GE Energy

Interconnections Standards Review Initiative

Prepared for:
California ISO

In response to:

Interim Interconnection Requirements for Large Generator Facilities Review Initiative

Draft Final Straw Proposal

April 20, 2010

April 28, 2010

Legal Notice

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1 INTRODUCTION

California ISO (CAISO) has developed proposed interim interconnection requirements for large generator facilities. This document offers the expert opinion of GE Energy's Energy Applications and Systems Engineering (GE EA&SE) consulting group regarding the appropriateness of the proposed requirements. GE EA&SE is a leading resource for power system analysis knowledge, modeling expertise and consulting services in the US. As a consulting practice, EA&SE has been a leader in the study of renewable generation integration into the North American power grid. A summary of our expertise is provided as an attachment to this document.

1.1 Philosophy of Grid Integration

A fundamental mission of CAISO is to maintain system reliability. The performance, and thus the reliability, of power grids is a function of the technical characteristics of its constituent elements. Power generation resources are the class of system elements having the greatest impact on reliability. Over the past century, the power grid has developed based on the core assumption that generation resources are provided by synchronous generators, and these generators are that are generally dispatchable. The recent emergence of variable energy resources (VER) has challenged this established paradigm, causing the introduction of new generation technologies that have characteristics differing from that of conventional generation. Despite the greater variety of generation technologies now connecting to the grid, maintaining grid reliability must remain a fundamental imperative.

As VER achieve greater penetration in the grid, it is inevitable that these resources will displace other conventional resources that have a greater marginal cost of operation. Although the power market is built around the supply of real power to the grid, including ancillary services, conventional generation resources have, as a matter of course, provided services and technical characteristics that are essential to the reliable operation of the grid. With the displacement of conventional resources, it is necessary that some means be provided to replace the functional support that these displaced conventional resources had previously provided. One alternative could be for the transmission provider to install dedicated equipment on the transmission system solely to replace the lost grid support. However, such an approach would be inefficient because, by the adoption of appropriate and available technology, VERs can provide most necessary grid support functions at a much lower incremental cost than required for the installation of dedicated transmission equipment to achieve the same functions. It is fair that all generation resources, where practical, provide a proportional share of grid support function. Therefore, it is reasonable, efficient, and prudent for CAISO to establish certain functional performance requirements, or grid code, as a condition for interconnection of all generation resources.

Many types of VER are composed of many individual generation units (e.g. wind turbines) interconnected to the transmission system by a dedicated collection system. Many such VER plants have non-generation devices as part of the plant design, such as capacitor banks and static VAR compensators, solely to produce a desired plant performance characteristic. While individual generation units are an especially important component of these VER plants and their capabilities and behavior will influence the plant design necessary to achieve desired performance, interconnection requirements should avoid inferences to the specific behavior of individual units. Instead, the requirements should be placed at the point of transmission interconnection, as CAISO has proposed in the interim interconnection requirements.

VER plants are not simply collections of individual generation units. Rather they must be integrated into fully engineered power plants, with many other critical components. With the progress that has been made in this area over the past few years, GE feels strongly that specifying a functional behavior of VER plants consistent with what is required for conventional generating facilities, to the maximum practical degree, is the proper approach. GE has provided detailed recommendations to others, most notably ISO New England [1], for standards to be imposed on future wind generation. Many of those recommendations, which are presently under stakeholder review, are consistent with the CAISO proposal.

1.2 Transition

Adoption of new requirements is inherently disruptive. Although this disruption is reduced by an extended transition time to new rules, this reduced disruption must be balanced against the system reliability impacts of the delay. VER interconnection are progressing at a rapid rate, and an extended transition time increases the amount of VER capacity that will be interconnected without performance capabilities judged to be necessary for grid reliability.

Long delays in implementing necessary reliability requirements increase the risk that retroactive requirements may need to be imposed in the future on non-conforming VER plants. In Spain, VER penetration has reached the levels where legacy VER plants, installed prior to the imposition of the current grid code, must necessarily be retrofitted with certain grid support functionality in order to maintain secure and reliable operation of the Spanish grid. Similarly, there is action underway to require certain key grid performance characteristics of existing plants in ERCOT on a retroactive basis. With the rapid growth of VER penetration in California, it is reasonable for CAISO to have proceeded with development of the proposed requirements on an expedited basis. In the long run, this may save VER plant owners from having to make very expensive plant retrofits in the future.

