NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Considerations for Performing an Energy Reliability Assessment

ERATF White Paper

March 2023

RELIABILITY | RESILIENCE | SECURITY




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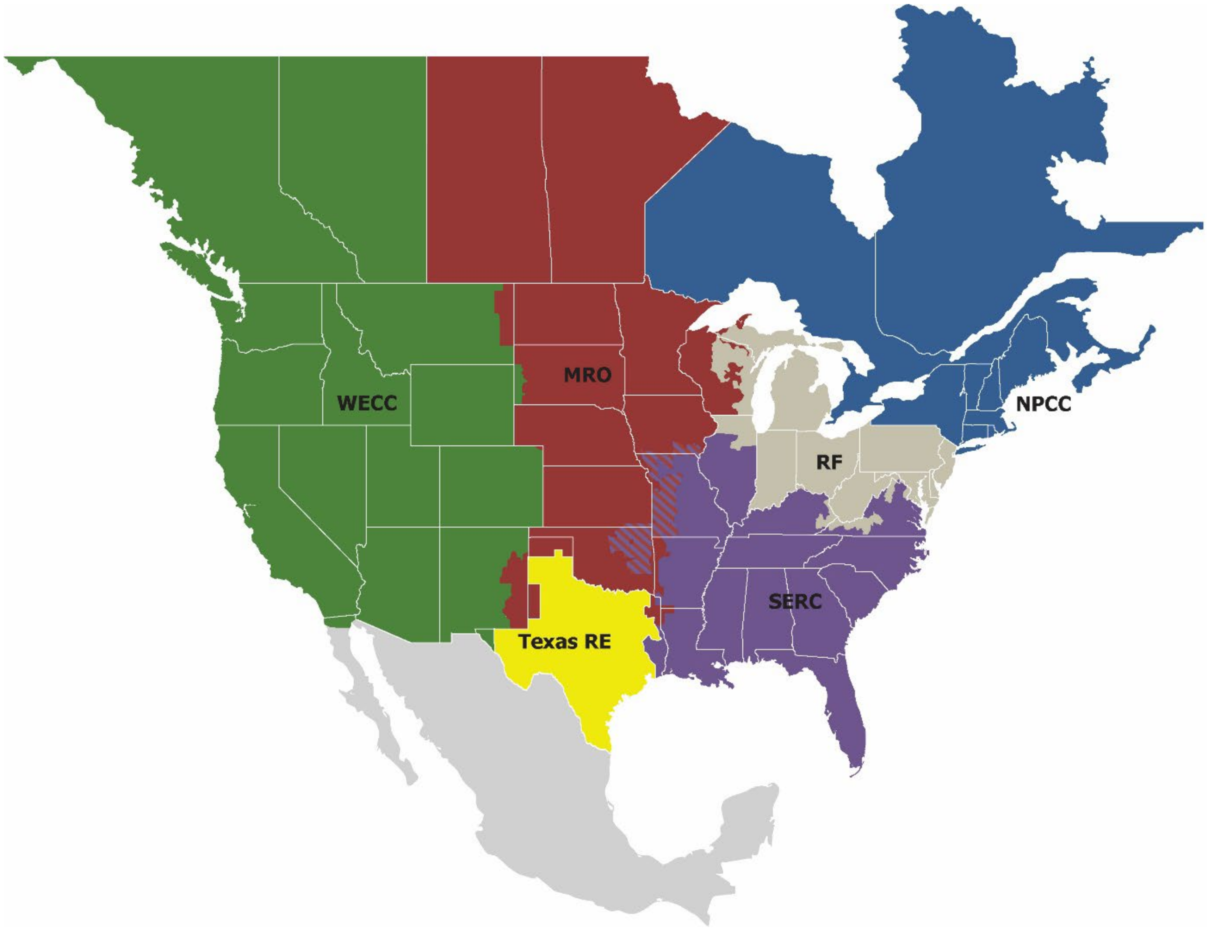
Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of NERC and the six Regional Entities, is a highly reliable, resilient, and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security
Because nearly 400 million citizens in North America are counting on us

The North American BPS is made up of six Regional Entity boundaries as shown in the map and corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one Regional Entity while associated Transmission Owners/Operators participate in another.



MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

Introduction

Energy reliability assessments are critical for assuring the reliable operation of the Bulk Power System (BPS) as the penetrations of variable generation resources and/or just-in-time fuels increase. In turn, dispatchable and quick start units are relied upon for flexibility, where sources such as energy storage and natural gas-fired generation deliver energy to support intra-hour and inter-hour ramping to match variations in demand and energy production from the rest of the fleet. Energy reliability assessments account for the finite nature of stored fuels and their replenishment characteristics. In addition, the availability of natural gas to supply electric generation can impact BPS reliability during high natural gas demand periods throughout the year. Energy reliability assessments provide assurance to planners and operators that resources can supply both electrical energy and ancillary services needs across a span of time.

In this paper, we refer to two main categories of fuels. The first is stored fuel (e.g., coal pile onsite, water reservoir, energy storage in battery) and the other is just-in-time fuel (e.g., natural gas from pipelines, sunlight on photovoltaic (PV) panels, wind through wind turbines, run-of-river hydro). Just-in-time energy resources are reliant on just-in-time fuels

NERC, working with the electric industry, developed this whitepaper focused on energy assurance and efforts needed to ensure the reliable operations of the BPS. These efforts began in late 2020 and are continuing today as presented in **Figure I.1.**

