Reliability in PJM: Today and Tomorrow

PJM Interconnection
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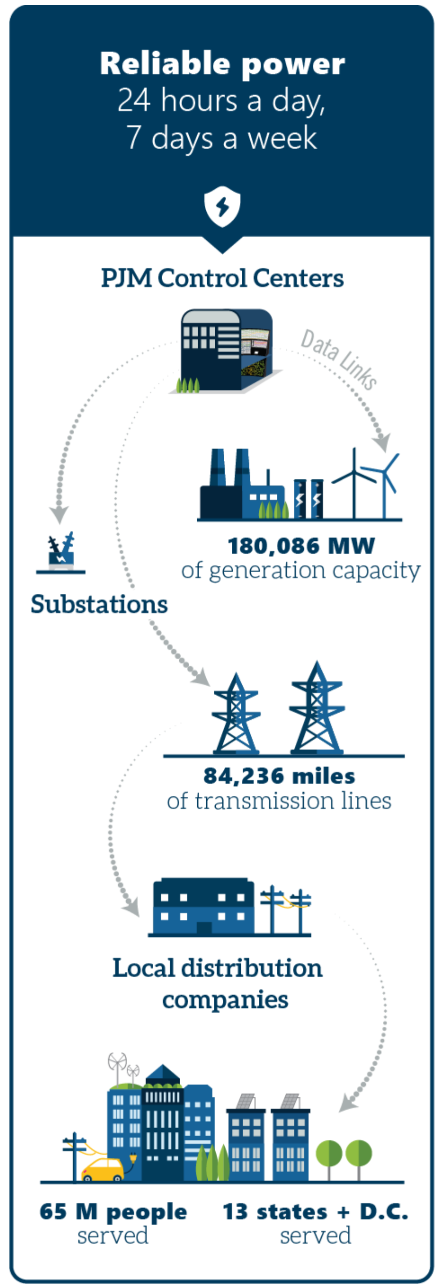
I. Introduction

Reliable and affordable electricity is essential to modern society. We depend on it every day to power our homes and businesses, and to support critical services such as health care, communications and transportation. This past year in particular has highlighted the need for reliable power amid the global pandemic – allowing people to work and connect remotely while supporting both the treatment of patients and the search for a vaccine.

PJM Interconnection, as a regional transmission organization (RTO), is responsible for the reliable operation of the power grid within its territory, which serves 65 million customers in 13 states and the District of Columbia. PJM works with its member companies to coordinate the production and instantaneous delivery of wholesale electricity across its footprint.

The job of ensuring safe and reliable bulk power system operations – keeping the lights on – is PJM's most important priority. It involves around-the-clock system monitoring and the dispatch of power by trained operators; real-time coordination with other operating entities and industry sectors; and extensive planning to ensure the grid is equipped to serve future needs.



The Changing Energy Landscape

A broad set of trends is reshaping the electric industry today, thus planning for the grid of the future is of particular importance. One such trend is the increasing number of states and stakeholders that are adopting decarbonization goals of varying ambition.

Renewable resources, whose power is intermittent in nature, are coming online at an escalating rate, and are expected to dramatically alter the resource mix over time. Currently, 92% of the 145 gigawatts[1] in the PJM interconnection queue – where generation projects apply to connect to the PJM system – are solar, wind, storage or combinations of wind/solar with storage resources, known as hybrids.

This will correspond with a rapid proliferation of distributed energy resources (DER) – smaller generation resources with limited visibility to PJM operators. At the same time, we expect significant new investment in grid modernization, coupled with intense innovation in technology, data management and new business models.

The Federal Energy Regulatory Commission (FERC), which regulates the interstate transmission of electricity and wholesale power markets, has supported the integration of DER into the wholesale electricity markets through the recent issuance of Order 2222. The purpose of this order is to remove barriers to entry for smaller-scale generation and storage on the

[1] 145 gigawatts in the PJM interconnection queue refers to the nameplate capacity of all projects.

distribution system, along with demand response and energy efficiency, by allowing those resources to aggregate and directly compete against larger, more traditional generation in the markets.

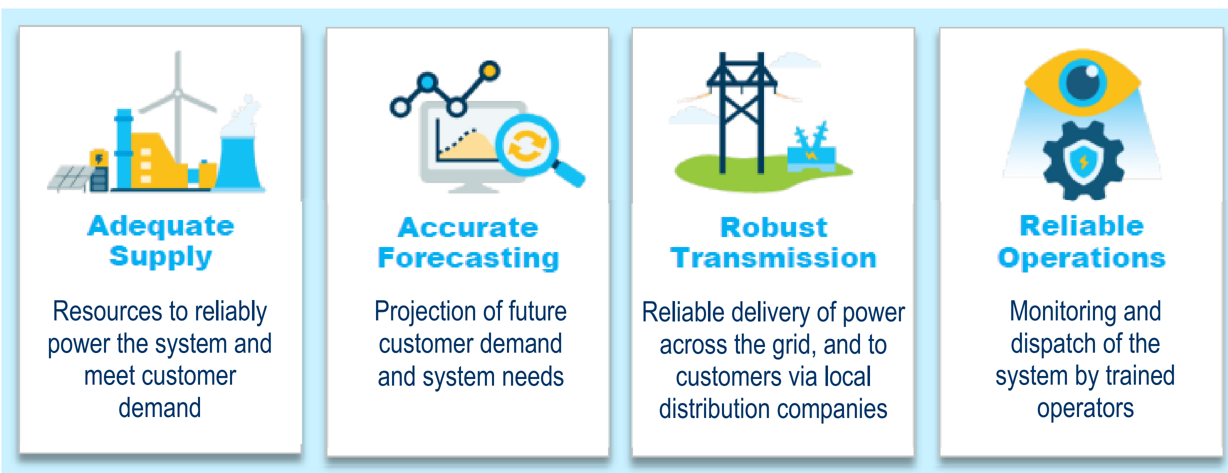
These emerging trends have benefits and offer new opportunities. They also begin to present new challenges for grid operators such as PJM. At the highest level, they largely represent a shift from what has long been a model in which the demand for electricity, or load, is predictable and supply is controllable, to one where they may be less so.

PJM anticipates that maintaining reliability in this new paradigm will require consideration of changes to the rules and processes followed in executing its core functions of planning, markets and operations. The topics discussed in this paper represent areas where change may be necessary to ensure a reliable future.

Framing the Discussion

The purpose of this paper is to help frame the forthcoming discussions on system reliability with policymakers and stakeholders, and begin reviewing how PJM's core functions, market rules, operations and planning processes should evolve to maintain reliability in the face of the changes occurring in the electric industry.

To help ground those discussions, the paper provides an overview of bulk power system reliability in terms of four basic building blocks that a grid operator must have in place today and plan to provide for in the future: adequate supply, accurate forecasting, robust transmission and reliable operations.



The paper then reviews how PJM achieves reliability today through each of these building blocks. It lays out how emerging trends in the industry will impact each aspect of reliability and highlights how PJM will need to evolve to ensure future system reliability.

The paper concludes with the next steps to continue the discussion with policymakers and PJM stakeholders on exploring the changes needed to support industry trends and future grid reliability.

Reliability Standards

The North American Electric Reliability Corporation (NERC), with oversight from FERC, is the regulatory entity responsible for developing and enforcing reliability standards in North America that PJM and other system operators must follow to ensure the safe and reliable operation of the grid.

NERC defines reliability of the bulk power system in terms of two fundamental aspects: Adequacy and Operating Reliability (also called Security). Adequacy refers to the ability of the electric system to supply the aggregate electric power and energy requirements of consumers at all times, while Operating Reliability refers to the system's ability to withstand sudden disturbances, such as the unanticipated loss of system components. The four building blocks of reliability discussed in this paper support these two fundamental principles.