There are other generation performance standards under development by WECC and NERC. In an ideal sense, it would be desirable for the CAISO grid performance requirements to be coordinated with the requirements of these other standards. However, the formal consensus standards development process is inherently slow. There are unique conditions of VER development in California that could imperil grid reliability there far sooner than in the average region within WECC or across the U.S. This includes extreme local penetration levels of VER in certain areas, and the potential for very large VER plants having extremely rapid power ramp rates. CAISO is ultimately responsible for the reliability of its own grid, and in our opinion, is justified to move ahead with interim requirements to address its own vulnerabilities without waiting for completion of WECC and NERC standards.

In the question of balance between speed and disruption¸ an important question is how fast can the VER industry reasonably implement modifications to generator and plant designs to meet the requirements. Experience in the wind industry suggests that new control and other grid related technologies have had rule-to-compliance times on the order of 6 to 18 months. For example, provision of low-voltage ride-through (LVRT) functionality at the New Mexico Wind Energy plant was delivered and commissioned within about nine months from the time that the systemic need for this capability was identified. The solar industry has not yet advanced to the level of the wind industry in terms of achieving grid support functionality across the range of major equipment vendors. However, the fundamental similarity of the power conversion equipment used in various non-wind VER with conversion equipment used in wind generators (specifically, Type 3 and Type 4 wind generators) indicates that there is no fundamental reason that the non-wind VER could not achieve similar functionality. Therefore, the compliance date of January 1, 2012, proposed by CAISO seems both reasonable, prudent, and achievable.

1.3 Alternatives

There is a natural desire on the part of those making capital investments to avoid incurring costs that do not result in commensurate revenues. Certainly the cost of providing of most of the functionality proposed by CAISO falls into this category in the eyes of prospective developers. However, there is practical precedent for making a uniform minimum standard of interconnection mandatory. Pushing all remedies on to the grid, while technically possible is at odds with other historical application of interconnection requirements and with good utility practice. In short, there are always alternatives. Rules governing interconnection of synchronous generation could be changed or eliminated by the same logic. For example, voltage control and reactive compensation could be provided entirely by grid/transmission resources, allowing generators to run at unity power factor. However, the loss of operational flexibility, the capital costs and the reliability penalties make such an approach impractical. CAISO may wish to allow VERs to contractually arrange for equivalent functionality to be purchased from other resources. The onus for demonstrating functional equivalence must fall on the VER, not the ISO.

2 Reactive Power and Voltage Regulation Capability

Reactive power is necessary to energize and transmit power in an ac system. Without reactive power, the system voltage cannot be maintained. There are various sources of reactive power in a transmission system, but the most controllable and robust source has been the synchronous generators connected to the grid.

Conventional synchronous generation has always provided the ability to supply or absorb reactive power, and this capability is routinely used to regulate the transmission system voltage. Providing this reactive capability inherently increases the costs of the generator. For example, a synchronous generator with a typical 0.85 power factor rating must be designed to carry armature current that is 15% greater than if the machine were to be designed for unity power factor operation. Thus, reactive capability has never come "free" for conventional generation, but has always been specified as an expectation.

Displacement of conventional generation by VER leaves the system deficient of reactive power resources. Also lost is the voltage regulation capability provided by each displaced synchronous generator, thus decreasing the voltage stability of the system. It is our opinion that replacement of the lost reactive power and voltage regulation capability is essential to grid security and reliability, and that demanding similar support from VER plants is fair, reasonable, and economically efficient.

2.1 Reactive Capability of VER Plants

Wind generation plants have been required for a number of years by FERC 661a to provide a 0.95 leading to 0.95 lagging power factor range at the point of interconnection, and voltage regulation functionality. These requirements have been met by two basic approaches. The first approach is the application of wind generator units capable of providing sufficient reactive range to deliver the required reactive power, combined with plant-level controls that coordinate the reactive outputs of the individual units to achieve the desired reactive output or voltage regulation at the point of transmission interconnection. The second approach has been to include auxiliary reactive power equipment in the wind plant design. This auxiliary equipment includes switched capacitor and shunt reactor banks, static var compensators, and STATCOMs.

Combinations of the two approaches are common as well. In some cases, the latter devices are also applied to achieve the low-voltage ride-through functionality required by FERC 661a, as well.