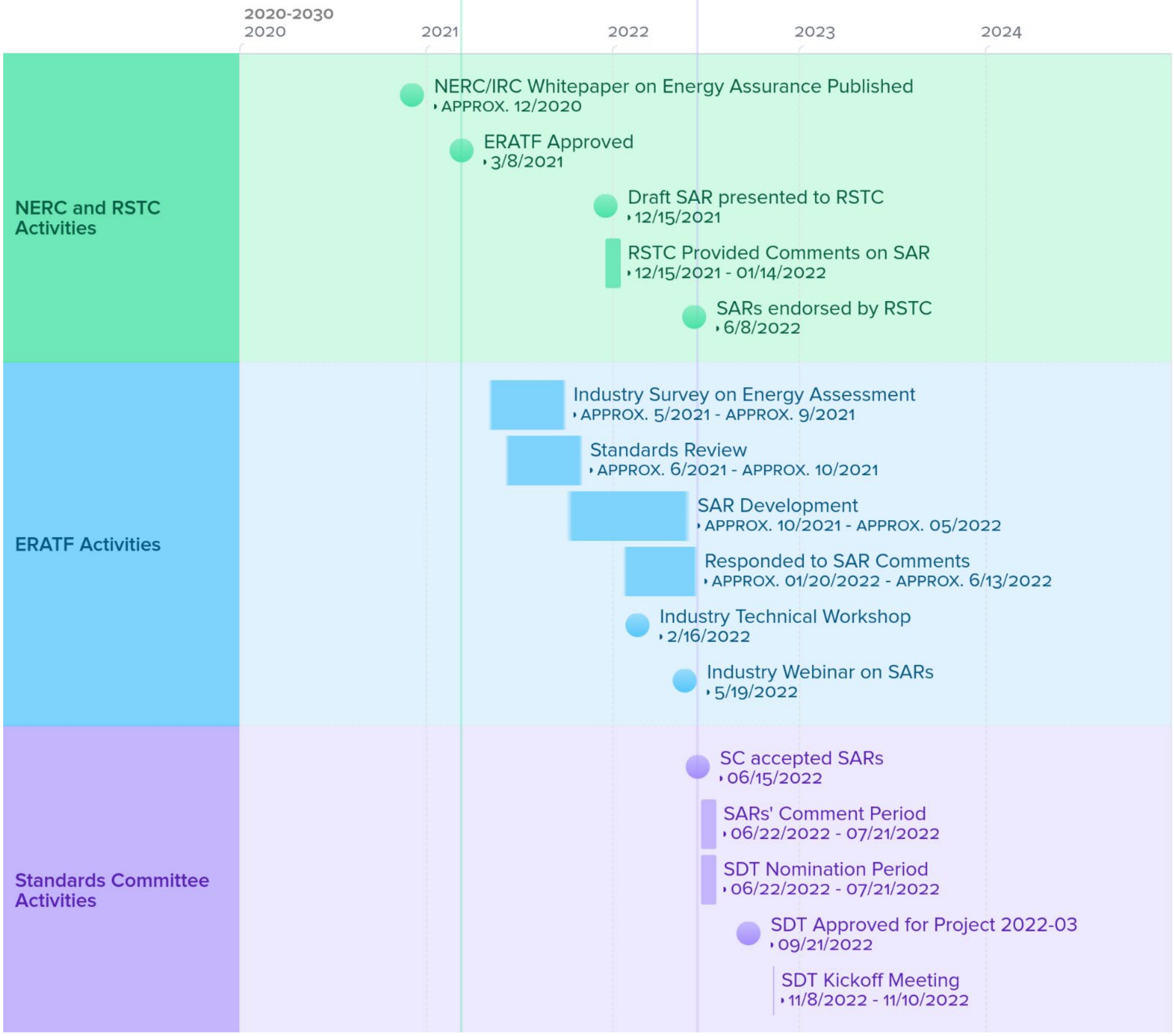


Figure I.1: Timeline of Relevant Energy Reliability Assessment Work at NERC

Purpose

The purpose of this whitepaper is to clarify what an energy reliability assessment is and recommend elements for consideration when performing an assessment. As part of ongoing BPS planning and operations, many entities have started incorporating some limited energy reliability assessments (e.g., uncertainty around variable generation output and natural gas delivery) into reliability studies that produce key risk metrics; however, there is inconsistency among entities on whether or not energy reliability assessments are performed at all. While organizations in different regions may implement energy analyses differently to focus on their most significant energy risks, the core principles and elements of the analyses are similar.

Chapter 1 of this whitepaper describes what an energy reliability assessment is and recommends elements for consistent evaluation across the industry. The whitepaper clarifies the distinctions between capacity reliability assessments and energy reliability assessments and examines the differences between the deterministic and probabilistic approaches in performing both assessment types. Chapter 2 provides a more in-depth discussion of some elements to consider for an energy reliability assessment related to supply and demand and includes a separate discussion on distributed energy resources (DER) that can blur the line between supply and demand.

Background and Rationale

As the North American electricity sector evolves, planners and operators must increasingly acknowledge uncertainties and risks with the increased use of just-in-time fuels (i.e., fuels consumed immediately upon delivery), stored fuel with limited energy resources, and demand side resources. Extreme weather events that impact generation resources, fuels, and load coincidentally have exposed the threats to BPS reliability due to insufficient energy even with sufficient capacity ostensibly available.[1] Unassured deliverability of fuel supplies and volatility in load can introduce additional risks to the reliable and resilient operation of the BPS.

Historically, analyses of energy available to the BPS focused on capacity reserve levels across peak demand time periods. These assessments included assumptions on equipment failures (e.g., mechanical failures) but often assumed that the requisite fuel would always be available. This is an acceptable assumption when fuel availability is assured. Methods of increasing confidence in fuel availability include, for example, fuel contracts, on-site storage (e.g., oil, coal, reservoir-based hydro), or required periodic and predictable fuel replacement (e.g., nuclear).

The availability of dispatchable generation with diverse fuel types promotes flexibility in providing energy for the BPS should one fuel type become unavailable.

Today's electricity system includes just-in-time energy resources along with additional supply chain pressures. This creates additional complexities and decreases confidence that energy will be available to serve load. As a result, there is a need to conduct energy reliability assessments in addition to capacity assessments[2] to identify new challenges. Potential findings and applications of energy reliability assessments could include but not limited to:

- identifying unexpected and unstudied energy issues in non-peak hours, a risk that would not be identified by traditional analyses focusing on capacity across the peak summer and winter demand periods;
- in areas with many variable energy resources, highlighting the value of having dispatchable resources with sufficient fuel available and ready to respond when needed;
- evaluating whether energy storage resources have sufficient energy to provide both balancing and energy;

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[1] The industry need is described in the *Ensuring Energy Adequacy with Energy-Constrained Resources* white paper, presented to the RSTC, December 2020. https://www.nerc.com/comm/RSTC/ERATF/ERATF Energy Adequacy White Paper.pdf

[2] For additional information, read Electric Power Research Institute, Resource Adequacy Philosophy: A Guide to Resource Adequacy Concepts and Approaches, EPRI, Palo Alto, Dec 2022. Link: https://www.epri.com/research/programs/067417/results/3002024368

- evaluating whether energy storage resources are sized appropriately (capacity and energy) to provide balancing;
- evaluating renewable resource generation and load forecasting uncertainties to ensure appropriate levels of balancing reserves;
- in areas with high concentrations of distributed energy resources (DERs), identifying complications with operational challenges resulting from added volatility into energy forecasts;
- assessing uncertainties or risks when the natural gas-fueled resources are subject to fuel curtailment or interruption (by virtue of fuel acquisition contracts) during peak fuel demand periods, especially where variable energy resources increase reliance on natural gas as a balancing resource;
- considering the design of natural gas pipeline systems and the availability of primary and secondary natural gas transportation paths which can impact individual generators and BPS reliability under pipeline disruptions such as natural gas supply chain scenarios (e.g., pipeline disruptions, wellhead freeze offs, compressor station outages, etc.);
- considering additional factors in the operational planning time frame, like anticipated performance of natural gas-fired units given recent run times, energy market pricing, environmental constraints, or testing results.
- evaluating the potential impact of extreme weather events and implications for system resilience;
- assessing the impact on resource and transmission planned outage scheduling and approvals during resource maintenance seasons; and
- identification of periods when the replenishment of fuel inventories are needed but are constrained by severe weather, transportation limitations, pipeline outages/maintenance, etc.

The variability of renewable generation, demand volatility, the need for sufficient energy from dispatchable generation resources, and the potential for natural gas supply and transportation interruptions all combine to highlight the need for energy reliability assessments that analyze all hours of a given study period rather than just the peak hours.

Energy Reliability Today

Energy assurance and fuel assurance risks are becoming more apparent as extreme weather has resulted in energy deficits (as opposed to capacity deficits) in recent years. During the past 10 years, there have been multiple extreme events across North America that have jeopardized BPS reliability where insufficient energy production had already impacted BPS operations. The following are some examples of those events[3]:

- In February 2011[4], an arctic cold front in the southwest United States resulted in generation outages and natural gas facility outages.
- In January 2014[5], a polar vortex affected the central and eastern United States and Texas.
- In January 2018[6], the south-central United States experienced many generation outages resulting in emergency measures.
- In 2021, California’s Oroville hydroelectric facility was shut down when reservoir levels, due to drought conditions, dropped below its minimum operating elevation.