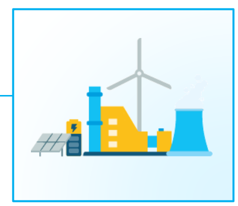
The intent of NERC Reliability Standards is to help ensure an "adequate" level of reliability. It is not possible, or economically feasible, to plan and operate the system in a manner that is perfectly reliable with no risk of power outages or blackouts. Many grid operators in the U.S., including PJM, set a target level of reliability to ensure that available resources on the system will be able to meet the demand for electricity and avoid involuntary customer load shed with a risk of no more than once in 10 years – known as loss-of-load-expectation (LOLE).

Grid resilience
is another important concept that is intertwined with reliability. Resilience involves preparing for, operating through, and recovering from events that impose operational risk, including but not limited to high-impact, low-frequency events not addressed by typical reliability standards. Those events may include a physical or cybersecurity attack, major disruption to generator fuel supplies, or the extended pandemic that we are currently facing. These events may be less frequent, but have the ability to significantly disrupt the bulk power system.

II. The Building Blocks of Reliability

This section provides a general overview of the four building blocks of reliability that any grid operator must have in place today and plan to provide for in the future.

Adequate Supply



Adequate Supply addresses whether there is sufficient generation and other resources, including demand response, available on the system to meet customer demand. This involves having adequate 1) capacity to meet peak demand on the system, 2) energy to meet the day-to-day and intraday demand and 3) ancillary services and reliability attributes, which refer to the essential grid services and resource characteristics needed to maintain system balance and stability and support the reliable operation of the grid.

Capacity

Capacity represents the capability of a resource to provide power or reduce demand as needed, particularly during emergencies. An adequate level of capacity helps ensure the availability of sufficient resources on the system to meet the peak demand of customers during the year, which, in PJM, occurs during the hottest summer days or coldest winter days when air conditioners or heaters are used most. This requires keeping a certain amount of capacity reserves above the expected annual peak load on the system to account for factors such as generator outages or times that customer demand exceeds expected levels.

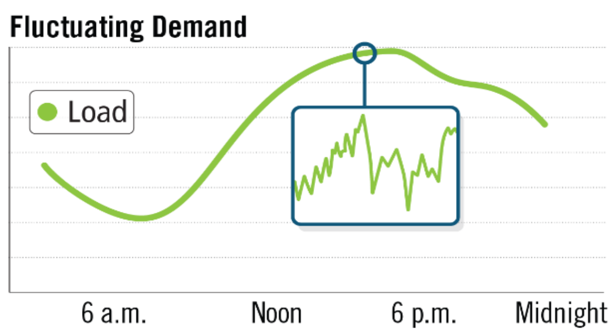
Traditionally, the amount of capacity on the system is measured in terms of installed reserve margin, which represents the level of capacity reserves – typically expressed as a percentage in excess of annual peak load – needed to satisfy some level of reliability criteria. As noted previously, most grid operators in the U.S., including PJM, use an LOLE reliability criterion of one day in 10 years.

Energy

Energy is the actual production of power over a period of time, often expressed in megawatt-hours (MWh). At a high level, the consistent delivery of electricity to consumers is what reliability is about. While adequate capacity ensures available resources to cover the peak demands during the year, sufficient energy is needed to meet the daily, hourly and sub-hourly demand of customers. Grid operators schedule resources to provide energy in advance of each day, and then adjust those schedules as needed throughout the day to balance supply and demand.

Ancillary Services and Reliability Attributes

Ancillary services and reliability attributes[2] are necessary to maintain system balance and support the reliable operation of the grid beyond the basics of providing real power. Certain ancillary services, such as frequency response, operate almost instantaneously in an automated fashion to keep the system frequency in check. Others operate more slowly but also help maintain system balance as load fluctuates second-to-second and hour-by-hour throughout the day. The reliability attributes and ability to provide ancillary services are not uniform across all resource types. Therefore, it is important that the evolving set of resources on the system, in aggregate, are capable of providing the level of services and attributes needed to support the reliable operation of the grid as requested by the system operator.



If an adequate level is not preserved, system operators may not be able to keep the system in balance, which can result in involuntary load shedding, rotating blackouts or even the complete collapse of the power grid. The following is a list of reliability services and attributes that are critical to ensuring reliable operation of the grid.

Frequency Response

The frequency of alternating current on the transmission system (scheduled to 60 Hertz in the U.S.) is a key indicator of the system's health and stability. It is impacted by any imbalance between load and generation, such as that which happens when turning on lights or when a generator trips offline. Frequency deviates upward when generation exceeds demand, and deviates downward when generation is insufficient. Frequency response is how quickly the

[2] PJM published a white paper in 2017 on fuel diversity and reliability, with detailed descriptions of reliability attributes.

system handles those deviations and returns the system to the scheduled frequency and is provided through the interaction of three components: inertial, primary and secondary frequency response.

Types of Frequency Response

INERTIAL	PRIMARY	SECONDARY
Inherently provided through kinetic energy stored in the rotating mass of synchronous generators to arrest changes in frequency	Autonomous and automatic reaction of a generator, or other resource, to rapidly change its output to control for frequency deviations	The centralized re-dispatch of resources capable of quickly adjusting their output. Also known as automatic generation control (AGC) or regulation
Immediate	*Within Seconds*	*Seconds to Minutes*

Ramping

Ramping is the ability of a generator to increase or decrease its output to help maintain supply-and-demand balance on the system in response to a control signal provided by the grid operator. This reliability attribute can be further broken down into the following categories and services:

- **Regulation** (i.e., Secondary frequency response): Resources capable of following automatic generation control signals and adjusting their output to manage minute-to-minute fluctuations in system demand
- **Load-Following** (Dispatchable): Ability of a resource to adjust its output to follow fluctuations in system demand throughout the day.
- **Operating Reserves:** An amount of generation or load curtailment that can be deployed within a defined timeframe to recover from a sudden supply shortage. Reserves come in different time steps such as 10 minutes, 30 minutes and 90 minutes. Reserves also come in different categories such as synchronized and non-synchronized.

Commitment Flexibility

Commitment flexibility is characterized by the ability of a resource to cycle (start up and shut down multiple times during a day) on demand, its total time to start, minimum run-time and the number of starts per day. Flexible resources capable of coming on- or off-line for short periods support reliability when system load, interchange or generator output change rapidly.

Voltage Control

System voltage is the second key indicator of system health and stability. Voltage on an electric line is similar to water pressure in a hose; it is needed to ensure sufficient flow. If voltages drop too severely, the low voltages can cascade through the system and lead to a localized or widespread blackout. If voltages get too high, it can cause failure or permanent damage to system equipment. Voltage control is a resource’s ability to either inject or absorb “reactive power” to maintain or restore system voltage to prescribed levels following a disturbance. Reactive power (measured in Mega VARs) cannot be easily transmitted over long distances like real power (measured in megawatts), and therefore requires resources used for voltage control to be located in close proximity to consumers or areas where voltage regulation is challenging.

Availability

Availability is a measure of the resource's ability to perform when needed by system operators. For thermal generation, it considers the probability that a resource will be on a forced outage when needed, due to equipment failures, inability to secure fuel, or other reasons. Availability for intermittent and storage resources is based on their expected ability to perform when needed during peak periods of demand, or those with the highest loss-of-load risk. Generally, resources with higher availability reduce uncertainty and provide a greater reliability value to system operators than resources with poor availability.

Black Start Capability

Black start capability is a reliability attribute provided by units that have the ability to start up and deliver electricity to the power grid without an outside source of power. Unlike services and attributes that routinely support reliability, these units are used for system restoration by helping to re-energize the grid following the unlikely event of a widespread outage or blackout.