The ability to deliver and consume reactive power in all VER plants can take functionally similar forms to those adopted by the wind industry. In many cases, the individual generation units are, or could be made to be, capable of reactive power supply. For example, the final power conversion process in photovoltaic generation units is provided by an inverter. The type of inverter commonly used is a voltage-source converter, of functionally similar design to the inverters used in Type 4 wind generators. In wind applications, these inverters are used to provide the wind plant's reactive power requirements and there is no fundamental reason that the same approach cannot be used in photovoltaic plants to achieve the same functionality. The reason that many PV inverter designs do not do so presently stems from the roots of many of these inverter designs in small distributed generation applications, where IEEE Std 1547 forbids voltage regulation functionality on distribution systems. Also, providing reactive power requires incremental current-carrying capacity in the inverters. This is identical to the current rating increase that has always been designed into synchronous generators to facilitate reactive power capability. The historical fact that many PV inverter designs do not provide for reactive power capability is not a reflection of the practical potential to do so, but rather is an indication of the relative immaturity of this industry. As the non-wind VER mature into significant bulk generation resources connected to the transmission grid, it is essential that equipment designs must also mature toward having functional capabilities consistent with grid reliability needs. The reactive power and voltage regulation requirements proposed by CAISO should serve to prod the less-mature VER technologies away from an IEEE 1547-compliant, distributed generation focus, toward functional capabilities consistent with becoming a mature bulk generation resource.

Arguments that certain VER generation technologies are inherently incapable of reactive power and voltage regulation functionality fall short when held up against the experience of the wind industry. Specifically stand alone shunt devices, including shunt capacitors, shunt reactors, and static devices (such as STATCOMs) are commercially available and can be controlled and protected to meet the proposed rule. Both the FERC 661a requirements for wind, and the proposed CAISO requirement for all VER, are at the plant level as measured at the point of interconnection. Many wind plants use Type 1 and Type 2 wind turbines, which are individually incapable of providing reactive capability. Because the requirements are at the plant level, the widely applied solution for wind plants with individually non-compliant generation units is to apply auxiliary equipment within the plant to generate and absorb reactive power, and to provide voltage regulation functionality. CAISO, in the proposed requirements, specifically allows this solution.

2.2 Financial Impact

The real issues are not the technical capability of VER to achieve the proposed reactive power and voltage regulation capabilities, but are rather the financial impact on the VER projects. In this case, the balance is between subjecting the VER owner with the costs related to the grid reliability resources lost due to displacement of the conventional synchronous generators by the VER, or socializing these impacts across all grid users. As a matter of fairness, the former approach, as chosen by CAISO, seems in our opinion to be fair and reasonable.

Furthermore, CAISO’s proposed requirements are rather permissive in allowing the use of shunt capacitor and reactor banks to meet this objective, rather than requiring all or part of the reactive supply to be produced by a smoothly-variable dynamic reactive source, similar to the variable output of synchronous generators displaced by the VER. Reactive capability provided by passive capacitors and reactors can be installed at a cost that is nearly an order of magnitude less, per MVAR, than dynamic sources like SVCs or STATCOMs.

2.3 Point of Requirement

The purpose of the requirement for VER plant reactive capability is to support the transmission grid and regulate the transmission voltage. Therefore, only reactive power delivered to, or removed from, the transmission system is relevant to this goal; reactive power losses or gains within the VER plant are irrelevant to this end. The proposed rule is aimed at the overall installation and the reactive power requirements are correctly applied at the point of interconnection. This allows developers and plant designers a broad range of options to meet the requirements, and is not prescriptive of technology. A plant design, for example, can include stand-alone devices to achieve the requirements independent of the reactive capabilities of the generation unit equipment that they have chosen to apply. Thus, in our opinion, applying the reactive power requirements for VER plants to be at the point of transmission interconnection seems both reasonable and justified.

The disparate requirement for power factor of conventional synchronous generators has historical roots. However, such plants are interconnected to the transmission system by a transformer with an impedance almost always falling within a known range, and without a complex collection system. These generators also are almost never applied with stand-alone reactive devices, which would be functionally unnecessary. With the broader power factor range required of synchronous generators more than compensating for step-up transformer reactive losses, the reactive requirements imposed on VER and conventional plants are functionally near equivalent, with the synchronous generator requirements perhaps a slight amount more demanding in practice from the standpoint of net reactive power to the grid.

3 Disturbance Ride-Through Capability

3.1 Systemic Need for Generation Ride-Through

A fundamental expectation in transmission system planning is that a normal fault event should not cause consequential loss of a generation resource, unless the fault event results in the loss of a radial connection to the resource. Conventional synchronous generation has been assumed to able to remain connected to the grid during and following fault disturbances, unless the severity of the event causes the generator to slip out of synchronism with the grid (transient or dynamic instability). There are specific planning criteria regarding the transmission contingencies for which the synchronous generation must remain stable and connected, and these are applied during the plant interconnection studies for new synchronous generation plants. If a plant is not able to remain stable for contingencies within the planning criteria, then the plant's developer is required to pay for sufficient reinforcements to provide the required stability performance.

