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Innovations in Bulk Power System Reliability Assessment: A North American View

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SUMMARY

With changing resource mix and new technology integration, traditional approaches may not be sufficient to provide meaningful assessment of bulk power system reliability. Tools, analysis techniques, and assumptions must be enhanced to adequately plan and operate a generation fleet predominately fueled by natural gas and renewables. Examples include integration of significant amounts of renewable (variable such as wind and solar), natural gas, storage and demand resources to provide energy and capacity. Industry's knowledge of the characteristics of the bulk power system comes from nearly a century of operational experience with the existing resource mix. However, integration of these new resources results in operating characteristics significantly different from conventional steam production facilities.

This paper will review the traditional assessment approaches used in North America, changing resource and technology landscape, and its impact on the way reliability assessments are performed. Further, the paper will identify new approaches and methods needed for further development to support a transparent, independent and thorough assessment of future bulk power system reliability.

KEYWORDS

Reliability Assessment, Generation Planning, Transmission Planning, Bulk Power System, renewable energy, smart grid

BACKGROUND

The North American Electric Reliability Corporation's (NERC) mission is to ensure the bulk power system in North America is reliable. To achieve this objective, NERC develops and enforces reliability standards; monitors the bulk power system; assesses and reports on future adequacy; and offers education and certification programs to industry personnel. NERC is a non-profit, self-regulatory organization that relies on the diverse and collective expertise of industry participants. It is subject to oversight by governmental authorities in Canada and the United States (U.S.).

NERC assesses and reports on the reliability and adequacy of the North American bulk power system divided into the eight Regional areas. The users, owners, and operators of the bulk power system within these areas account for virtually all the electricity supplied in the U.S., Canada and a portion of Baja California, Mexico.

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FRCC	Florida Reliability Coordinating Council
MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RFC	ReliabilityFirst Corporation
SERC	SERC Reliability Corporation
SPP RE	Southwest Power Pool Regional Entity
TRE	Texas Reliability Entity
WECC	Western Electric Coordinating Council

NERC's primary role in providing reliability assessment is to identify areas of concern to the reliability of the North American bulk power system and to make recommendations for their remedy. Section 215 of the U.S. Energy Policy Act of 2005 [1] does not authorize NERC to order construction of additional generation or transmission or adopt enforceable standards having that effect. In addition, NERC may not preempt any authority of any State to take action to ensure the safety, adequacy, and reliability of electric service within that State, as long as such action is not inconsistent with any reliability standard. NERC does not make any projections or draw any conclusions regarding expected electricity prices or the efficiency of electricity markets.

The seasonal reliability assessments and *Long-Term Reliability Assessment (LTRA)* provide key findings, a high-level assessment of future resource adequacy, an overview of projected electricity demands and demand response resources, planned and proposed generation and transmission additions, emerging issues and their potential reliability impacts, operational reliability trends, Regional assessment highlights, scenario analysis update and Regional self-assessments. The LTRA represents NERC's independent judgment of the reliability and adequacy of the bulk power system in North America for the coming ten years.

The bulk power system is made up of three main parts: generation, transmission, and load (i.e. customer electric demand). The electric industry uses terms such as reliable, unreliable, or system reliability as qualitative measures of the relative strength or balance of the bulk power system. Reliability is the term used by the electric industry to describe and measure the performance of the bulk power system. It is the degree to which the performance of the elements of that system results in power being delivered to consumers within accepted standards and in the amount desired. The degree of reliability may be quantitatively measured by the range of operating conditions under which the system performs within acceptable parameters.

Meeting the reliability expectations of consumers requires the bulk power system to be planned, designed, constructed, operated, maintained, and restored (as necessary following the loss of electric infrastructure) as described by specific, pre-determined tests or criteria. As such, the bulk power system is evaluated, assessed, and planned to ensure that an adequate supply of electricity is available to meet current and future needs.