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[3] These listed events do not include all events or near miss events which entities have identified.

[4] Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011 - FERC and NERC

[5] Polar_Vortex_Review

[6] 2019 FERC and NERC Staff Report: The South Central United States Cold Weather Bulk Electric System Event of January 17, 2018

- In February 2021, a cold weather event impacted fuel and energy availability in the states of Mississippi, Louisiana, Arkansas, Oklahoma, and Texas.

Energy reliability assessments that look at extreme events are needed to analyze subsequent impacts to the reliable operation of the BPS under adverse conditions. It is beneficial to perform assessments to identify conditions where energy supply would be stressed and identify actions that may be needed to mitigate the potential loss of load. NERC, and its many industry committees and working groups, have done considerable work to address these events. The Electric-Gas Working Group (EGWG) created the *Reliability Guideline - Fuel Assurance and the Fuel-related Reliability Risk Analysis for the Bulk Power System*[7] to help perform fuel assurance studies, and the Reliability Issues Steering Committee published the *2021 ERO Reliability Risk Priorities Report*[8], identifying risks to the BPS. Efforts like these highlight emerging risks that the industry needs to focus on. A more detailed discussion of the need for energy reliability assessment can be found in the "Energy Assessments with Energy–Constrained Resources in the Planning Time Horizon"[9] and "Energy Assessments with Energy–Constrained Resources in the Operations and Operations Planning Time Horizons"[10] SARs and associated technical justification document[11].

As part of long-term planning, the number of entities that incorporate energy reliability assessments into reliability studies is growing. These studies often produce key metrics on resource adequacy including Loss of Load Expectation (LOLE), Loss of Load Hours (LOLH), and Expected Unserved Energy (EUE)[12].

For example, *WECC's Western Assessment of Resource Adequacy*[13] incorporates multiple energy risk drivers, including extreme weather, changing climate patterns, significant increases in variable energy resources, the reliance of sub-regions on imports, coincidence of demand spikes over larger geographic areas, and others. The results of WECC's energy reliability assessments from the probabilistic model are fed into a deterministic production cost model to assess its energy needs in the operating time horizon. This assessment can be used to assess expected conditions as well as specific conditions that could threaten energy assurance. For example, cases previously evaluated were a low hydrological or drought condition and an extreme high demand scenario. WECC uses this study to inform Balancing Authorities (BA) of supply and demand conditions that could result in loss of load and holds webinars to ensure the results of the energy assessments are communicated clearly to all stakeholders. This process has contributed to the reexamination of demand and supply forecasts focusing on extreme events.

In Quebec, a primarily hydrological system, energy reliability assessments are a part of its regulatory requirements. An assessment is performed for the internal demand, which represents 99% of the total demand. This assessment covers a period of ten years and is performed for the 50/50 scenario demand. Unserved energy and surplus of generation are metrics used to identify risks. Further, two energy criteria are used:

1. The supply plan must satisfy a scenario of demand that is one standard deviation beyond the 50/50 scenario at five years notice (including demand and weather uncertainty), without incurring a dependency greater than 6 TWh per year from the short-term horizon markets.
2. The supply plan must maintain a sufficient energy reserve to hedge against possible low inflow deficits of 64 TWh over two consecutive years and 98 TWh over four consecutive years.

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[7] *Reliability Guideline - Fuel Assurance and the Fuel-related Reliability Risk Analysis for the Bulk Power System*

[8] *2021 ERO Reliability Risk Priorities Report*

[9] "Energy Assessments with Energy–Constrained Resources in the Planning Time Horizon"

[10] "Energy Assessments with Energy–Constrained Resources in the Operations and Operations Planning Time Horizons"

[11] "Energy Assessment Technical Justification"

[12] For more information on these metrics, see Electric Power Research Institute, Resource Adequacy for a Decarbonized Future: A Summary of Existing and Proposed Resource Adequacy Metrics, EPRI, Palo Alto, CA. April, 2022. Link: https://www.epri.com/research/products/000000003002023230

[13] WECC Assessment of Resource Adequacy

Operations planning entities have also started incorporating some of the uncertain variables (e.g., fuel availability) into short-term horizon reliability studies that are used to produce key operations reliability metrics. For example, CAL-ISO does an annual flexible capacity analysis to determine the monthly flexible needs on the system. In addition, ISO New England (ISO-NE) has Operating Procedure 21 (OP-21 - Operational Surveys, Energy Forecasting & Reporting and Actions During an Energy Emergency) which is specifically designed to assess energy within a 21-day future forecast period. This operating procedure was developed for the winter of 2005/2006, following severe damage to both oil and natural gas infrastructure in the Gulf of Mexico caused by Hurricanes Rita and Katrina. The OP was redesigned for the winter of 2018/2019, to fully integrate weekly generator fuel surveys into its overall energy assessment process. The objectives of the OP are:

1. To facilitate strong lines of communication among Independent System Operators (ISO), interstate natural gas pipelines, Liquefied Natural Gas (LNG) import facilities, gas Local Distribution Companies (LDC), and owners/operators of generating units (resources) regarding all matters relating to resource fuel availability and environmental limitations.
2. To facilitate identification of critical infrastructure of the interstate natural gas pipeline system to ensure critical components are not included in automatic or manual load shed schemes.
3. To alert regional stakeholders of actual or anticipated near-term energy deficiency conditions such that stakeholders with resources in short supply of fuel, or with potential environmental limitations, can take action to replenish fuel supplies and/or take action to mitigate environmental limitations.
4. To alert regional stakeholders of potential energy deficiencies such that they may take action to shorten or reschedule maintenance or repairs to transmission facilities or resources throughout the region.
5. To raise the awareness of New England consumers, market participants, stakeholders, officials of the New England states, regional and national regulators, and regional and national reliability organizations of potential energy deficiencies that may be faced by the region.
6. To allow for timely implementation of load and capacity relief available within actions of ISO-NE Operating Procedure No. 4 – Action During a Capacity Deficiency (OP4)[14] or through implementation of load shedding through ISO-NE Operating Procedure No. 7 – Action in an Emergency (OP7)**[15],** in order to address future capacity deficiencies expected as a result of an Energy Emergency.

While these examples demonstrate excellent ways that the industry is informing and developing action plans using energy reliability assessments, there is inconsistency among entities on if, when, and how the assessments are performed. Currently Reliability Standard, TPL-001-4 calls for modeling the loss of a large natural gas pipeline (and subsequent loss of interconnected gas-fired generation) as an extreme event that should be studied for areas with significant natural gas-fired generation, but beyond this mention, current NERC Reliability Standards do not explicitly require identification and mitigation of scenarios that identify energy assurance risks to the reliable operations of the BPS.

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[14] Operating Procedure No. 4 – Action During A Capacity Deficiency (OP4)

[15] Operating Procedure No. 7 – Action in an Emergency (OP7)

Chapter 1: What is an Energy Reliability Assessment?