Historically, VER had been treated as insignificant and non-essential to grid resource requirements. The VER had been allowed, or even desired, to trip off line in response to a grid event. Some types of VER have had their initial applications at the distribution level where a behavior of trip response to faults is required by IEEE Standard 1547.

As VER has matured and grown in penetration, it can no longer be considered an insignificant contributor to grid resource requirements. A transmission fault can cause depression of voltage over a wide area. If this voltage depression causes a large amount of VER to trip, the loss of operating generation capacity can exacerbate the severity of the initial fault disturbance, and may seriously imperil grid security and reliability. Frequency variations are seen across an entire interconnection (e.g., WECC), and a frequency event caused by loss of generation would be increased in severity if other generation, including VER, were to trip off in response to an underfrequency event. Such sympathetic tripping could easily result in cascading of a survivable event into an interconnection-wide blackout having massive economic consequences.

The need for wind generation to ride through grid disturbances began to be recognized in vulnerable areas of the transmission grid, such as New Mexico and Colorado, early in the prior decade. This awareness culminated in the imposition of disturbance ride-through requirements for wind VER in FER Orders 661 and 661a. The extension of disturbance ride-through requirements by CAISO to all types of VER is, in our opinion, a fair and reasonable requirement that is necessary to maintain grid security and reliability as the penetration of VER grows in their system.

3.2 Practicality of Disturbance Ride-Through Capability

The wind industry has been required to provide for disturbance ride-through capability in wind plant designs, either through the capabilities of the individual generators, or through the addition of auxiliary wind plant equipment. Compared to most other types of VER using asynchronous generation, the inherent technical challenge for providing this ride-through capability for wind generation is considerably more challenging. This is due to the need to manage mechanical stresses and the inherent performance issues of Type 1 and Type 2 (induction) wind turbines, which are not an issue for photovoltaic, and many other types of VER.

The major issue for many photovoltaic inverters is that manufacturers have chosen to design inverters for compliance with distribution-oriented IEEE 1547 and UL-1741 standards, and developers have chosen to apply these inverter designs for bulk, transmission-connected PV plants. These inverters are substantially similar to inverters used in Type 4 wind turbines, that are disturbance ride-through compliant. There is no inherent technical reason that ride-through capability cannot be added to other inverter-interfaced VER. For most types of non-wind VER, particularly PV, this should not be a substantial technical challenge because there are no mechanical issues involved. Although not expected to be a technical challenge, significant control modifications of many VER designs is recognized to be necessary to achieve compliance with the proposed CASIO disturbance ride-through requirements. It is our opinion that this is a necessary step in the evolution of these various segments of the non-wind VER industry away from a distribution focus towards becoming a transmission-connected bulk power resource.

3.3 Cost Implications

Wind generation, which has the greatest inherent technical costs of meeting ride-through requirements, has already addressed the issue in response to FERC 661a. The costs for achieving the ride-through capability proposed by CAISO may involve relatively little cost for most types of non-wind VER, including PV, for clean-slate new designs. Adaptation of existing designs may involve somewhat more cost and time. These costs need to be weighed against the cost of the alternative, which is to maintain extra spinning reserves in the CAISO market in order to cover for potential VER tripout during faults. The costs for VER plant modification for ride-through functionality pale in comparison to the high costs of spinning reserves. Also, it is our opinion that burdening the entire market with extra costs to mitigate the performance characteristics of one class of generation resource would be unfair.

4 Active Power Control

4.1 Systemic Needs for Active Power Control

Conventional synchronous generation has always had the ability to control active power output as a result of 1) a dispatch command from the system operator or 2) a change in system frequency that initiates an automatic response of the governor control to modulate fuel valve or inlet gate position. The systemic need for active power control is driven by the inherent necessity for power grid operators to keep transmission infrastructure (transmission lines, transformers and other serial devices) within thermal and stable operating limits and to maintain system frequency within prescribed bounds. Managing the system to meet these constraints is a key element of overall network reliability. One big risk to network reliability comes in the form of system-wide cascading outages due to self-protective tripping caused by overloaded and sagging transmission lines, overloaded transformers, and frequency excursions. A key method to manage flows around the network and avoid the aforementioned is controlled curtailment of generation through voice-communicated or automatic dispatch commands. Another key method is to employ automatic governor control. It is reasonable to expect that these functional requirements apply to all forms of generation (including VER) connected to the network.