Accurate Forecasting

Accurate forecasting plays an important role in maintaining the reliability and efficiency of the power grid. Predicting the total demand, and net demand (demand minus solar and wind output), for electricity for the next hours and days, as well as many years into the future, allows for reliable planning and operation of the system.

Load Forecasts

Planning for the grid of the future requires the development of long-term load forecasts that address a myriad of underlying drivers, including weather, economics and customer behavior. These forecasts, made multiple years in advance, become the basis for the extensive, comprehensive planning needed to identify required transmission enhancements to the system, as well as the system's future capacity needs.

Short-term load forecasts are necessary for grid operators to balance the supply of electricity with ever-changing demand, typically over time horizons of minutes to days. The models and techniques used for short-term load forecasting vary, but generally consider many of the same factors as long-term load forecasts.

Distributed Energy Resources (DER)

Distributed energy resources, such as rooftop solar installed on the customer's side of the electric meter and electric vehicles, can reduce or increase the amount of electricity a customer draws from the grid depending on their operating state. The ability to forecast the proliferation and output of different types of DER on the system directly impacts the accuracy of the long- and short-term load forecasts that are needed for grid reliability.

Renewable Output

Intermittent renewables, particularly wind and solar, are greatly influenced by the weather, and outputs vary throughout the operating day with the resource's energy source. The output of solar resources, which largely depends on incoming solar radiation and weather conditions, tends to be more predictable than wind as it typically tracks the rising and setting of the sun. In order to balance supply and demand, grid operators must be able to forecast the output of intermittent resources with reasonable accuracy to ensure that other, dispatchable resources are available and scheduled to meet the net demand remaining on the system.

Robust Transmission

Electricity is a real-time, on-demand commodity used virtually the moment it is created. Like any commodity, it must be delivered from the point of production – a generator – to the point of consumption – our homes and businesses. Transmission lines are the highways across which electricity is delivered. At its most fundamental, the transmission system ensures that electricity can be delivered reliably across the grid to customers the instant it is needed via the distribution system.

Transmission reliability is a function of thermal, voltage, stability and short-circuit power system fundamentals. The standards for these are set by NERC.

Thermal Overloads

Power flows across each transmission facility according to the relationship of its impedance (opposition to electrical flow) with respect to the broader network. Thermal ratings, or the amount of power that can be reliably transmitted through a given facility, are established by examining the most limiting element of a facility: for example, transmission cable or substation terminal equipment. PJM identifies facilities that have power flow loadings that exceed applicable thermal ratings for pre-contingency conditions and for the loss of a single or multiple generator(s), transmission line(s), transformer(s), or combinations of those elements.

Voltage Limits

Voltage is critical to reliable, on-demand electricity delivery. NERC standards require that a transmission system remain stable within applicable thermal ratings and within established substation voltage ranges. Both voltage that is too low and voltage that is too high can become a serious concern, depending on the availability of resources – both generation and transmission – to produce or absorb reactive power to aid in voltage control.

In real time, operators use transmission system equipment to control voltage, up to and including switching transmission lines in and out of service, switching capacitors or reactors, or adjusting voltage set points on static volt ampere reactive (VAR) compensators.

System Stability

System instability can arise under any number of conditions. The most common condition, however, is when a fault occurs on the transmission system, resulting in a generator going into an over- or under-speed condition, causing it to trip off-line. Under such conditions, if there is insufficient inertia to compensate, that generator may shut down, along with additional cascading transmission and generator trippings, up to the point where blackouts can occur. PJM performs multiple tiers of stability analysis, consistent with NERC criteria, to develop transmission solutions that ensure generators remain synchronized with the rest of the grid.

Short Circuit Limits

NERC requires that each bulk electric system circuit breaker have adequate fault-interrupting capability in order to isolate the transmission facility and remove the fault, or abnormal electric current, from negatively influencing the broader transmission system. PJM runs short circuit simulations that utilize circuit breaker ratings provided by the transmission owner to evaluate the breaker-interrupting capabilities. Any deficiencies in breaker ratings are identified by PJM, and necessary enhancements are developed by both PJM and the transmission owner. Solutions may require replacing the breaker itself to implement a higher current-interrupting rating, or sometimes even redesigning significant portions of the electrical infrastructure. All breakers whose calculated fault currents exceed breaker-interrupting capabilities are considered overdutied, or operating in excess of equipment ratings, and are reported to transmission owners for confirmation and solution development where required.

Reliable Operations

A system is only reliable when operated properly. A robust system may be planned and designed well, but if it isn't operated properly it will not be reliable. This is particularly true for the bulk electric system, as unexpected disturbances on the system can quickly escalate to cascading failures and widespread power outages if not handled properly. To keep the system reliable, grid operators work around the clock to monitor and control the system, directing how much energy should be supplied by generators to match the demand, ensuring transmission lines and facilities stay within their operating limits and constantly preparing for the unexpected.

Supply and Demand Balance

The demand on the system changes throughout the day, and one of the essential roles of a system operator is to maintain the balance between the supply and demand for electricity. System operators maintain that balance by sending signals to generation resources to increase or reduce their output to match the demand on the system.

They also commit additional resources to respond to increases in demand or loss of generation, as well as directing controllable loads to curtail energy usage at times. Maintaining system balance is essential to grid stability and keeping system frequency at 60 Hz, the standard for all of North America.

As the supply and demand change throughout the day, operators must also monitor the transmission network to ensure that the power flows on transmission lines and facilities do not exceed their ratings, as this can lead to equipment damage and cascading failures on the system.

Preparation for the Unexpected

Part of reliable operation is to expect and prepare for the unexpected. Unanticipated events like the loss or reduction in output of a generator or generators, a sudden shift in load, or the failure of a piece of transmission equipment due to severe weather like thunderstorms or tornados, can all affect the reliability of the bulk electric system. System operators proactively take actions to position the system to operate reliably through these events and hold resources in reserve to restore supply-and-demand balance following an event.

A recent example of this occurred in PJM on Feb. 12, 2021, when PJM issued a Cold Weather Alert for the western part of the RTO. Temperatures were forecasted to be in the single digits and lower across much of the region. The purpose of a Cold Weather Alert is to prepare personnel and facilities for expected extreme cold weather conditions. PJM dispatchers then recall or cancel non-critical generation and transmission maintenance outages, and generation owners and transmission owners make final preparation for cold weather operation.

Coordination with Asset Owners and Neighbors

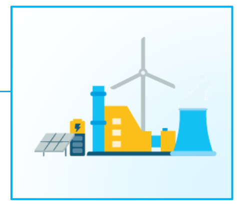
Operators of the bulk electric system coordinate closely with other operating entities, such as generation and transmission owners, as well as other system operators, to maintain grid reliability. There are times that transmission and generation owners need to take their equipment or facilities off-line for maintenance or improvements. System operators coordinate with these entities to plan sufficient time for maintenance activities while maintaining reliability during that time.

PJM and other system operators are linked by transmission infrastructure throughout the Eastern Interconnection. These system operators coordinate with neighboring operators, because the power-flows across the border of two regions affect reliability. During extreme conditions, PJM can provide megawatts to bolster a neighboring system facing major outages. PJM is also able to receive power from neighboring systems. Geographic diversity can also bolster reliability. In PJM, for instance, weather patterns impacting Illinois are not likely to be affecting Virginia in the same way. During the severe winter storms of February 2021, the eastern portion of PJM's footprint experienced milder weather than the western half, and PJM's generators were able to export record amounts of electricity to surrounding systems.

III. PJM: Achieving Reliability Today and Tomorrow

The following sections review how PJM maintains reliability today for each building block and highlights key areas of change that will need further discussion and exploration to ensure the continued reliability of the grid.