Energy reliability assessments are performed inconsistently across regions. While some entities perform energy assessments, currently, no formal definition of an energy reliability assessment exists, and consequently, the elements and methods evaluated are not consistent and are not clearly differentiated from capacity reliability assessments. For the purposes of this whitepaper, an energy reliability assessment is described as:

An evaluation of resources that supply electrical energy and ancillary services for the BPS to reliably meet the expected demand and operating reserves during the associated time-period. It is advisable that this evaluation include the following:

- Consideration of impacts associated with limited resource availability and depletion over time, including constraints imposed by the unassured and limited supply of fuel and other consumable resources (e.g., cooling water) that may be depleted or unavailable and necessary for the reliable operation of a power plant, especially resources depleted by multiple generators simultaneously.
- Consideration of the combined limitations (including emissions limitations) applicable to all resources and transmission.
- Representation of load uncertainty and the impacts of load reduction resources such as curtailable load programs and distributed energy resources and resource depletion, including energy storage and hydro resources.
- Consideration of variable generation uncertainty and energy resource depletion, including energy storage and hydro resources.
- Consideration of common-mode failures within regional fuel supply infrastructure.

In an energy reliability assessment, fuel is any energy source from which a generator extracts energy and converts that energy into electrical power. These inputs used to produce electric power include, but are not limited to, combustible fuels (e.g., coal, oil, biomass, hydrogen, natural gas) and other energy sources (e.g., uranium, hydrogen, wind, water, sunlight, heat).

Capacity versus Energy

While considering generation capacity is necessary for an energy reliability assessment, it is important to clearly distinguish capacity and energy to properly evaluate BPS concerns and determine mitigation strategies. Capacity is the maximum output an electric generator can produce based on specified operating conditions, measured in megawatts (MW). Energy is the amount of electricity a generator produces or potentially produces over a specific time period, measured in megawatt-hours (MWh). Energy availability depends on both the available capacity and the availability of fuel (both stored and just-in-time fuels) as well as other necessary inputs (e.g., cooling water) to produce a consistent supply of electrical energy.

Capacity Assessment versus Energy Reliability Assessment

Energy reliability assessments differ from capacity assessments in that energy reliability assessments examine a span of time over all hours rather than independent points in time. Both types of assessments are valuable while providing different insights. A capacity assessment evaluates a snapshot in time with limited regard for the system conditions during previous and subsequent periods of time. Even for capacity reliability assessments that perform hourly simulations, the assessments usually treat each hour as independent without considering energy assurance issues related to depletion of energy resources and inter-hour operational constraints. For decades, studies have been performed that assess the total installed capacity (or a capacity adjusted for outage rates) to serve peak load. Some regions have included higher levels of details in their capacity assessments that factor in concepts of energy availability; for example, some capacity assessments already consider the detailed modeling of hourly loads, intermittent generation profiles, storage charging/discharging and fuel constraints.

In contrast, an energy reliability assessment considers the unavailability of a generator whether the outage is caused by the depletion of stored fuel over time, disruption of upstream delivery of fuels (both stored fuels and just-in-time fuels), or the *prolonged* unavailability of a generator due to unavailability of just-in-time fuel. An energy reliability assessment deals with the entire duration of a given time period (hourly or at some other time resolution) period and accounts for the impact of changes in conditions over time on different aspects of generator operation and demand behavior.

A series of sequential capacity assessments is not equivalent to an energy reliability assessment. Since energy reliability assessments consider the ability to deliver energy over the study duration over a specific time period, an energy reliability assessment needs to include the constraints on different types of resources throughout the time-period.

An assessment that looks only at instantaneous fuel availability may show the system to have adequate fuel and fail to identify overall fuel depletion caused by dispatching the resources to provide the energy needed to match morning, evening, and intra-hour ramping throughout the entire study period.

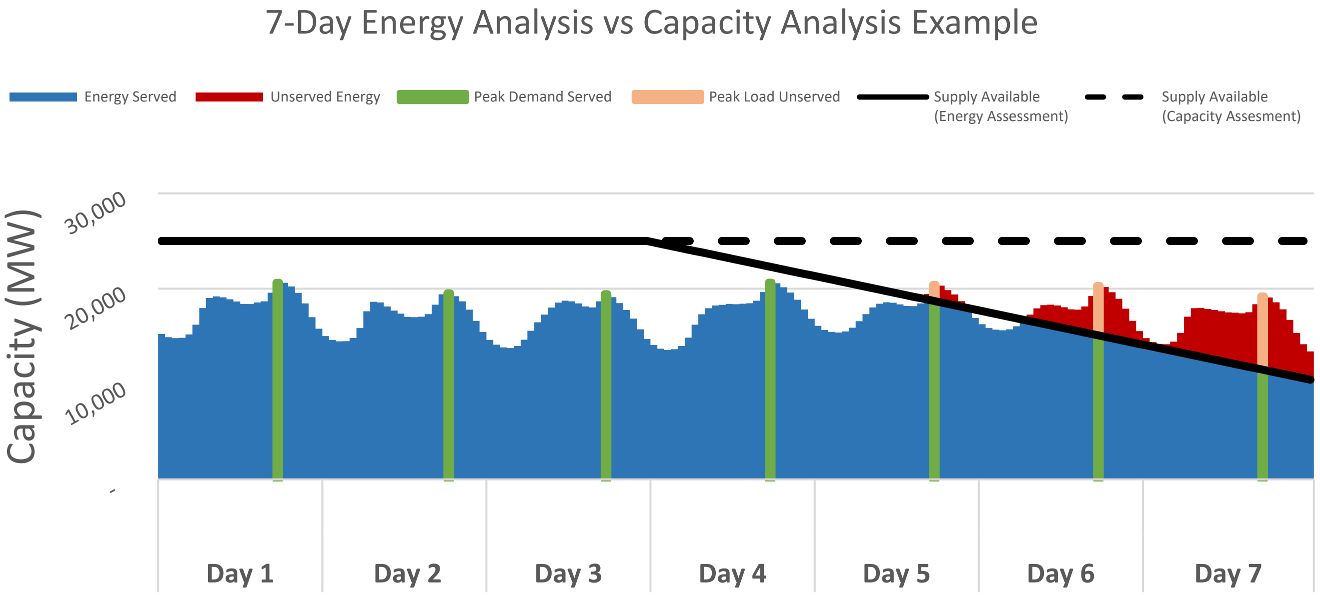

Figure 1.1: An Energy Reliability Assessment versus a Capacity Assessment

A capacity assessment looking at snapshots in time would fail to account for the impact of limited energy supply on the ability to serve demand. **Figure 1.1** illustrates an operational example of the difference between energy and capacity assessments for a 7-day horizon. The example assumes 7 cold days of operation during which a stored fuel such as oil may be necessary to serve load and is depleted during earlier days. For a capacity assessment, a snapshot of the highest demand (green line in **Figure 1.1**) determines if there is sufficient capacity; the available capacity (dotted line) would be 25 GW throughout the week regardless of fuel depletion required from operation of the system over a seven-day period. The capacity assessment would indicate sufficient capacity available to meet demand. Even if the capacity assessment included some inputs related to fuel supply risk, the lack of fuel available in later days would not capture the impacts on available capacity that is dependent on fuel oil consumption and/or replenishment earlier in the week.

An energy reliability assessment would include the effect of all time periods throughout the horizon. As oil is consumed to meet energy needs earlier in the week, the available capacity is dependent on how fuel reserves are conserved, replenished and/or depleted. The energy reliability assessment identifies the risk of unserved energy (red area in Figure 1.1) and unserved capacity (red line in Figure 1.1) in later days due to limited energy. These risks cannot be adequately observed in a capacity assessment which does not consider the chronology of the declining energy availability and resulting generator constraints over a longer period. By the last two days, even the demand at the low points in the load cycle are unable to be served due to depleted energy supply.