4.2 Technical Feasibility and Technology Availability

Today's wind technology has matured to the point of having the physical capability of providing a wide range of active power control and regulation functions with only marginal increases in equipment cost to do so. Unlike voltage regulation and fault-ride through, US industry rules and practice for active power control of wind plants are less refined and uniform. All US wind plants are subject to curtailment: they must accept instructions from grid operators to reduce power output. The details of how each plant responds to such commands and the circumstances under which the host ISO may invoke these curtailment commands varies considerably. At present, instructions are issued on a purely manual basis.

US industry is just starting to address the need for more automated behavior from wind plants. Response of wind plants to frequency variation using functionality similar to that of conventional generation governors is not required in the US, but is in several other countries (e.g. Ireland) that have reached or are soon to reach relatively high levels of wind penetration.

To address power curtailment needs, one solution is to have a coordinated plant control manage plant curtailment and ramp rate command. The curtailment control can be executed at the plant level based on a SCADA signal from the grid operator or a change in set point by the plant operator. Alternatively, for plants who select generation equipment from OEMs that do not supply a coordinated plant control, manual curtailment of wind turbines is possible by shutting down individual generators or feeders one at a time. This is less ideal because a plant operator does this curtailment manually in discreet blocks and the transition is not as controlled as a coordinated plant management system could do, but the curtailment requirement may still be met by using this method. The ability to selectively disconnect individual generators or feeders in response to commands issued by CAISO will provide a step-wise response. As long as the steps are within reason, this can meet the systemic needs that are the reason for the standard. "Within reason," of course, is problematic. Step sizes must be accordance with good utility practice in terms of the resultant voltage step. Under normal circumstances, the resultant voltage steps should be on the order of 1-2%, and should not exceed 3% under any normal system conditions (per IEEE std). Further, the total MW switched should be consistent with system balancing needs; this is a grid level concern so fine steps are not needed. Generally, steps of 10 MW should be acceptable, and not impose undue capital cost burden on the plants. Justification for a specific maximum step in MW needs further investigation. The ISO does not necessarily need continuous control, although it would be highly welcome. From the perspective of the plant owner, continuous control is preferred as well, since fine control of MW should always result in less energy loss than block curtailment.

In principle, active power control of PV systems can be provided by control of the inverters without substantively affecting the inverter ratings. As mentioned earlier, this requires controls to do so, which are not generally provided today by PV OEMs. Development of those controls will be needed. However, very similar to wind, other remedies exist to meet the intent of this requirement. Large PV plants will rely on multiple inverters of moderate rating. Most systems today are sub-MW size. The ability to selectively disconnect individual inverters or strings of inverters in response to commands issued by CAISO will provide a step-wise response. The same argument for wind earlier also applies to solar regarding curtailment in discreet blocks and reasonable step-size.

Our opinion is concurrent with CAISO regarding the need for active power curtailment capability. From a reliability standpoint, it is straightforward and rests on sound utility practice and commonsense.

Due to the nature of wind turbine controls, capabilities and physical size, changes in active power due to changes in wind speed can be significantly large and fast; in many cases, much faster than conventional generation. This is also true for solar generation with changes in sunlight. Ramp rate controls, especially to limit large and sudden swells of power due to increasing wind and sun, are also especially important for VER due to the non-controllable nature of fuel source. It is our belief that, with today's available control technology, it is reasonable to expect ramp rate limits be executed at the plant level of VER to control the rate of change of power for all situations except the loss of fuel.

For over-frequency excursions on the grid, it is reasonable to expect all connected generation to respond by automatically and dynamically curtailing power output to mitigate the excursion. To assure that all connected generation fairly shares the burden to correct over-frequency, is it reasonable (and also standard industry practice) to allow a governor droop function to coordinate active power response between all plants experiencing the excursion. Wind and solar technology available from some OEMs has the capability of accepting a function to control frequency with droop as a part of the plant control logic. While most wind plants have this capability already, solar technology does not, primarily due to its distribution-connected history. It should be possible for this requirement be met by adding control logic to solar inverters. For VER that do not already have it, addition of control logic to allow frequency regulation is expected to have relatively minor implications to cost of equipment and insignificant cost implications due to lost revenue during the frequency excursion.

