal rating for short periods of time. Synchronous machines can produce several multiples of their normal reactive power rating for short periods. Dynamic FACTS devices can be more limited than synchronous machines but can be designed to provide additional short-term capability. Static reactive devices, on the other hand, lack this increased short-term capability but tend to be less costly. FACTS devices as well as synchronous machines depend on reliable station service. In contrast, static devices do not require station service or cooling. However, they lose effectiveness when the voltage decreases by the square of the per unit voltage.

It should be noted as well that generators with bus-fed excitation systems have a limited capability to provide this short-term reactive capability.

Q5: How, what and when are dispatch signals for reactive power sent to market participants?

Response: From an operations perspective, transmission operators establish the voltage schedule and reactive power requirements. These requirements are dispatched or communicated through verbal instructions by the transmission operator to the generator operator. As system conditions change, the reactive power output may be adjusted as directed by the transmission operator by instructing the generator operator to adjust the output voltage schedule of the generator(s) to meet the changing system conditions.

From a planning perspective, voltage schedules are provided for all critical generators to follow.

Currently, most ISO market systems use DC Security Constrained Optimal Power Flow (SCOPF) programs in dispatching generators (i.e., unit commitment). DC SCOPF programs do not consider reactive power and voltage constraints of the system, including availability of reactive power. This approach is understandable because the market focuses on real power and not reactive power. DC SCOPF programs assume that voltages are equal to 1.00 per unit at all buses. Therefore, units will always be dispatched optimally for real power only.

AC SCOPF programs, in dispatching generators (i.e., unit commitment), consider the reactive power and voltage constraints of the system, and will optimally dispatch generators if reactive power is needed.

Q6: Should the general approach to voltage scheduling be reexamined to improve reliability and efficiency?

Response: No, because reactive power requirements are location specific. A coordinated approach to voltage scheduling within a region as well as between neighboring regions should continue to be followed. Generally, the voltage scheduling system within system operations is effective and the process works adequately.

Having said this, if reliability benefits can be extracted from an enhancement, then the effort should be put forth. However, the basis used to support reexamination of voltage scheduling needs to be further defined and clarified.

Q7: Should generators be required to supply an identified range of reactive power without compensation?

Response: Not applicable.

System Planning

Q8: How are reactive power reserves determined? How are reactive power reserves quantified?

Response: Several different approaches may be used, including static and dynamic methodologies. However, reactive power reserve requirements are typically location specific and are based on system analysis including contingencies (e.g., voltage stability analysis such as PV and QV studies), without a system-wide quantification of reactive reserve.

In general, while the calculation of reactive power reserves is possible, the practical real-time measurement of adequate reactive power reserves is difficult.

A transmission operator should have its own reactive adequacy and reserve methodologies and determine how reactive power reserves are quantified within its footprint. Local reactive reserves are necessary and vital to the interconnected EHV transmission system, and reactive power resources, demand, and reserves need to be monitored and assessed at the reliability coordinator level.

Q9: Do we have enough reactive power capability in our generators to meet the reliability needs of our power system? If so, how do we know?

Response: Generators by themselves do not generate enough reactive power to meet reliability needs.

Reactive power from generators is one component of ensuring voltage stability, but it is not the only component. Reactive power compensation is also provided by static transmission reactive power sources (capacitor banks, reactive banks, and FACTS devices) and load power factor correction at the load or on the distribution system primarily through the use of fixed, switched, and seasonally switched banks of capacitors. System studies are performed to determine the reliability needs of the power system, including adequate reactive power capability. If individual system and regional criteria and NERC reliability standards are followed, each system should have adequate amounts of dynamic and static reactive power resources.

Q10. What should the static reactive power capabilities (or reserves) be? What should the dynamic reactive power capabilities be? What should the reactive power capabilities be used for?