Both types of assessments have value and must be understood and treated differently to evaluate both energy and capacity impacts to the BPS. **Table 1.1** provides a summary of differences between capacity and energy reliability assessments.

Table 1.1: Capacity Assessment versus Energy Reliability Assessment

	Capacity Assessment	Energy Reliability Assessment
Demand Representation	Uses forecasted load scenario(s) that represent a snapshot in time (e.g., 50:50 load, 90:10 load, peak hour load).	Uses time-series demand to incorporate the load changes throughout each day, hour, or year.
	Uses individual snapshots of fixed loads and operating reserves, typically peak demand.	Includes flexible load and net-load variability.
Supply Representation	Uses statistical representation of generator availability to calculate capacity contributions (e.g., UCAP[16], ELCC[17]) resulting in a single value that represents the outage potential at a single point in time.	Represents generator outages based on separate outage modes (e.g., equipment failure, fuel unavailability, network issues), each with a different probability of occurrence, impact, and duration.

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[16] UCAP: Unforced Capacity is a value that is assigned to a supply resource (e.g., generator) that represents the amount of power generation not subject to forced outages. UCAP is a function of EFORd, the equivalent demand forced outage rate, and ICAP, installed capacity.

[17] ELCC: Effective Load Carrying Capability is a representation of a supply resource's contribution to serving demand in reference to a theoretical resource that is not subject to outages

Table 1.1: Capacity Assessment versus Energy Reliability Assessment

	Capacity Assessment	Energy Reliability Assessment
Transmission Representation	The transmission model is likely to be similar for a capacity and energy reliability assessment. It is possible to use the exact same model for both types of analysis.	The added complexity of an energy reliability assessment may necessitate a different, potentially simpler, transmission model.
Risk and Reliability Evaluation	Evaluates reliability by simulating snapshots of BPS operation.	Evaluates time-series of BPS operation with fuel stock and other finite resources to be considered.
	Uses clearly defined industry standard capacity or reserve margins to determine the system's level of reliability in terms of magnitude of insufficient supply.	Measures energy-based metrics to evaluate magnitude, duration, and frequency of energy insufficiency over the study period. Though some are maturing, these metrics can be in their infancy and may not be well developed or standardized.

Probabilistic vs. Deterministic

Both energy and capacity assessments can be performed using deterministic or probabilistic methods. Both methods have advantages and disadvantages.

A deterministic approach uses one set of events that will occur for a given scenario. The results of those events have a single outcome for each modeled scenario. An array of assumptions can be made such that there are different outcomes, but the outcome is coupled with the fixed inputs. While the deterministic method may not model a large number of scenarios compared to probabilistic method, if the modeled scenarios are well chosen, these scenarios allow for a clear design basis that ensure a larger number of potential events have sufficient reliability. Deterministic studies can make it easier to make a decision and communicate the decision and its rationale.

A simple example of a deterministic study would be the contingency dispatch of generation to replace the largest generation source loss that would challenge fuel adequacy. The source loss is selected, the initial conditions are fixed, the energy necessary to replace the contingency is selected and dispatched. By looking at the largest generation loss, if all other conditions stay the same, there is a reasonable confidence that any mitigation action is sufficient to respond to unstudied smaller resources that also experience outages.

A probabilistic study uses a range of inputs, often sampled from a distribution of inputs or historical data, to produce a distribution of results instead of the single result in the deterministic case. The results of a probabilistic study have both a magnitude of impact, duration of events, and a likelihood of occurrence. These distributions of results can be represented by an expected value or risk metric. These risk metrics can assess adequate BPS reliability and resilience by setting limits for these metrics.

In a probabilistic assessment, a loss of load expectation (LOLE) can be calculated. If you simulate 1,000 annual operations of a power system which are equally likely to occur and count the number of days with insufficient energy for any duration, you will have a distribution of the number of days with energy shortfalls per simulation. If this distribution of outcomes has a total of 25 days with a loss of load, the loss of load expectation is 0.025 days/year.

Table 1.2 contains a summary of the comparison between deterministic and probabilistic assessment methods that can be used in an energy reliability assessment.

Table 1.2: Deterministic Versus Probabilistic Assessments

	Deterministic	**Probabilistic**
Demand Representation	Considers a single demand forecast or set of discrete forecasts with a separate case for each	Considers multiple demand forecasts and considers uncertainties such as: weather impacts on demand, weather impacts on net-load/behind-the-meter generation, economic drivers. Input data may be based on distributions of data.
Supply Representation	Considers a singular supply shape per case – e.g., extreme weather, one 'hydro year'. Can include operational constraints (e.g., ramp rates)	Considers multiple supply scenarios and factors uncertainties such as: temperature, water availability, multiple outage scenarios, and fuel risks. May consider a distribution of events or multiple weather years for wind/solar/hydro. Input data may be based on distributions of data.
Transmission Representation	Uses a single transmission model with transmission availability of each element considered, independently.	Considers correlation of transmission topology/availability – temperature, multiple outage scenarios
Risk and Reliability Evaluation	Determines unserved energy for a single run[18]	Uses multiple metrics (e.g., LOLE, LOLEV, EUE, LOLH, VaR) based on to evaluate expected magnitude, duration, and frequency of energy insufficiency. Theses metrics are based on the results of stochastic modeling methods.
	Determines sufficient reliability by evaluating sufficient power in each scenario, separately.	Determines sufficient reliability using risk metrics, which includes probability of scenarios while individual simulations may not have sufficient reliability.

One of the challenges of probabilistic assessments is developing and understanding the impact of discrete mitigation activities. Deterministic assessments can be used in conjunction with probabilistic assessments to explore a scenario in greater depth and confirm whether a selected mitigation strategy can effectively address that scenario. Risk-informed scenario development can be used to ensure that reliable operation is maintained during low probability (albeit, not necessarily rare) and likely events (e.g., multiple cloudy/rainy days). Hybrid probabilistic and deterministic modeling approaches can be effective to develop a resource mix and transmission systems that meet the desired reliability and resilience goals.

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[18] Unserved energy and expected unserved energy (EUE) are related concepts but differ in their calculation and interpretation. Unserved energy is a metric calculated for individual scenarios. EUE is a probabilistic risk metric calculated based on average unserved energy from many scenarios and combined based on the probability of those scenarios occurring to produce a single metric. EUE includes the likelihood of modeled events to calculate the value in terms of unserved energy per a time period (often unserved energy per year).

Table 1.3: Summary of Assessments

	Deterministic	Probabilistic
Capacity Assessment	A single or few sets of discrete inputs for supply and demand looking at a single snapshot in time	Numerous sets of dependent and independent input variables representing supply and demand looking at various possibilities for a single snapshot in time
Energy Reliability Assessment	A single or few sets of discrete, dependent, and independent inputs for supply and demand looking at a long duration of interrelated steps in a multi-interval case resulting in specific final conditions describing the state of a system in operational terms	Numerous sets of dependent and independent input variables representing supply and demand looking at a long duration of interrelated steps in a multi-interval case resulting in a distribution of risks with associated probability and impact

Study Frequency, Horizon, and Duration

The design of a process to conduct energy reliability assessments includes consideration of the study frequency, horizon, and duration.