How PJM Maintains Adequate Supply



Adequate supply is largely achieved in PJM through system planning and the operation of competitive wholesale markets. Markets provide a powerful tool for attracting investment in new generation and technology at the lowest cost, and support reliability by providing financial incentives and encouraging competition to provide electricity where and when it's needed. PJM markets that support adequate supply are the capacity market, energy market and ancillary service markets. Each of these markets serves a separate function, but all work together to provide the right price signals and revenues to resources that are needed to achieve adequate supply.

Administering the Capacity Market

PJM's capacity market, called the Reliability Pricing Model (RPM), promotes reliability through competitive auctions that secure capacity resources to meet system reliability three years in advance. The auctions allow both new and existing resources to participate, and provide forward price signals that support the efficient entry and exit of resources on the system. PJM secures capacity in the auctions on behalf of load-serving entities – including local utilities, competitive suppliers and public power – using a sloped demand curve that sets the clearing price.

A few additional key elements of PJM's capacity market design include:

Locational pricing to reflect transmission limits and promote capacity in locations where it is most needed

Performance obligations to require committed resources to be available and respond when needed in real-time, or face significant financial penalties

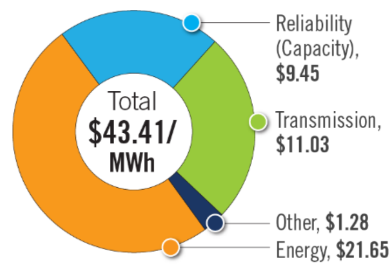
Non-discriminatory and open participation for a variety of resources types, including generation, demand response, and energy efficiency

PJM's capacity construct also allows for certain load-serving entities, particularly utilities, to opt out of RPM auctions and instead satisfy the capacity obligations of their load through self-supply or bilateral contracts. This option is called the Fixed Resource Requirement (FRR) Alternative.

Administering the Energy Market

PJM's energy market secures electricity to meet consumer demand during the course of the day (Real-Time Market) and also for the next day (Day-Ahead Market). It is the largest of the PJM markets, typically making up about 60 percent of wholesale electricity costs. Both the Day-Ahead and Real-Time Markets focus on procuring electricity at the lowest cost to meet consumer needs. Prices in the energy market are based on the concept of Locational Marginal Pricing, or LMP (see sidebar below).

2020 Total Wholesale Cost



Day-Ahead Market

The Day-Ahead Market is a forward market where electricity is procured for the following operating day. Hourly prices are calculated based on generation offers, demand bids from load-serving entities, and other transactions that are submitted to the market. PJM clears the market in a least-cost manner ensuring that cleared demand is met with the lowest cost supply. Resources that clear in the Day-Ahead Market have a financial obligation to provide power the following day, with any deviations from the cleared amount settled in the Real-Time Market.

After the posting of Day-Ahead Market results, PJM performs a second resource commitment, known as the Reliability Assessment and Commitment (RAC) run, which includes updated resource offers and availability, as well as updated load forecast information, to commit any additional resources needed for reliability the next day.

Real-Time Market

The Real-Time Market, or balancing market, is a spot market where PJM procures electricity for immediate delivery. Every five minutes, PJM provides dispatch signals indicating to resources what their energy output should be in order to follow fluctuations in demand and supply and maintain grid balance at the lowest cost.

Locational Marginal Pricing (LMP)

- LMP reflects the price of electricity and the cost of congestion and losses at points across the power grid.
- These prices serve as benchmark signals for market participants to make decisions about future investments.
- Higher LMPs signal where new generation is needed most and where new transmission would relieve congestion and provide the greatest economic benefit to consumers.
- Lower LMPs signal where demand customers can locate to find the cheapest power.

Administering Ancillary Service Markets

PJM operates ancillary service markets for both regulation (i.e. secondary frequency response) and several reserve products. The commitment of energy, reserves and regulation are co-optimized through various market clearing processes, with the objective of finding the most economical set of resources to meet the combined requirements.

Regulation Market

PJM's regulation market provides market-based compensation to resources for providing regulation. Resources in the regulation market must follow one of two types of regulation signals: the Regulation A signal that is primarily followed by conventional generation resources capable of quickly adjusting their output up or down, and the dynamic Regulation D signal intended for faster resources such as batteries. The market clears and commits resources on an hour-ahead basis via co-optimization with energy and reserves to satisfy the regulation requirements of the RTO. Signals for regulation are sent out every two seconds to resources providing regulation to help keep the system in balance and frequency at 60 Hz.

Reserve Markets

PJM's reserve markets provide compensation to resources that provide various types of operating reserves. The market rules were recently amended[3] to procure three reserve products in both day-ahead and real-time:

- Synchronized Reserves with a 10-minute or less response time
- Non-synchronized Reserves with a 10-minute or less response time
- Secondary Reserves with a 30-minute or less response time

The procurement of these products will eventually incorporate Operating Reserve Demand Curves (ORDCs), or sloped demand curves that provide incrementally higher price signals as the system's reserve levels decrease. The quantity of reserves required by the ORDCs considers the loss of the single largest contingency on the system, as well as the uncertainty inherent in the forecasts of wind and solar output, generator outages and net interchange with neighboring systems.

Services Not Compensated Through Markets

There are certain ancillary services that are not explicitly modeled in PJM markets today. Some of these services are compensated under the PJM Tariff and others are not.

- **Voltage Control**: Generators capable of providing reactive power support can be compensated through rate-based monthly payments at a rate filed and approved by FERC, as well as lost opportunity credits to the extent a resource is redispatched at PJM's direction to address a voltage concern on the grid.
- **Black Start Capability**: PJM uses a request-for-proposal (RFP) process to evaluate future needs and procurement of black start resources, which includes an economic evaluation. Selected resources are eligible to receive payments for recovery of the cost of providing black start service.
- **Inertial and Primary Frequency Response**: Generators that provide these types of frequency response are not explicitly compensated for this service under today's rules.

[3] FERC order approving PJM's reserve market enhancements was issued in May 2020 with new rules taking effect in May 2022

Future of Adequate Supply

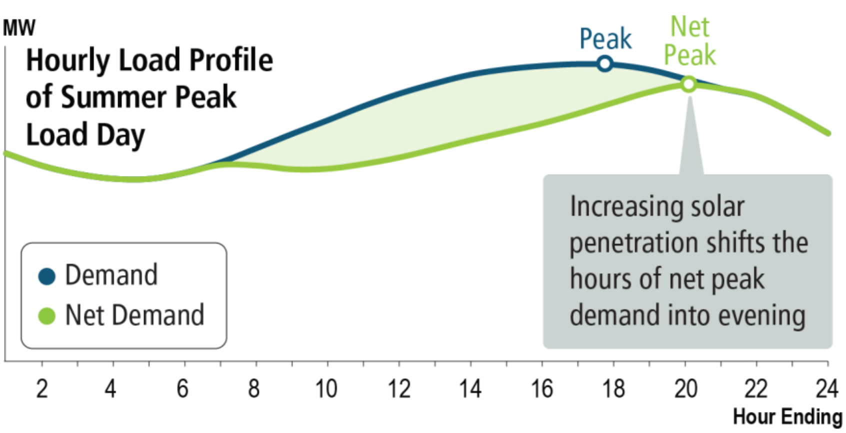
The changes occurring in the electric industry and evolving resource mix have the potential to significantly impact the provision of adequate supply and reliability in PJM.

Greater Focus on Adequate Energy, Net Peak Demand

Historically, adequate system capacity has resulted in adequate energy, as most traditional generation is capable of running 24 hours a day. As the level of renewables and storage rises, however, ensuring adequate energy across all hours of the day will be an increasingly important consideration, because the available output of those resources can vary significantly throughout the day. Resource output can vary with the energy source (in the case of wind and solar), or may be limited in the number of run hours at full output (in the case of storage).