Response: Static and dynamic capabilities are location dependent and should be determined by system (regional and transmission operator) studies. Both types of reactive power capabilities should be used to keep voltages within acceptable limits for the full range of contingencies as described in individual system and regional criteria and NERC reliability standards. The dynamic reactive power capabilities should be based on the locational reactive power needs complemented by the static reactive power capabilities incorporated close to the load. Sufficient dynamic reactive capability is needed on a transmission system to recover from a contingency event without cascading, or wide area voltage collapse, or large scale loss of load.

The total of the static and dynamic reactive power capability should exceed the total reactive power 'absorbed' by the load, the transmission lines, and transformers in the system by an 'adequate' margin (also called the reserves). The computation generally is made for a variety of contingencies. The difficulty is in exactly computing what the 'reserves' should be and what the static and dynamic portions should be that will be 'adequate' for various operating conditions. This analysis has to be done on a case-to-case basis. Rule-of-thumb or arbitrary numbers or ranges will not work. To date, there is no generally applied reactive power reserve margin.

Q11. Should reactive power reserve requirements be locational and/or better defined like real power reserves?

Response: Reactive reserve requirements are localized in nature due to physics, and vary from geographic area to area. Due to the reactive power limitations across transmission lines, reactive power resources need to be located closer to the demand than the real power resources. Reactive power reserves cannot be defined like real power reserves.

The term “reactive power reserve requirements” is not widely used throughout the industry in the same manner that the term “real power reserves” has been used. Real power reserves are used to maintain frequency following a generation contingency, while reactive power reserves are generally used to maintain voltage stability after a contingency.

Q12. Should reactive power reserves be procured competitively?

Response: Not applicable.

Q13. Are there optimal design characteristics with respect to reactive power for generators, transmission and load? If so, how are they derived? Or, do they depend on system characteristics? If so, how are they derived?

Response: Optimization problems always need to ask what one is trying to maximize or minimize. Optimization will depend upon system characteristics (e.g., line charging, reactive load, etc.) as well as the characteristics of reactive power sources. It may not be practical to apply optimization principles here.

The power factor of the load in general should be corrected as close to unity, to the greatest extent practical, to minimize the amount of generation dynamic reactive resources required to supply the load reactive requirements. Basic load power factor correction/compensation is more efficiently accomplished with static (fixed or switched) shunt capacitors allowing dynamic resources to be available for voltage control and regulation or contingencies.

From a planning perspective, there is no one optimal mix of reactive supply for generation, transmission, and distribution. There may be several mixes of supply that will satisfy individual system and regional criteria and NERC reliability standards.

Generation

Q14: What is "good utility practice" for reactive power supply and reserves from generators?

Response: Assuming static and dynamic reactive power supplies have been properly planned and operated, all generators within an area should be capable of holding an assigned voltage schedule for normal system conditions and have sufficient dynamic reactive capability to provide for voltage regulation, and maintain adequate system voltages following contingencies specified through individual system and regional criteria and NERC reliability standards. Generators should also be able to both supply and absorb vars to the extent required by the system for pre- and post-contingency conditions with consideration to reasonable equipment capabilities.

Generators should provide valid machine data for use in planning models.

Q15. What reactive power capabilities, if any, should be required of generators without compensation?

Response: Not applicable.

Q16. Is a generic power factor requirement the best approach to reactive power capabilities or should it be based on system requirements?

Response: A generic range of 0.95 leading to 0.95 lagging at the point of interconnection should be adopted. This approach is the best course of action as it will allow for the changing system requirements over time, which will continue, in turn, to dictate needed reactive power capabilities.

A generic power factor correction for reactive power capabilities and a generic load power factor compensation requirement are both necessary, lacking a detailed assessment of system requirements.

Q17: Are the interconnection standards with respect to reactive power capability clear? Is it clear what it means to have a 0.95 power factor requirement in the Large Generator Interconnection Procedures (LGIR)?