LONG-TERM PLANNING

Long-term power system planning encompasses the development, evaluation and assessment of various potential outcomes for one or more years into the future. Operational planning can and does use similar concepts as long-term power system planning, with a focus on one day and one year. Both long-term and operational planning must address the uncertainty in the assumptions, such as forecast load, generation dispatch, the status of transmission elements, and loop flows, all of which define the operational state of the network. The primary difference is in the range and uncertainty addressed.

Generators and transmission elements are the building blocks of the bulk power system. The number and configuration of generators and transmission lines contribute to the reliability of the bulk power system. The planning process assesses the performance of the existing bulk power system with respect to various reliability objectives to determine its ability to meet forecast requirements with adequate reliability. Such objectives and methods are typically described as either deterministic or probabilistic.

- **Deterministic** reliability measurements have traditionally been applied to test the ability of the Bulk Power System to meet acceptable performance metrics for different contingent states, for example the ability to operate within applicable limits and ratings for an N-1 contingency event.
- **Probabilistic** methods have traditionally been applied in resource adequacy planning and use characteristics of system components to predict the likelihood that demand will be served.

Deterministic and probabilistic are different and complementary methods to analyze bulk power system reliability. A deterministic analysis is based on a set of general assumptions regarding the nearly infinite number of variables which define an operating state of the bulk power system. These include the status of generating units and transmission elements, weather conditions to define facility ratings and forecast load, Regional load diversity, generation dispatch and net scheduled interchange. Having defined assumed operating state events which are considered credible based on past performance and which tend to be associated with a change in status of generating units and/or transmission elements are identified for assessment to determine their impact on reliability. Judgment is used to determine how many coincident or simultaneous credible events will be considered, what levels of sensitivity analysis will be included for the variables that define the operating state, and what types of mitigation, if any, will be required to provide acceptable levels of reliability.

Probabilistic analysis describes events in terms of how probable they are, and requires knowledge of the performance characteristics of the components of the bulk power system. Measurement of past performance of the bulk power system can be expressed precisely in terms of frequency, duration, and the number of elements affected in past events. Measurement of future reliability is not as precise, and must be expressed in terms of the expected performance of the system components, and of the uncertainty in those expectations. These characteristics can be brought together to derive various measures of the reliability of the bulk power system. Probabilistic methods rely on either statistical analysis of historical performance of system elements to identify the system scenarios/events to simulate or enumeration techniques which are capable of simulating large numbers of contingencies up to a specified n-k depth. However, the choice of methods and selection of acceptable reliability levels are still matters of judgment. Further, based on the number of variables, it can be challenging to perform a statistically significant sample to have acceptable confidence in the results.

BULK POWER RELIABILITY AND PLANNING

Two fundamental and measurable characteristics of bulk power system reliability, proposed by NERC, are a vital foundation for the concepts described in this document: Bulk power system reliability can be addressed by considering two basic and functional aspects of the bulk power system – *adequacy* and *operating reliability*.

- ***Adequacy*** is the ability of the bulk power system to supply the aggregate power and energy requirements of the consumers at all times, taking into account scheduled and unscheduled outages of the system components.
- ***Operating Reliability*** is the ability of the bulk power system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components.

Planning the transmission system requires four major ingredients:

- ***Load forecast:*** The load forecast is developed in a variety of ways using a variety of assumptions, econometric models and statistical information. System planners incorporate such load forecast in the transmission base cases and conduct analysis to identify generation and transmission expansion needs to meet demand.
- ***Generation and transmission plans already in place*:** The system planner needs to accommodate those generation and transmission facilities that are either planned or are in

various stages of construction. These plans include independent power plants, and power plants and transmission lines in other electrically related areas.

- ***Knowledge from operations and past performance:*** System planners benefit from learning which contingencies are likely to occur and how the interconnection actually performs following real contingencies.
- ***Planning criteria:*** For many years, NERC published collections of the Regional planning criteria, and from those criteria, developed the current planning standards—specifically, the Transmission Planning (TPL) series.