Table 1.4: Definitions of Study Frequency, Horizon, and Duration

	Definition	Example
Study Frequency	How often a study is performed	Performed once per year
Study Horizon	How far in advance the study analyzes	Analyzed year one through year five
Study Duration	The length of time of the study period	Studied a 90-day period

An energy reliability assessment consists of multiple consecutive hours/days/months, in contrast to a single-hour capacity study or multiple hourly capacity studies with dependencies between hours not being considered.

Several factors, depending on how far in advance the study is being performed, will limit the level of detail provided by the energy analysis. Short study periods that are near-term horizon (e.g., performed today for the next 7 days) have forecasts available and can be very precise. Longer horizon studies have a wide range of input variables. High precision is not necessarily available, or even desired, and a wider array of input assumptions is necessary to properly account for realistic possibilities. The study frequency, horizon, and duration are highly dependent on the challenges faced and are regionally specific.

Study frequency considerations should include how fast input data changes, how much time and effort are needed to complete a study, and how long it takes to determine and execute mitigating actions. If assumptions change enough on an annual basis to repeat a study, then the frequency would be annual. Shorter horizon studies will generally have a study frequency that updates as the time that was studied in the prior iteration expires.

The study horizon will generally be defined by what actions can be taken in the time between when the study is performed and when period of interest occurs. Short horizon actions such as outage coordination of existing resources would drive the need for a short study horizon. Long lead time actions such as expanding resource portfolios (i.e., building new generators) would lead to a long-term study horizon. Long-term horizon studies necessitate more assumed inputs than a near-term horizon study, reducing the importance of precision.

The study duration of an energy study is likely more difficult to define until work has been done to better understand what is being studied. It could be arbitrarily defined as a 90-day period or a full year. Once that study is complete, subsets could be brought into focus for producing more precise studies.

The study frequency and study duration must be determined by the desired outcome and align with the logistics related to the timeframe. For example, performing short-term horizon studies with assumptions that transmission facilities will be built are unrealistic. Performing long-term horizon studies with single weather forecasts will fail to evaluate the equally likely conditions.

Considerations for determining the optimal study duration and study horizon should include elements such as fuel replenishment and other logistical constraints, storage capabilities and expected inventory, accuracy and timeliness of weather/climate forecasts, and the expected duration of long-term events (e.g., cold spells and heat waves). Fuel replenishment timelines relate to study horizon and study duration in that there may be sufficient time to complete mitigation efforts. An example in the operations planning time frame could be:

- If the process of refilling an oil tank takes two weeks to complete, from the time the need to refill the tank is recognized to the time the tank inventory has been replenished, the study should be performed using at least a horizon that allows sufficient time for refueling to occur. On the other side of the spectrum, weather forecasts begin to lose accuracy beyond a week. Attempting to forecast weather too far beyond that period would likely lead to less accurate results.
- Alternatively, when performing longer duration and longer horizon studies, seasonality should factor into the decision. It would be prudent to study a winter season, with similar risks and conditions for a three- month period. It could be confusing to study combined winter and spring seasons in a single study.

As stated before, all of these study horizons have regionally specific considerations for selection based on realistic, though potentially extreme, conditions.

Chapter 2: Elements of an Energy Reliability Assessment

This chapter explores the different elements of an energy reliability assessment. There are considerations to be made for supply and demand as well as other variables that could impact both. This chapter discusses some of the elements to consider for an energy reliability assessment related to demand, supply, with a separate discussion on DERs that can blur the lines between supply and demand.

Energy Demand Considerations

Instantaneous (Peak) Demand vs. Prolonged Demand

Energy reliability assessments take into consideration prolonged energy demand (power demand over time) to assess the availability of supply across a pre-determined study period. Meeting peak demand requires supply to reach a single high point at an instant in time before ramping down into the off-peak hours of the day. Off-peak demand still consumes energy, albeit at a lower rate. Modeling time-sequenced demand gives an analyst the ability to measure the impact of all demand and the effect it has on supply that would be necessary to serve that demand at each individual point in time. Hourly integrated demand is given as one example, but time periods may vary, depending on the scope of the assessment.

In the operations time frame energy reliability assessments should include a demand forecast across an appropriate study period to effectively study the impact of resource depletion while allowing time to react, with at least hourly granularity, but could necessitate higher precision when intra-hour constraints present a risk to reliable operations.

In the operations-planning horizon (1 day to 1 year), an energy reliability assessment includes a demand forecast across a time horizon that is tailored to the system being studied, with at least hourly granularity.

In the long-term planning horizon (> 1 year), an energy reliability assessment includes an hourly demand forecast for a longer study period, e.g., the entire study period.

Behavior of Demand

In the operations and operations planning time frames, demand behavior is primarily influenced by weather. Weather forecasts are incorporated into the energy reliability assessment, where it impacts demand.

In the long-term planning time frame, changes in demand will be influenced by many variables such as: economic growth, changes in the penetration of behind-the-meter resources, climate trends, market mechanisms involving demand response and other demand response behaviors, such as vehicle-to-grid energy supply, new types of loads (e.g., hydrogen production, crypto-mining), heating electrification, electrification of other commercial and industrial processes, and energy efficiency advancements.

Behind-the-meter generation can obscure the line between supply and demand. Some behind-the-meter locations are comprised of solar PV, energy storage, and electric vehicles at the same location making it difficult to predict the net flow at these distribution level locations. Behavior may also be potentially shaped by market mechanisms or other programs that incentivize voluntary curtailments of specific demands at certain times, declared events, or via real-time dispatch. Because demand response programs are usually designed for peak load management, voluntary curtailments frequently result in increased energy demand during subsequent time periods.

While the current capability of these programs may be limited for now, advances in smarter devices can provide better capability for external control in the future. A potential benefit of increased external control and dispatchability is that it reduces the burden to serve that demand using grid-connected resources.

Technological advancements may provide better capability for external control in the future.

Usage and Controllability of Demand

An important consideration in the demand forecast is whether the demand can be controlled or whether it is fixed. For example, controllable demand includes programs that exist to target the conservation of energy at specific times to reduce the real-time demand on the BPS for a variety of reasons. Opportunity exists to expand the capability of controllable demand as appliances become more sophisticated and interconnected on the Internet of Things[19]. Controllable demand can be used to shape and shift demand in a day or week to help balance supply and demand but still requires energy. Response fatigue can potentially limit the amount of response that would be seen after enough calls for conservation are made. Eventually, the consumers of electricity may elect to disregard conservation requests if they are over-used. Consideration for the controllability of demand allows for more accurate modeling of how the system would operate and also gives options for determining solutions when supply resources may not be available to produce power.

Distributed Energy Resources

Distributed Energy Resources (DERs) are becoming a more integral part of the power system and must be included in studies. This is true today, and studies that look beyond the next year or two should make reasonable assumptions of the growth of such resources. In some cases, DERs can account for over 30% of a BA's supply. Some BAs are experiencing operational challenges due to the variability of DERs, whether it be predictable or volatile. DERs do not have to be of any specific class of generation but are more likely to be comprised of solar and solar coupled with energy storage, especially if those resources are new and built as part of plans to meet decarbonization policy goals[20]. Modeling DERs refines the precision of an energy assessment and gives the analyst more insight into the behavior and risks of bulk power supply versus distributed power supply (DER).