Response: From a reliability standpoint, FERC LGIA 9.6.1.1. defines the point of interconnection and is clear. However, consideration of generators operating under automatic voltage regulator control may require more definition. For example, for AVR operation, a generator voltage setpoint needs to be stated not a power factor number. Reactive power requirements should be based on providing a specified power factor operating range at the point of interconnection, along with the ability to maintain a scheduled voltage and voltage range.

Q18: Where should the power factor requirement for generators be measured at the high or the low side of the step-up transformer?

Response: The power factor requirement for generators should be measured at the point of interconnection, in most cases the high side of the generator step-up transformer. Otherwise, the generator step-up transformer requirements, such as impedance, would also need to be specified along with information about plant auxiliary load (MW and Mvar) at the generator terminal bus.

Q19: Should there be the reactive power requirements for non-synchronous generators (wind, solar)? If so what?

Response: Yes, the reactive power requirements should be the same at the point of interconnection as for synchronous generators.

Q20: What is the role of distributed generation in providing reactive power?

Response: Distributed generation should either provide its own reactive requirement, or have a vicinal reactive compensation by the generation owner or load serving entity. It should not add to the reactive burden on the system. Alternately, distributed generation can provide local voltage regulation and contribute to power factor correction in subtransmission and distribution facilities where it is connected. However, there is no assurance that it can be controllable from a transmission standpoint. Distributed generators will likely be too small to significantly contribute to dynamic supply that responds to bulk system contingencies.

Q21: What are the options for reactive power output as a function of investment in generator design?

Response: Not applicable.

Q22: Does it make economic sense to oversize the generator or the turbine?

Response: Not applicable.

Q23: Should required reactive power capability differ based on location on the system? For instance, should we allow generators distant from load to have less capability?

Response: No, as a minimum all generators should meet LGIA 9.6.1.1. One cannot assume that generators distant from the load should have less capability; they might need more. For example, from a transient stability perspective, a distant generator may require more reactive capability. Generation remote from the load also may require greater reactive compensation to transfer power. Generator interconnection studies should identify whether additional reactive compensation is required. Further, one cannot assume that loads will not develop in the vicinity of the generator.

Q24: What are the advantages of supplying dynamic reactive power locally from distributed energy resources (DER)?

Response: The ideal place for reactive compensation is the place where the reactive load is located. DER's could, mixed with switched capacitor banks, be an ideal source for variable reactive power needs. However, as stated earlier, distributed energy sources on the distribution system are not likely to be able to solve bulk system reactive power and voltage stability requirements.

Q25: Should there be interconnection standards with respect to merchant transmission?

Response: Yes, individual system and regional criteria and NERC reliability standards must be met.

NERC does not distinguish between types of transmission ownership. All transmission must be integrated into the interconnected transmission system and required to supply all of its reactive demand (including commutation and line losses) to its design capability.

Q26: Can thermal transmission constraints be relieved by supplying or consuming reactive power? If so, how and to what extent?

Response: Yes, but not to a great extent on the bulk transmission system and as such there would be little benefit on the bulk transmission system. There is more potential benefit on sub-transmission and distribution systems.

In theory, reducing reactive power flow on a transmission line could reduce thermal loading. However, if incremental reactive power flow causes an overload, the transmission line was probably near its thermal limit due to real power loading.

Line thermal ratings are basically ampere ratings. By keeping bulk system voltages within normal limits, and most of the current used to supply real power rather than reactive power, line thermal capabilities can be more efficiently utilized.

Q27: Can nonthermal transmission constraints be relieved by supplying or consuming reactive power? If so, how and to what extent?

Response: Yes. In general, voltage stability constraints can be relieved by reactive power resources. In some cases, angular stability limits also can be increased or improved by reactive power resources. However, the means and the extent to which a constraint could be relieved can only be determined for individual cases based on specifics of supply and type or severity of the constraint.

Systems Operators

Q28: How are voltage schedules determined? Who decides? What are the criteria? Are they optimized? Are generators required to operate at a given power factor, or are they required to maintain a specified voltage? Are generation costs incorporated into voltage schedule decisions?