As the CAISO report rightfully pointed out, under-frequency response would require spilling wind or sun during normal operation to keep a certain percentage of available power in reserve and dynamically increase power to mitigate the excursion. While this may have only minor cost implications to add control logic to equipment, it has significant cost implications due to lost revenue. Therefore, we concurrently believe under-frequency response is should not be required at this time.

4.3 Cost Implications and Market Rules

Any action by the ISO that causes VER generation to reduce power output below that possible with the available fuel source (wind or sunlight) has the potential to have significant revenue impacts for generation owner. VER owners irrevocably lose the energy sale when wind or solar (or hydro) power is “spilled”, and as such they have very legitimate concerns about the requirement for VER plants to be equipped with control features that enable such curtailments. However, it is worth noting that any grid operator, including CAISO, *always* has the ability to curtail (up to an including disconnecting) any generator for reliability reasons. That is true today. If power producers want to connect, they are subject to this now. The proposed technology rule will, in fact, reduce risk to large PV producers by providing CAISO with a mechanism that can be used with more finesse, and therefore affecting less potential energy production, than the present in-place requirement that will result in CAISO just opening the plant breaker.

4.3.1 Market Rules

The discussion of systemic need and technical feasibility leaves unaddressed the issue of financial impact on VERs. The technical interconnection rules proposed by CAISO are rightly not intended to address market and contractual issues. It is entirely appropriate that CAISO prudently require that VER plants have the *capability* to meet these active power control requirements. Nevertheless, the potential for VERs to suffer from the *use* of these capabilities is great. It is incumbent on CAISO and the relevant regulating entities to establish clear criteria under which these active power limiting features may be invoked. While the details may vary, the fundamental premise must be that the benefit produced by active power control of theVERs *cannot* be meet less expensively by other means. In practice, this probably means that VERs should be treated as price takers, and that market prices (LMPs) should be allowed to go substantially negative. Further, procurement of ancillary services that could mitigate reliability impacts of, for example, fast ramping of VERs, must be the first line of defense for the ISO. California must must pay attention to the flexibility of the entire generation fleet in order to successfully integrate large amounts of VER generation [2],[3].

5 Conclusions

Increased penetration of VER in the CAISO system has the potential of compromising grid security and reliability, if measures are not enacted to require technical performance capabilities of the VER that are compatible with achieving the minimum negative impact. It is our opinion that CAISO must act promptly, and cannot afford to continue interconnection of VER without regard to future grid performance. The performance required by CAISO's proposal are within the capabilities of available technology, and the costs to implement are favorable with respect to the overall societal benefit. We conclude that CAISO's proposed requirements are practical, prudent, and fair.

References:

1. ISO New England, "Technical Requirements for Wind Generation Interconnection and Integration", November 3, 2010.
2. California Energy Commission's Intermittency Analysis Project Study "Appendix B - Impact of Intermittent Generation on Operation of California Power Grid" http://www.energy.ca.gov/2007publications/CEC-500-2007-081/CEC-500-2007-081-APB.PDF
3. International Electricity Agency (IEA), "Empowering Variable Renewables: Options for Flexible Electricity Systems", 2008, IEA Head of Communication and Information Office, 9 rue de la Fédération, 75739 Paris Cedex 15, France

Attachment - GE Expertise

The foundational strength of GE's Energy Applications and Systems Engineering consulting group lies in the experience and expertise of its employees, a total staff of approximately 112 employees, with most having advanced degrees in engineering disciplines, including ten with doctorate degrees. Their total experience spans over 1500 man-years. EA&SE is distinguished by having six engineers presently on staff who have been elevated to the esteemed status of IEEE Fellow, the highest honor bestowed by IEEE.

Cumulatively, EA&SE engineers have published hundreds of technical papers and authored or co-authored many textbooks. Our engineers on the team play an important role in the power industry by leading and participating in a number of industry organizations, including thirty IEEE Committees, Subcommittees and Working Groups, and five CIGRE Working Groups as well as international standards committees, such as IEC.

GE EA&SE has made major contributions to the development and application of technology for transmission planning and analysis. GE EA&SE is a leading resource for power system analysis knowledge, modeling expertise and consulting services in the US. As a consulting practice, EA&SE has frequently been called upon to draft, interpret and apply the NERC reliability criteria. In the recent past, there have been dozens of instances in which EA&SE has utilized these rules in performing studies of the impact of proposed generation or transmission projects on transmission reliability.

GE EA&SE has also made major contributions to analyzing North American power grids with the intent of identifying technical, operational and economic improvements required to accommodate higher penetrations of renewable generation. This analysis includes areas such as New York, California, Ontario, Texas, New England and the WestConnect region of WECC.