In addition, the rise of solar generation on the PJM system will change the hours most at risk of load shed. Historically, this has been the hours of peak demand in the summer, when temperatures are at their highest. In a system with a high penetration of solar, those hours of risk shift to later in the evening, when the sun is setting and solar performance is decreasing while temperatures remain high (See Figure 2 below). This has been observed in California, which has a much higher penetration level of solar than PJM at this time. The California ISO, in their report[4] on the August 2020 rotating outages, pointed to the shifting risk from gross- to net-peak demand as a key contributor, and an area that requires further attention in the future.

Figure 2. Impact of Solar on Net Peak Demand



Evolving Reliability Contributions and Criteria

PJM recently made an important first step in evaluating the reliability contribution of renewable resources with a filing on effective load carrying capability (ELCC), currently pending before FERC. ELCC replaces the existing methodology of determining the capacity value of renewables, which only considers performance during certain peak hours in the summer. ELCC uses a more robust, probabilistic analysis that considers the contribution to reliability that resources provide during all hours of high risk, including net-peak-demand hours, and accounts for the limited duration of storage resources.

Another area to explore is the reliability criterion that PJM uses in the capacity construct, currently set to a maximum frequency of one loss-of-load event every 10 years on average. This is also known as the 1-in-10 LOLE standard. LOLE has historically worked well to ensure resource adequacy in PJM, but does not account for load shed duration or magnitude. That means a load shed event of one MW in one hour is currently treated the same as a 1,000 MW load shed across 10 hours. The transition from conventional generation capable of 24-hour output to resources with shorter output durations can result in more, disparate load shed events which would be better represented in reliability criteria considering duration and/or amount of load shed.

[4] Final Root Cause Analysis report on California August 2020 rotating outages

Explicit Modeling of Certain Ancillary Services and Reliability Attributes

Today, PJM has an adequate supply of services and attributes; some are explicitly modeled and compensated in the PJM markets, others are not. As the supply mix continues to evolve, the levels of reliability attributes and ancillary services required will also change. Further, renewable resources interconnecting into PJM today and in the future may not be capable of providing the same ancillary services and reliability attributes as the resources they are replacing. To ensure reliability in the grid of the future, certain ancillary services and reliability attributes may need explicit modeling, with set requirements, to keep an adequate aggregate level on the system. It may be valuable to explore where and how market-based mechanisms can be used to send appropriate price signals for these services.

Inertial Frequency Response

The inertial frequency response of the system drops as large synchronous generators are retired and replaced with inverter-based resources such as wind, solar, and storage. This can be a concern in a grid with high penetration of renewables, as it can result in a faster and larger frequency decline following a system disturbance because of a reduced level of reliance on generators with large rotating masses[5]. In the future, consideration of how to incentivize inertial frequency response may become necessary to ensure an adequate supply on the system at all times and appropriately compensate those resources providing the service.

Ramping and Commitment Flexibility

The influx of intermittent resources on the system, with outputs that can rapidly change throughout the day based on weather, will require an adequate level of ramping and commitment flexibility. These are resources that can be dispatched up and down, or cycled on and off in relatively short periods of time at PJM's direction, to maintain supply and demand balance throughout the day. The need for ramping and commitment flexibility has been shown in other regions with greater levels of renewable penetration than currently seen in PJM, such as California ISO and the Midcontinent ISO, which explicitly model and compensate flexible ramping products in their markets.

How PJM Forecasts System Needs

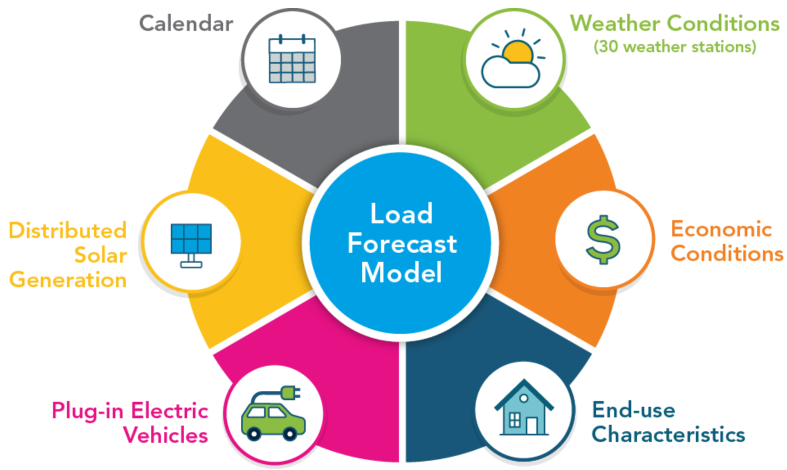
Accurate forecasting enables PJM to make decisions about how to plan and operate the power grid in a reliable manner, and how to effectively administer competitive power markets. PJM engineers and operators use a variety of tools and data sources to plan for the system and anticipate how much electricity consumers will use in both the near- and long-term.

Forecasting Long-Term Load

PJM's load forecast model produces a 15-year forecast for each PJM zone, sub-zone (Locational Deliverability Areas), and the RTO. The model estimates the historical relationship between load (peak and energy) and a range of different drivers, including weather variables, economics, calendar effects, end-use characteristics (equipment/appliance saturation and efficiency) and distributed solar generation, and leverages those relationships to derive forecasted load.

[5] NERC March 2020 whitepaper on frequency response and impact of inverter-based resources

- **Weather conditions** across the RTO are accounted for by calculating a load-weighted average of temperature, humidity and wind-speed data from over 30 identified weather stations across the PJM region.
- **Calendar effects** are unique variables for the day of the week, month and holidays.



- **Economic impacts** on load forecasting are addressed by one indexed variable that incorporates six economic measures. This allows for localized treatment of economic effects within a zone. PJM contracts with an outside vendor to provide economic forecasts for all areas within the PJM footprint.
- **Distributed solar generation** acts to lower load from what it otherwise would be. Recent years have witnessed a significant ramp-up in behind-the-meter distributed solar resources. PJM's load forecast accounts for this increase – which reduces PJM's total load -- taking into account PJM's own experience and vendor-supplied forecasts. These forecasts consider assumptions for federal and state policy, net-energy metering policy, energy growth, solar photovoltaic capital costs, power prices and other factors.
- **End-use characteristics** are captured through three distinct variables designed to capture the various ways in which electricity is used, including weather-sensitive heating, weather-sensitive cooling and non-weather-sensitive use. Each variable addresses a collection of different equipment types, accounting over time for both the saturation of that equipment type as well as its respective efficiency. For instance, the cooling variable captures the increasing efficiency of central air conditioning systems.
- **Plug-in Electric Vehicles (PEVs)** are now also an explicit adjustment to account for charging at peak load and to maintain reliability as the PEV share of overall number of vehicles on the road continues to grow.

Historically, economic growth has meant an increase in electricity demand. But today, notably, PJM's load forecast model recognizes the weakening of the relationship between energy and economics. In large part, this reflects the continued evolution of a more service-driven economy, which is less energy-intensive than a manufacturing economy, combined with the accelerated proliferation of more energy-efficient electrical appliances and equipment.

Forecasting Short-Term Load

PJM regularly prepares short-term load forecasts used in maintaining day-to-day reliability of the system and in power market activity. PJM prepares two primary short-term products:

- **Hourly Forecast:** An hourly forecast that looks seven days ahead. Members often use this forecast in planning their bidding strategies in the Day-Ahead and Real-Time energy markets.

- **Five-Minute Forecast:** A five-minute forecast that looks at conditions for five-minute intervals, six hours ahead. This forecast is used by PJM's SCED tool, which helps PJM operators dispatch power plants in the most economic order throughout the day, as they continuously balance electricity supply and demand.