Response: Voltage schedules are usually determined by the transmission operator based on planning or operation-planning system studies. Generators are typically assigned a voltage schedule to meet normal and contingency system requirements.

The voltage schedule is generally such that under peak load conditions, the generator’s overexcited reactive capability should not be exceeded and under light load conditions, the generator’s underexcited reactive capability should not be exceeded.

Automatic over-excitation and under-excitation limiters in generator automatic voltage regulators ensure that reactive capability limits are not exceeded during operation.

Transmission voltage is a transmission system performance characteristic. Therefore, transmission operators almost always set transmission system voltages. Generators are expected to operate to those voltage schedules rather than a specific reactive output. Generators also are required to vary reactive input and output up to the generator's maximum limits to maintain the prescribed voltage. This is accomplished by having the generator's automatic voltage regulator set to regulate generator terminal voltage, in combination with other generator operator actions. The transmission operator relies upon the generator operator to perform this function, and the transmission operator operates transmission and distribution controls (reactive resources, tap changers, etc.) to maintain adequate overall voltage stability.

N/A (for last question)

Q29: Should the approach to voltage management and scheduling be re-examined? How does voltage scheduling affect economic operations? Should there be incentives for voltage management?

Response: No. Transmission operators should continue to continuously evaluate their voltage scheduling and management methodology to ensure the reliability of the system. To enhance this process, NERC is also discussing whether additional voltage or reactive power operating standards are needed.

When sufficient reactive support (capability, reserves, or controllable load) is not available to maintain the voltage schedules, it may become necessary for the transmission operator or reliability authority to curtail power transfers.

N/A (for last question)

Q30: Should system operators take transmission lines out of service to balance reactive power?

Response: Generally, taking transmission lines out of service is not an effective option, and potentially makes the system weaker and more vulnerable for the next contingency. Removing a transmission line can degrade overall system reliability because it reduces the connectivity of the transmission network and should not be planned as an alternative to proper reactive resource management practices. However, it can be effective in some extreme cases to mitigate high voltages during light load periods when the system is in an unusual operating condition.

Q31: What instructions or signals (prices, real power, reactive power, voltage, frequency) does the system operator send to generators, transmission and load? (In particular, for reactive power)

Response: Generally, the transmission operator submits voltage schedules to generator plants or unit operators. In addition, the transmission operator will use manual control to adjust static reactive power devices on the transmission system. In some cases, switching of the static devices may be automatic to control voltage within a pre-determined voltage range.

Q32: What information does the system operator have on generator capabilities and how is it used?

Response: The transmission operator and balancing authority should have all appropriate generic capability information for all generators connected within their areas (net-MW seasonal demonstrated maximum net capabilities, operational low and high limits, net- and gross-Mvar lagging/leading capabilities) and instantaneous net MW, Mvar outputs, and terminal and high-side voltages.

Q33: Under what circumstances might a generator be required to reduce real power output due to a shortage of reactive power?

Response: In general, when a generator is producing near its maximum MW output, it may be able to reduce its real power output and produce more reactive power to compensate for a reactive power deficiency.

It is possible this could happen, but without valid justification, it is unlikely that an operator would make that request for other than a system emergency situation or a potential emergency situation.

For example, generators may be instructed to reduce megawatt output to allow additional megavar production when system voltages are at or below system operating limits (or projected to drop below operating limits on a contingency basis). The degree of megawatt reduction depends on where the generator is operating on its real/reactive D-curve. However, that said, many RMR (Reliability Must Run) units are scheduled (uneconomically) to serve this very need.

Q34: Are phase shifters set to get optimal system performance? If so, how?

Response: Phase shifters or phase angle regulating transformers control the flow of real power to maintain line loadings within applicable ratings and are also used as a bridge between systems where there are large phase angle differences. Phase shifters do not have a significant wide area effect on voltage control.

Q35: Are D-curve parameters of each generator available to the control area or system operator?