Design Standards play an essential role in preventing major system disturbances following severe events. Bulk Power System planners deal with future systems that are only "operated" in system simulation studies. Since planners cannot simulate *all* single-element outages under various system conditions, they simulate two types of contingencies as part of their design criteria for new transmission facilities: the single-element (N-1) contingencies, and multi-element contingencies (e.g., a single line-to-ground fault on a bus section, which may remove several circuits from service.). In planning studies, the performance expected for multi-element outages may include loss of firm load, but the resulting disturbance is designed not to cascade and the system must remain stable, within the applicable ratings for thermal and voltage limits.

Planners normally model both single-element (N-1) contingencies, and multi-element contingencies, usually assuming no other element forced-out. Experience has shown that simulated transmission systems withstanding both single and multi-element contingencies are capable of withstanding single-element contingencies in a real-time operating environment with other elements out of service. Withstanding multi-element contingencies is a planner's way of providing bulk power system operational margins for System Operators, compensating for the assumption of "all lines in-service."

Planners also evaluate extreme contingencies involving two or more element outages of an extreme nature. These contingencies may lead to cascading outages and system instability. Extreme contingencies are assessed to determine their consequences only; transmission facilities are not constructed to avoid the consequences of extreme contingencies.

RELIABILITY ASSESSMENT

Reliability assessment is the process of investigating plans of future adequacy and operating reliability of the bulk power systems. It may involve comparison of expected system performance with specific criteria to identify possible weaknesses, or it may be more general expression of potential problems. Extensive planning criteria and assessment approaches have been developed by the electric industry in North America. Assessment procedures test bulk power systems against a variety of measurements/criteria to provide confidence that foreseeable weaknesses of the studied bulk power system are identified. Since generation and transmission planning of any utilities are affected by the plans of other interconnected electricity suppliers, many of these criteria have now become NERC or Regional Entity mandatory performance Standards.

The measurement of bulk power system reliability is intended to ascertain the capability of the system. It may also identify thresholds of unreliability by examining increasingly severe conditions. Simulated deterministic testing and probabilistic studies are means of assessing how the performance of a proposed system compares with reliability objectives. Such examinations must be completed in a structured and consistent manner facilitating comparisons.

Bulk power system contingency criteria (for example, the NERC Transmission Planning or TPL Standards, Table 1, categories A, B, C and D) have been developed for nearly half a century, their development beginning when computer software enabled simulation and evaluation. Experience has showed that if certain deterministic tests of the system (criteria) were met in conjunction with system sensitivity assessments (such as incremental transfer capability studies) the system as designed, when built, would have suitable planning margins to meet the multifarious conditions faced by operators. If planners met the established criteria with consideration to system uncertainty; operators would have a system that could be operated with acceptable performance even if the conditions differed significantly from those assumed by the planners.

For reliable service, a bulk power system must remain intact and be capable of withstanding a wide variety of events and disturbances [2] over a wide range of system operating conditions. Therefore it is essential that a system be designed and operated so that the more probable events (sometimes called contingencies) can be sustained with no loss of firm load (except that connected to the faulted element) and so that the most adverse possible events do not result in uncontrolled, widespread and cascading power interruptions.

PLANNING MARGINS SUPPORTING RELIABILITY

The industry measures the ***operating reliability*** of the future bulk power system to deliver power and energy by noting the response of future systems scenarios (through simulation) when subjected to a variety of contingencies or severe disturbances. NERC Standards define a wide range of contingency states (see Transmission Planning Standards [3] TPL-001-0 through TPL-004-0), for which the bulk power system shall be tested to assess acceptable performance. Planning studies combine contingency analysis with sensitivity analysis of the results to system state conditions to assess overall system adequacy. Although there is no guarantee that major disturbances will not happen, the assessment procedures do provide reasonable assurance that the system as designed will ultimately be capable of being operated with an acceptable level of reliability over a sufficient range of operating states.