PJM utilizes both vendor and in-house forecast models to generate short-term load forecasts, including neural network models that use machine-learning algorithms, models that use pattern-matching algorithms looking for similar historical days and blended models that consider both. These models consider factors including weather, calendar effects, measured and historical loads, and behind-the-meter solar projections. If the models are unable to produce sufficiently accurate results, such as during storms or unanticipated changes in human behavior, PJM operators can step in and modify the forecasts based on their experience and judgement.

Forecasting Renewable Output

In addition to behind-the-meter distributed solar, accurate forecasts of grid-connected solar and wind generation are important to the reliable operation of the power grid. In the long term, projection of renewable generation is important in determining a resource's reliability value, as their output and penetration levels impact the demand patterns and hours of loss-of-load risk in PJM. PJM's ELCC filing in October 2020 proposed utilizing a vendor forecast to develop the level of renewable penetration expected in PJM up to 10 years in the future.

In the short term, projection of renewable generation throughout the operating day has a direct impact on the reliable and efficient dispatch of other resources to meet net demand. PJM forecasts solar and wind data for each grid-connected solar park and wind farm, using various vendors. To account for error in those forecasts in the future, PJM will consider the uncertainty of renewable output in determining the operating reserve demand curves used to set prices in its reserve markets[6].

Future of Accurate Forecasting

PJM's load forecasting model has gotten more complex in parallel with the electric system overall, and future models are likely to become still more complex. This complexity ensures a more accurate model, as recent history has indicated. Incorporation of energy efficiency trends and behind-the-meter solar began with the 2016 load forecast. Techniques refined in 2020 and again in 2021 have yielded even more accurate modeling.

Forecasting models are built to understand the underlying drivers of historic patterns in order to make informed forecasts. Energy efficiency is a prime example: data is now showing lesser impacts to load growth from energy efficiency than were experienced from 2010–2019.

DER Visibility

The ability to forecast the volume and types of DER on the system directly impacts the accuracy of the long- and short-term load forecasts. In the future, as the penetration level of DER rises, it will become increasingly important for PJM to have visibility into the output and impact of distributed resources on the system. PJM plans to collaborate closely with distribution system operators to have that visibility. FERC Order 2222 may help improve that visibility to the extent DER chooses to participate in the PJM wholesale markets.

[6] This will be future practice starting in May 2022, as part of PJM's reserve market enhancements

Long-Term Load Forecast Model

Long-term load forecast models support future reliability by allowing system operators to properly plan for transmission upgrades and the capacity needs of the system. Two areas of recommendation to support the future accuracy of the long-term load forecast model are:

- **Exploring the benefits of adopting an hourly load forecast model.** As part of the ELCC work, PJM utilized a model with hourly load forecasts, along with hourly generation profiles that captured the intermittency of renewable resources and the limited duration of output from energy storage resources. Further review of the benefits of an hourly load forecast model should be explored and considered for use in different planning studies, such as the annual Reserve Requirement Study that determines the reserve targets used in the capacity market.
- **Utilizing consultants to review load forecast models and provide recommendations for improvement.** Supplementing the years of experience and expertise of PJM planning engineers can only serve to further sharpen the accuracy of the load forecasts.

Renewable Output Forecast Improvements

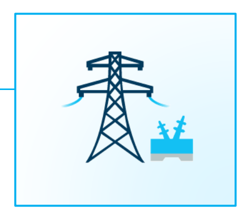
Grid operators rely on accurate short-term predictions of demand and net demand to efficiently schedule resources and maintain system balance. As the penetration level of renewables continues to rise on the system, PJM will need to explore ways to handle the additional uncertainty to net demand on the system, or improve the accuracy of forecasts, to maintain reliability.

One option for handling the additional uncertainty would be to commit additional operating reserves on the system, as the operating reserve demand curves are designed to do. However, that may not be the most cost-effective solution as the volume of renewables continues to increase.

A few areas to explore that may improve our forecasting of renewable output include:

- Swapping or adding vendors to provide more accurate renewable forecasts
- Enhancing the modeling of weather patterns and individual resource characteristics to predict the output of renewable resources
- Enhancing market incentives for operators of renewable generation to provide accurate forecasts

How PJM Plans a Robust Transmission System



PJM is required by NERC to plan and operate transmission facilities at 100 kV and above, as well as lower-voltage facilities if requested by the transmission owner. In response to identified regional reliability, market efficiency or public policy needs, PJM staff recommends projects to include in the PJM Regional Transmission Expansion Plan (RTEP), to be approved by the PJM Board of Managers.

New transmission projects serve one or more operational purposes, for example:

- **Increase power-flow capability** – New lines and transformers, existing line re-conducting and bus reconfigurations

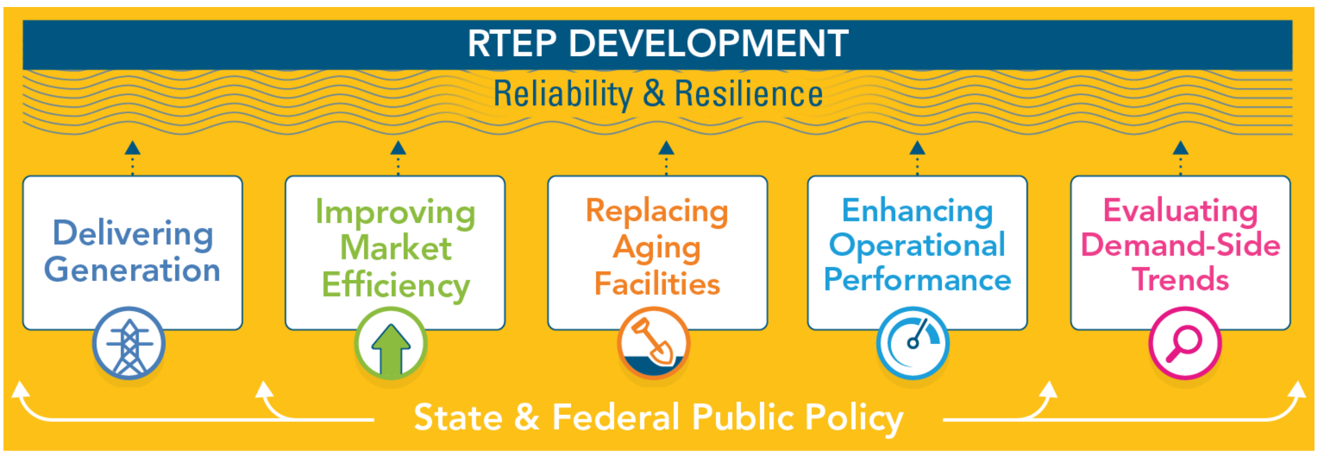
- **Provide voltage support and improve generating-unit stability –** New devices like shunt capacitors and static VAR compensators
- **Ensure safe transmission line operation –** New substation equipment like circuit breakers, switches, relay protection and control equipment, and instrumentation

Frequently, new facilities built to serve one purpose address others as well.

Developing the Regional Transmission Expansion Plan

PJM's comprehensive RTEP process identifies the need for changes and additions to the system up to 15 years into the future. PJM's regional planning approach makes the transmission planning process more efficient by considering the region as a whole, rather than as individual states or separate transmission zones. Transmission system enhancements are driven by a variety of evolving and interrelated industry, market, and public policy issues (see Figure 3).

Figure 3. Transmission System Enhancement Drivers



As noted earlier, PJM's regional planning process spans transmission owner (TO) zonal boundaries and state boundaries to address the comprehensive impact of many system enhancement drivers, discussed earlier. Operationally, the system enhancements arising out of PJM's RTEP process reduce emergency procedures and alerts, increase operating margins, and improve the ability to import/export power with neighboring grid systems. RTEP projects are planned to address one of more of the following criteria described below.