Response: Yes, D-curve parameters of generators are generally available or could be made available if requested. The practice varies throughout the industry. Care should be used in applying generator D-curves. Other factors, such as excitation system limiters, step-up transformer taps, and plant auxiliary equipment can affect generator performance, and the D-curves may not reflect the impact of these other factors.

Costs

Q36: What are the cost differences among reactive power from capacitors, FACTS and generators?

Response: Not applicable.

Q37: What is the incremental investment cost for generator reactive power capability?

Response: Not applicable.

Order No. 888 Rate Design

Q38: Are independent power suppliers being compensated comparably to the generation supplied that is owned by transmission owners?

Response: Not applicable

Q39: Can the capital costs of reactive power capability be effectively unbundled? Should reactive power pricing be unbundled? If so, how?

Response: Not applicable

Q40: Does Opinion No. 440 properly encourage efficient reactive power capabilities? If so, how? If not, how should it be changed?

Response: Not applicable

Q41: How can we streamline the Opinion No. 440 process for establishing rates?

Response: Not applicable

Q42: How does the reactive power capability of existing and interconnecting independent power producers impact system reliability?

Response: Quite simply, the same as any other generators. Without sufficient coordinated reactive capability from all generators, the reliability of the system could not be maintained. All generators need to meet individual system and regional criteria and NERC reliability standards.

RTO Markets

Q43: What software advances are needed for efficient and reliable reactive power markets?

Response: Not applicable.

Q44: Should reactive power capability requirements be locational and procured in capacity markets?

Response: From a reliability and technical perspective, reactive power capabilities must be locational. Development of a reactive power market is outside of NERC's scope.

Q45: How are generator capabilities used in the ISO/RTO markets?

Response: NERC prefers to leave this question to the ISOs and RTOs to answer.

Q46: How should merchant generators and transmission be compensated for the capability to provide reactive power?

Response: N/A (The remainder of these questions deal with reactive power compensation, and NERC does not believe these questions are reliability issues.)

Q47: How should distributed energy resources (DER) be compensated for supplying dynamic reactive power?

Response: Not applicable.

Q48: How should reactive power rates and markets be designed in RTOs? Should there be different prices for reactive power produced by static and dynamic sources?

Response: Not applicable.

Q49: Are there incentives for generation, transmission and load to increase their capability, e.g., by increased cooling where needed? If not, why not?

Response: Not applicable.

Q50: Should reactive power be paid opportunity cost compensation based on the real power price?

Response: Not applicable.

Q51: Should a separate reactive power capacity market be developed? If so, what should the capacity supply obligation time frame be? Daily? Monthly? Annually?

Response: Not applicable.

Q52: Should there be different types of payments or markets for reactive power from different sources (generators, capacitors, SVC, STATCOM, synchronous condensers, etc)?

Response: Not applicable.

Q53: What are the computational impediments to including a reactive power in the day-ahead and real-time markets?

Response: Not applicable.

Q54: What are the noncomputational impediments to including a reactive power in the day-ahead and real-time markets?

Response: Not applicable.

Q55: What kind of market power mitigation would be needed?

Response: Not applicable.

Q56: What is the magnitude of reactive power value (price) relative to real prices?

Response: Not applicable.

Q57: What is the volatility of reactive value (price) compared to real power?

Response: Not applicable.

Q58: How would a reactive power market reflect the high opportunity cost (a cascading blackout) of insufficient reactive power? Is the market suspended for emergency situations?

Response: Not applicable.

Conclusion

NERC is dedicated to enhancing the reliability and security of the bulk electric systems, and recommends that individual system and regional criteria and NERC reliability standards be followed and met to help ensure an adequate reactive power supply. Additional work in the reactive power area is under way based on the NERC recommendations from the August 14, 2003 blackout, including a review of the existing reactive power and voltage control standards and their implementation by the ten NERC regional reliability councils. Based on this evaluation, appropriate revisions to the standards or process improvements will be recommended to ensure that voltage control and related stability issues are adequately addressed.

Respectfully submitted,

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