Energy Supply Considerations

Fuel Assurance and Logistics

Generating electricity is a complicated process. There are numerous steps in supply chains that depend on each other to provide the necessary fuel and materials, to a highly complex set of machines that ultimately generate electricity. Each supply chain is critical to the operation of each individual facility, have some intersection along the way, and are often controlled by entities outside the organization of the grid operator or generator that depend on them. Failure of any of several chains can result in reduced capability or full outages. Studies should consider the supply chains of fuel, consumable emissions control supplies, repair parts for routine maintenance and/or unplanned repairs including those for electronic control equipment, transmission facilities, and even personnel.

Some supply chains remain relatively unconstrained and can be assumed to be available at all times. These will not necessitate detailed modeling as other fuels may, but a thorough evaluation should be used to justify the exclusion of detailed modeling.

Supply chain demand outside of the electric sector that competes for the same resources should also be considered. Supplies that depend on trucking or rail transportation (for example) are competing with a variety of unrelated goods that share the same transportation and associated resources. Demand on gas pipelines for heating, hot water, and other residential/commercial/industrial use can stress natural gas supply and transportation networks and reduce the amount of fuel available for power generation. Each region of the country may have its own specific (and seasonal) constraint points on regional fuel supply chains. Competing demand is not limited to natural gas. Fuel oil for home heating and generation is a shared commodity. Increased demand for home heating oil depletes stocks and

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[19] https://en.wikipedia.org/wiki/Internet_of_things

[20] For example, as of January 2020, California has building codes mandating new single-family homes and multi-family dwellings up to 3 stories high must install solar panels.

potentially stresses supply chains for fuel oil for generators as well. The United States Census Bureau provides information on the types of fuels used to heat homes, broken down by region[21].

To go one step further, fuel supply chains are linked through the demand for those fuels. When coal is depleted for power generation, it must be replaced, likely with either gas- or oil-fired generation. That replacement stresses the supply chain for those fuels. Additionally, replenishment is not instantaneous in most situations. Even natural gas, which flows through high-throughput pipelines from the production source to the demand location necessitates advance scheduling to keep the transportation network in balance. Stored fuels need additional time to arrange delivery in the amount and timeline that is necessary to ensure continued operation. Not all resources can replenish faster than they can use stored fuels. The method of replenishment (barge, truck, pipeline, etc.) is important when attempting to model energy. Replenishment strategies also play a role in energy modeling. Knowing what decisions will be made to maintain inventory should be considered for energy analysis modeling.

Some stored fuels are sourced overseas and need days, or even weeks, to deliver. The logistics of these actions is where energy analyses can provide the necessary situational awareness needed for power generators to make timely decisions to signal the need to schedule and deliver fuel. Beyond logistics is the impact of worldwide events on supply chains. This concept is referenced in *Reliability Guideline: Fuel Assurance and Fuel-Related Reliability Risk Analysis*[22]*.*

Loosely related in terms of fuel supply chain are the supplies of fuel to variable energy resources, primarily solar, wind, and run-of-river hydroelectric generation. The nature of the generator is to produce electricity at nearly 100% of the capability of the incoming fuel supply. Since the fuel supply is heavily dependent on factors outside of human control, efforts must be made to forecast the availability, or at least make reasonable assumptions, such that the reaction can be measured. The reaction, in this case, is to balance supply and demand with other types of resources, such as oil, natural gas-fired generators, and energy storage.

Modeling fuel supply constraints to generators gives an analyst the ability to better understand the profile of electric output as it pertains to using other dispatchable supply resources to balance the power system.

In the Long-term Planning horizon, fuel assurance can be assessed using scenarios or probabilistic analyses that consider:

- Multiple water years (e.g., high, medium, low drought conditions).
- Storage capability and inventory level of fuel, including natural gas, and time for stored fuel to be delivered to generators.
- Multiple wind and solar profiles (e.g., multiple years of data or scenarios with reduced availability of wind/solar).
- Multiple generation installation and retirement scenarios which have the potential to reduce available fuel diversity and amplify dependence on other fuel inventories.
- Project future bulk electric and fuel transmission capability and topology.

Outages and Failure Modes

For many capacity studies, forced outage rates serve as a proxy to generator outages caused by various failure methods including fuel insecurity, and work well for a given set of conditions. When a fleet of similar generators perform with high capacity factors, or at least with the ability to perform at high capacity factors, average outages can be applied as de-rates to the generation fleet to assume an average outage amount (in MW) for a capacity study.

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[21] https://data.census.gov/cedsci/table?q=heat&tid=ACSDT1Y2019.B25040

[22] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Fuel_Assurance_and_Fuel-Related_Reliability_Risk_Analysis_for_the_Bulk_Power_System.pdf

Changing the type of study from capacity to energy or the generation fleet to be less consistent or predictable necessitates additional inputs to be considered, or the existing inputs to be used differently. In the case of a fleet of widely variable generators (wind and solar), forward-looking studies must consider a wide array of outcomes in a probabilistic study. Usually, the forced outage rates are treated as independent events. However, correlated factors such as weather, hydro conditions, and generator outages should be linked as such and not treated independently. Weather drives demand and impacts the probability of outages. A prime example is the case with extreme cold or hot weather which directly correlates with higher loads and indirectly correlates to higher forced outage rates (FOR). To capture this temperature/availability relationship, the modeling of a monthly or seasonal FOR of a generating unit is more accurate than using an annual average FOR. If these events are studied independently, the likelihood of this event will be overestimated and will skew the results of the study to be more favorable. This masks the true expectation of failure and can be worse than not knowing the actual risk.

An additional consideration to be included in energy reliability assessments is the likelihood of increased forced outages of natural gas-fired generation as more variable generation is added to the grid. Natural gas-fired units may cycle and remain offline more often raising the likelihood of start-up and operational failures due to a higher off-line frequency.

Using the generation forced outage rates to represent outages to occur at the single specific hour of the study is adequate until the study becomes more complex. Simple analyses may reduce the output of each generator by an assumed amount to approximate outage impacts on the overall energy picture. Giving generators a “haircut” better approximates energy capability over a long period of time but may obscure specific problems when performing complex, time-dependent studies.

There are many failure mechanisms for generators, each with different probabilities of failure and different impacts for each failure mode. There is a higher probability that a generator will be reduced by a small percentage for a few hours, but still a non-zero chance that the same generator will be out of service for months or longer, all depending on how it fails.

In a probabilistic study, each failure mode can be modeled with its probability of occurrence, the associated impact, and study period. The probability of occurrence is some fractional value that the outage would occur. The impact of a failure will be dependent on the failure mode as well. For example, a natural gas-fired, combined cycle generator with supplemental heat recovery steam generator (HRSG) firing may continue to operate but will suffer a capacity reduction due to failure of the supplemental firing system. Other failure modes will result in different impacts and must be accounted for accordingly. Finally, the study period must be accounted for. Every failure mode should also have an expected duration of impact. This is important for an energy reliability assessment in that MWhs will be replaced by other resources and could have cascading effects.

Each generator will have a different set of assumed failure modes. Classes of generators can have a similar set of assumptions, but a holistic system study could benefit from more specifics based on the generator or generator type. Another consideration for failure modes is associated conditions. Some failure modes can only occur, or have a higher probability of occurrence, during specific conditions. Wet coal problems can only occur under rainy or snowy conditions. Generator freezing can only occur during cold weather, increasingly so as temperature drops.