Baseline projects:
Address reliability criteria violations including thermal, voltage, short circuit and stability, TO criteria violations, and those violations driven by market efficiency, as well as expansions required to meet public policy.

Network projects:
Ensure that new generation and merchant transmission projects interconnect reliably to the grid as submitted through PJM's interconnection queue.

Supplemental projects:
Identified by TOs to address their own local transmission reliability needs. These projects direct repairs or improvements to local transmission lines and equipment, and address local operational issues, customer load growth and resilience. Even though the TO develops these projects, PJM reviews them to evaluate their impact on the regional transmission system, to coordinate necessary construction outages, and to implement necessary changes in PJM models and system operations.

Baseline Reliability

Baseline reliability analyses assess base-case thermal and voltage conditions under defined test conditions for load deliverability and generation deliverability under summer peak load, winter peak load and light load system conditions. Contingency analyses examine all PJM bulk electric facilities, lower-voltage facilities monitored by PJM and critical facilities in systems adjoining PJM, including tie lines. All reliability analyses are conducted to ensure compliance with NERC and PJM regional criteria.

Transmission Owner Criteria

The PJM Operating Agreement specifies that individual transmission owner planning criteria are to be evaluated as a part of the RTEP process, in addition to NERC and PJM regional criteria. Frequently, transmission owner planning criteria address specific local system conditions, such as in urban areas. Transmission owners are required to report their individual local planning criteria annually through FERC Form 715. As part of its RTEP process, PJM applies transmission owner criteria to the respective facilities that are included in the PJM Open Access Transmission Tariff facility list.

Operational Performance

Under the PJM Operating Agreement, PJM may also identify transmission enhancements to address system limitations encountered during real-time operations, often under recurring similar system conditions. To that end, PJM planners meet with operations staff to assess the need for transmission enhancement plans that would address identified thermal, reactive, stability and other issues. Over the past several years, for example, some operators have experienced high-voltage alarms under light load conditions. Additional studies replicating operating conditions have revealed that reactors were needed in certain areas to resolve the issue.

Generator Deactivation

When generation owners decide to retire a facility, they are required to notify PJM of their intent. These generator deactivations alter power flows that can cause transmission line overloads and, given reductions in system reactive support from those generators, can undermine voltage control requiring system reinforcement.

Addressing Aging Infrastructure

The regional high-voltage transmission system is aging; many facilities were placed in service in the 1960s or earlier. They are deteriorating and reaching the end of their useful lives.

Nearly two-thirds of all bulk electric system assets in PJM are more than 40 years old and more than one-third are more than 50 years old. Some local, lower voltage equipment, especially below 230 kV, is approaching 90 years old. Most of this equipment – cable, tower structures and tower foundations, for example – is outdoors and deteriorates with age. Some tower structures – often at 115 kV and 138 kV voltage levels – were originally constructed of wood and have begun to deteriorate; others originally constructed of iron exhibit significant rusting and degradation. Loss of structural integrity subjects transmission lines to increased maintenance costs and reliability risks.

Addressing this deterioration and the associated costs and risks is subject to each transmission owner's broader asset-management strategy. Once a transmission owner determines a facility to be at its end of useful life, replacement of those facilities offer the opportunity to explore the use of newer technologies that will result in a more efficient transmission system.

Evaluating New Service Requests

New service requests include generator interconnection requests as well as merchant transmission interconnection, merchant network enhancements, long-term firm transmission service and incremental auction revenue rights. A new service request is assigned a queue position only when all Tariff-required information, data, executed agreements and deposits are submitted. PJM then conducts deliverability and other tests to identify and solve any NERC, regional and transmission-owner reliability criteria violations that may require transmission system reinforcement to ensure deliverability.

Under the terms of PJM's Reliability Assurance Agreement, in order to qualify as a capacity resource, sufficient transmission capability must exist to ensure that generator output is deliverable to PJM's aggregate network load under peak load conditions at the requested interconnection point. PJM's annual RTEP cycle encompasses studies that assess transmission expansion plans needed to ensure the ongoing deliverability of all generators within PJM.

Supporting Public Policy

PJM's State Agreement Approach (SAA) embodies an Operating Agreement RTEP process to identify required transmission to be built for and funded by a state or multiple states to meet public policy objectives. One or more states may voluntarily agree to fund transmission system enhancements to address public policy requirements like delivering offshore wind-powered generation.

States can request that PJM study a project designed to address public policy requirements. Or, they may ask PJM to study a project to meet reliability or market efficiency needs through existing RTEP process avenues. Regardless, PJM can only implement public policy requirements if sufficient direction is provided. The translation of policy objectives into planning criteria must be reasonably evident and not depend heavily on subjective judgment.

Accounting for Congestion's Impact on Reliability

PJM operates the grid by scheduling and directing the lower-cost power resources to generate electricity first, incrementally adding more expensive resources as they are needed, and using the highest-cost resources only during the relatively brief periods of peak customer demand. Comprehensive reliability planning ensures that peak demand can be met without encountering reliability criteria violations.

For hours other than those during peak load conditions, market economics drive how generation is dispatched and power flows to customers across transmission facilities. At times, transmission can become limited by ratings on transmission equipment, creating congestion. PJM system operators must reroute power flow by deploying higher-cost generating units to avoid overloads and risk losing transmission equipment. Such operation creates market inefficiencies for which PJM planning studies seek transmission solutions so that reliability is preserved and the lowest-cost power can reach the greatest number of customers.

Future of Robust Transmission

PJM continues to expand RTEP process flexibility to build the grid of the future through the integration of new technologies, renewable generation, distributed resources, and federal and state RTO policies while simultaneously maintaining a reliable, efficient and resilient regional bulk electric system. PJM will continue to explore synergies between the identification of expected aging infrastructure facilities and future system needs that are driven by the increase in renewable generation.

Evolving the Interconnection Process

The grid continues to support a historic and unprecedented generation shift, as coal-fired generation retires and is replaced by gas generators and renewables like solar, wind and battery storage. On the load side of the equation, distributed energy resources (DER) and energy efficiency are off-setting most new load growth.

A robust transmission system enables new technologies to be sited, configured and operated reliably. New transmission assets maintain grid reliability, permitting older generators to retire without causing transmission line overloads or other reliability criteria violations. New natural gas and renewable generation relies on new transmission in order to sell reliable, economic power into PJM markets.

The size and fuel type of generation projects seeking interconnection in PJM continues to change. New resources are now primarily renewable and storage. Such projects tend to be smaller in size compared to conventional base-load generation. As part of this generation shift, PJM's queue volume has grown as a result: There were 970 new service requests in 2020, more than double the 470 projects proposed just two years prior. At the end of 2020, PJM initiated a series of workshops to begin exploring potential reforms to the interconnection process to enhance queue efficiency and other growing stakeholders concerns. PJM looks forward to working with stakeholders to develop necessary changes through this process.

Integrating Offshore Wind Power

Interest continues to increase in large-scale offshore wind generation projects driven by state initiatives. PJM is engaging states, transmission developers and other stakeholders interested in pursuing implementation of PJM's State Agreement Approach for developing offshore wind to achieve state objectives. PJM continues to add process detail to the SAA, based on experience to date, to enable states to pursue those objectives. PJM is also currently conducting educational outreach to states and multi-state coordinated offshore wind studies to identify transmission needs.