Likewise, the industry can measure the ***adequacy*** of the future bulk power system to meet forecast demand by comparing generation energy and capacity to forecast net internal energy and peak demand. This comparison may incorporate a consideration of the bulk power system's ability to deliver energy requirements. Each generator is typically described with a capacity and energy component along with a probability or other indication of its availability. The forecast internal demand and network requirements are many times described by a peak demand, a pattern of demands or a variety of scenarios with a distribution of uncertainties. Comparing generation capacity/energy with a variety of forecast internal demands/energy requirements using a range of probabilities and uncertainties, results in a measure of future bulk power system adequacy.

Beyond meeting pre-specified criteria, planners in most organizations perform sensitivity analysis in conjunction with the TPL pass/fail tests to measure the resulting relative operational reliability and adequacy planning margins. System sensitivities are measured by applying and simulating a multitude of transfers (import/exports) and system conditions (load levels and transmission/generation conditions), based on past experience and engineering judgment. These additional tests identify insufficient planning margins, based on each organization's specific system conditions and their desired final reliability level. Additional planning margins are then built into the system to fortify the bulk power system preparing for the time the system will be ready for operation.

CHALLENGES RELIABILITY ASSESSMENT IN THE FUTURE

There is an unprecedented level of overlapping and coincident changes across the U.S. electrical power system; from the integration of variable generation, increasing cyber security concerns, reactive power issues, and many other emerging issues [4]. It is an industry in transition on nearly all fronts. At the heart of this industry is the bulk power system, the core system that literally ties all of the actors and stakeholder parties together. Coordination among these parties at the bulk power system-level is essential to achieve renewable integration, smart grid implementation, enhanced end-use participation, and other objectives while ensuring the lights stay on. Despite emerging issues, credible contingencies, and the technological evolution of the entire system, the bulk power system must remain reliable. Industry directly responsible for the bulk power system has a responsibility to ensure reliability, even as the industry works aggressively to achieve various policy goals.

Today's bulk grid is planned and operated to meet the fundamental requirement of providing an "adequate level of reliability." For example, smarter grids can support and maintain an adequate level of reliability, even as the wider industry is challenged to meet broad policy and legislative directives that are impacting and changing the attributes of the U.S. bulk power system.

As policy and regulations on greenhouse gas emissions, notably CO_2, and mandated Renewable Portfolio Standards (RPS) are being developed by states and provinces throughout North America, the addition of renewable generation into the bulk power system is expected to grow considerably in the near future. The level of commitment to renewables offers benefits such as new generation resources, fuel diversification, and greenhouse gas reductions, and also presents significant new challenges to bulk power system reliability that need to be properly addressed. Unlike traditional mostly non-renewable resources, the output of the wind, solar, ocean and some hydro generation resources varies according to the availability of the primary fuel (wind, sunlight and moving water) that cannot be reasonably stored. Therefore, these resources are considered variable, following the availability of the primary fuel source.

Reliable power system operation requires ongoing balancing of supply and demand at every moment in time in accordance to prevailing operating criteria. Power system planners and operators are already familiar with a certain amount of variability and uncertainty, particularly as it relates to system demand and, to a lesser extent, with conventional generation. However, large scale integration of variable generation can significantly alter familiar patterns for a system planner and operator, mainly due to the added variability and uncertainty associated with variable generation. These resources are not always fully dispatchable, thereby requiring the availability and use of other controllable or dispatchable resources to balance the supply and demand.

CONCLUSION

Fundamental changes in bulk power system structure, fuel mix and technology deployment is resulting in a deep review of the way that reliability is measured and addressed. There are a great many potential benefits and challenges. For example, planning systems based solely on capacity will not be useful for systems that are becoming more energy limited. Generating characteristics that were expected from systems with sufficient capacity, such as frequency response, inertia response, etc. will need careful attention in design as demand response and variable generation may not always offer expected amounts of stabilizing energy.

New methods and approaches may be required to ensure that the unprecedented changes result in a reliable bulk power system in the future. This requires both careful planning and design. Metrics and measurement of requirements must be developed, and transition to energy focused approaches will support transitions to a reliable and stable bulk power system in the future.

BIBLIOGRAPHY

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