As an example of the changes needed to improve outage characterization, IEEE Standard 762 “Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity”, which provides guidance on calculating outage rates, is currently being updated. Prior editions of IEEE Standard 762 did not distinguish the reasons a unit failed to produce electrical energy, other than distinguishing between planned and unplanned outages and reserve shutdowns. Without this distinction, at times, the standard has been used to enumerate only equipment failures. The draft revision to the standard[23] acknowledges the broader range of failure modes by introducing a new term "resource unavailability." This is the unavailability that is normal to the generation technology employed and captures full and partial outages as a result of such drivers as:

- Regular (hour-to hour, diurnal, and seasonal) energy unavailability for both variable energy resources (e.g., sunlight and wind), and conventional resources. For conventional resources, this can include low water for a hydro plant or inadequate fuel supply (including diversion of the resource to other users by the supplier) or transportation infrastructure disruption for a thermal plant; and
- Circumstances where the energy resources exceed a limit for safe operation, such as when wind speed exceeds a wind turbine's cut-out speed.

Such characterization of outages, and the additional information that it can provide, will be useful for performing a more rigorous energy reliability assessment.

Transmission and Reliance on Inter-area Interchange (External Assistance)

The supply of electricity is only as good as its ability to reach the load. If power cannot move from the supply to the demand, the production capacity is irrelevant. That concept applies to intra- and inter-regional transmission systems. Electric transmission is part of the supply chain to deliver electricity to end users. Transmission constraints that limit the flow of electricity are one of the better understood parts of this problem as they have been studied for decades. Transmission system constraints are usually separated into constraints that are contained within an area (intra) and the constraints between areas (inter).

Even an unconstrained transmission system can present obstacles to be studied. Areas that serve demand with supply from outside their region make assumptions about the availability of energy in the outside region. Available Transfer Capability for imports does not necessarily mean that energy from imports is available and these limitations should be included in an energy reliability assessment. The availability of imports is dependent on energy issues or demand requirements in external regions. Coordinated studies would show the assumptions of imports and exports at adjoining interfaces, ensuring that energy is available to support exports to an area that is depending on the corresponding imports, and is not counted in multiple energy reliability assessments. Conflicting assumptions could leave operators unexpectedly energy deficient.

Traditionally, peak demand is the point at which the BPS experiences its highest usage and potentially highest stress level while transferring the most power from generators to load centers and loading transmission lines most heavily. With the influx of DERs usually being smaller and (as the name implies) more distributed, the riskiest period of the BPS operation may no longer coincide with peak power demand. Off-peak hours in this case could be at any other period of the day, based on the variable nature of modern generators. Examples include peak photovoltaic or wind production, when generation could go beyond a simple offset of demand to the point where a change in load and generation patterns would cause transfers across the transmission system to operate closer to limits, potentially causing congestion mitigation measures to be implemented, at a time when studies would not normally be performed. There are potential constraints on the BPS that would be made apparent using studies that go beyond the snapshot of peak demand.

Modeling or making assumptions of transmission capability and availability of imports provides more accuracy for an assessment while giving potential insight into stress on the system beyond peak demand periods.

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[23] Please refer to IEEE P762™ (Draft 41, October 3, 2022), Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity has been approved in balloting and is undergoing final editing

Energy Storage

Until recently, pumped storage hydro-electric was the main type of energy storage on the BPS and is typically used to provide fast-start balancing of supply and demand or contingency recovery (via the triggering of operating reserves). Pumped-storage hydro can also be used to provide additional demand on the BPS, typically when light load conditions exist, and the BPS is operating in a "minimum-generation" state. Depending on the configuration, pumped-storage hydro can be used on a daily or weekly cycle. Today, with more variable supply resources, the role of storage has trended more towards balancing, with the objective of stabilizing the supply for what may now consider a relatively consistent demand curve.

The operation of a specific facility, including the duration of time that energy storage can discharge to the grid, varies by the design of the site and technology type. Long duration storage such as pumped storage hydroelectric and newer storage technologies have the potential to inject energy at various times when conditions may otherwise not support adequate supply for several days. This would be the case when there is unfavorable weather to produce solar and wind power (i.e., cloudy and calm) for multiple days. Energy assessments may provide insight into the amount of storage needed for a specific scenario. Storage is quantified in both capacity (MW) and energy (MWh) and must be modeled as such.

Stand-alone storage is a device that takes power from the system, saves it as some form of potential energy, and uses it to provide electricity later. The efficiency of storage should be considered in an energy analysis. Furthermore, the fact that stand-alone storage resources are overall consumers of energy means that they should be considered for exclusion from operation when facing a risk of fully depleting energy constrained resources. However, if storage is co-located with a supply resource, then the storage can provide capacity and energy at times when the supply resource is not operating.

Co-located or hybrid storage includes storage coupled with a supply resource like solar, wind, or other energy supply. These storage types can be modeled as a single facility or broken down into individual components, so long as the capabilities are accurately included in the assessment.

Modeling storage is key to future studies when each instance in time could be dependent on storage just to meet the energy needs.

Operational Characteristics and Balance of Supply and Demand

To effectively simulate the multi-hour interdependencies between supply and demand, considering the impacts of operational characteristics of resources on energy availability is important. Such operational characteristics include startup and shutdown profiles of generators and intertemporal constraints such as minimum down times, minimum and maximum run times, and number of startups allowed, which may depend upon the generator's technology type or emissions restrictions. The operational profile can also impact the duration of energy availability should limited energy resources be depleted to support ramping or other ancillary services or BPS needs. Models that simulate chronological unit commitment and dispatch are integral to the assessment of multi-hour energy availability.

In a power system with generation that can change output at a rate faster than the rate of change in power demand, ramping is not a concern. Traditionally, generators are dispatchable from a minimum output to a maximum output at the discretion of a system operator whose goal is to maintain supply balanced with demand. Simply, this is a two part equation with supply on one side and demand on the other. Supply is either set to a fixed output that does not usually change over time (e.g., nuclear power plant), variable output that can be accurately predicted and/or does not represent a large portion of the generation fleet (e.g., run-of-river hydro or low-penetration of wind generation), or dispatchable that follows dispatch instructions and assumed fuel availability. A new addition to this equation can be described as generation with variable output that cannot be accurately predicted and can be far less certain. Even in a situation where predictability is perfect, potentially high ramp rates from non-dispatchable resources need analysis, and potential mitigating actions, when the offsetting, or replacement ramping capability may be insufficient. As the penetration of resources that rely on just-in-time fuel, and/or variable energy resources that rely on weather conditions increases, the overall variability of the supply increases, leading to higher levels of uncertainty in energy supply.

Demand on the system is also becoming more variable as a result of changes to the demand composition including electric vehicles, price responsive loads, demand response, and combined heat and power plants. All these demand elements may on short notice either self-supply on-site demand or increase system demand on the grid. As a result, supply and demand intra- and inter-hour ramps are increasing and are expected to increase in the future, placing a greater burden on existing dispatchable resources. For this whitepaper, flexible resources refer to any system resource that is available or can be called upon in a short time to respond to changing system conditions.

Conclusion

Energy reliability assessments are moving into the spotlight as a critical tool to fully understand the operation and planning of the BPS. The evolving grid will rely heavily on increased levels of variable and flexible resources to meet future energy needs. Consequently, the behavior of all resources must be understood and accurately modelled. Performing energy reliability assessments and ensuring the validity of assumptions used in those assessments are important foundational activities for maintaining BPS reliability and resiliency.

Appendix A: Contributions

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