Modernizing the Transmission System

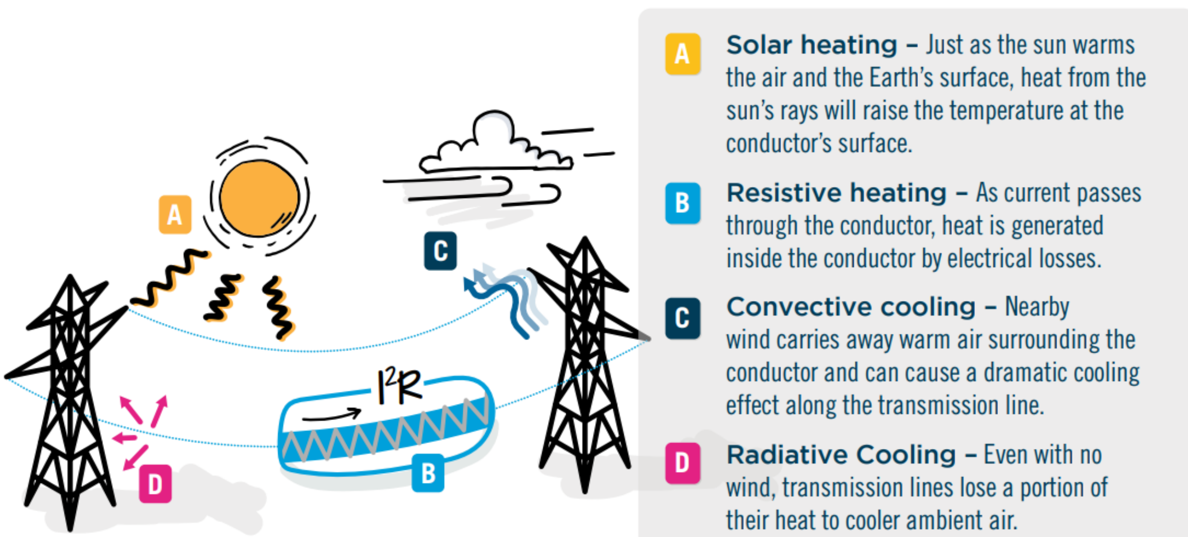
Modernizing the existing transmission system will provide significant benefits: withstanding more extreme events, lowering the frequency and shortening the duration of outages, reducing public and employee safety risks, and improving system operability, efficiency and security. Doing so will ensure a future characterized by enhanced reliability, cost savings, and environmental and societal benefits.

The last five years have brought substantial modernization to system infrastructure. Enhancement of existing equipment, coupled with the application of new tools, has increased efficiency of the equipment and of system operation. Technologies like these are providing PJM with additional tools and operating flexibility to ensure reliability at the lowest cost. Various technologies provide a range of benefits, including the following:

- **Flexible AC Transmission Systems (FACTS)** devices take more conventional power system components – capacitors and reactors – and integrate them in various configurations with intelligent power electronics, high-speed thyristor valve technology and voltage-sourced converter (VSC) technology. By doing so, FACTS devices can directly support additional transmission line power flow with reactive power injections at their point of interconnection, and can indirectly control power flow by modulating transmission line impedances.

- **Transmission Line Technology** includes new developments such as implementation of composite-core conductors that can lower line losses by 25 percent to 40 percent compared to traditional aluminum-conductor steel-reinforced cable.
- **Storage as a Transmission Asset** may connect to the transmission system as a transmission facility used to address and solve a PJM RTEP system reliability violation. The rules to govern this are being considered in our stakeholder process.
- **Dynamic Line Rating Technology**, shown in Figure 5**,** uses advanced sensors and software to monitor real-time conductor temperature along a transmission line. This data is then used to calculate an actual rating for the line based on environmental conditions that may identify additional capacity on transmission lines. Such technology can potentially relieve congestion, create economic efficiencies and contribute to system resilience by providing better real-time transmission monitoring capability.

Figure 5. Dynamic Line Rating Technology



CIP-014-02 Critical Facilities

Concerns across the industry about grid security and resilience continue to grow. NERC's CIP-014-2 standard for critical infrastructure requires transmission owners to identify and protect transmission stations and transmission substations – and their associated primary control centers – that could cause instability and uncontrolled separation if rendered inoperable or damaged as a result of a physical attack. Specifically, PJM continues to support efforts to eliminate current vulnerabilities for CIP-014 critical infrastructure while also working to develop RTEP resilience criteria to avoid and mitigate the risk of future CIP-014 critical infrastructures facilities.

How PJM Operates Reliably

Operating reliably, simply put, is keeping the bulk power system secure and serving load – and is always PJM's first priority. Reliable supply of electricity is essential to the economy and to the health and well-being of the 65 million Americans in our footprint. While the PJM system features a diverse fleet of generation, with healthy reserves and a robust transmission system, the reliability of the grid still requires constant attention.

PJM's specialized team of system operators work around the clock, along with operators throughout the footprint from various member companies, to maintain the uninterrupted flow of high-voltage electricity. PJM system operators use advanced analysis tools to monitor and control the bulk electric system from two redundant control centers. They constantly adjust generation output to match the load on the system, while respecting equipment limits such as thermal ratings and voltage levels, and continuously prepare for the unexpected.

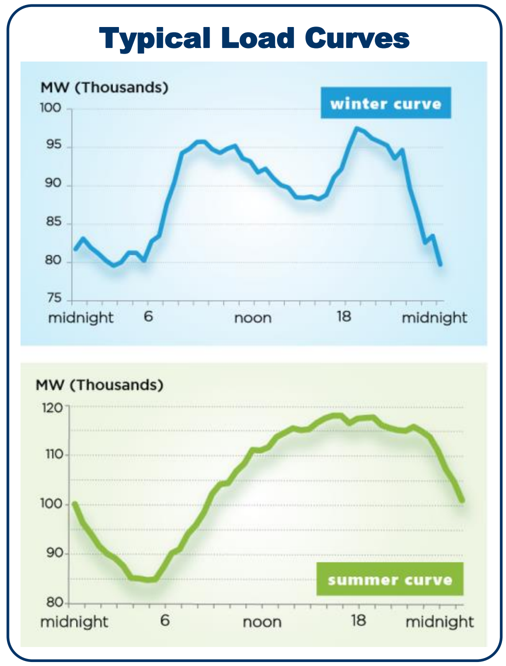
The control centers require extensive telecommunication facilities to support voice communications with other operating entities, while also transferring the vast amounts of data and control signals needed to operate the system.

PJM's operations team works closely with transmission-owning members and generation owners to plan for maintenance activities and to coordinate operations in real time. PJM's system operators also coordinate operations with neighboring regions to support reliability on both sides of the borders with these adjacent systems.

Figure 6. System Operations – PJM Control Room

Balancing Generation with Load

The demand on the system changes throughout the day, and one of the essential roles of a system operator is to match the load with generation resources. As load begins to increase in the early morning hours of the day, system operators provide signals to generation resources to produce more power to match the increasing demand for electricity. System operators continue to increase the amount of power being generated until the peak of the day. After the peak of the day, operators begin to reduce the amount of power being produced by sending signals to the resources to reduce power. That cycle is repeated every day of the year.



Power flows from the generators to the loads across the transmission system. Just like any machine, the transmission system has limits that must be respected in order to be reliable. Transmission system facilities have ratings that specify the amount of power that can reliably be transferred across the facility. Every system operator must make sure that the amount of power being transferred across a facility does not exceed the rating of the facility.

Preparing for Extreme Conditions

Reliable operation starts with preparing the system for the next peak season, whether it be summer or winter. Seasonal studies are completed to assess the reliability of the system for the upcoming peak season. These operational studies stress test the system to identify issues that may require special operating plans and include sensitivity analyses to evaluate a range of credible scenarios that may include, for example, higher loads resulting from extreme cold weather or the loss of multiple generators connected to a common gas pipeline. Such studies help to prepare personnel for the types of conditions they may see during the next peak season.

HOW WE GET READY

Summer Checklist

1. *Perform sensitivity studies.
2. Perform summer operating study.
3. Review ReliabilityFirst summer assessment.
4. Facilitate operator training seminar.

Winter Checklist

1. Hold winter prep meeting with members.
2. Members complete fuel survey.
3. Meet with gas pipelines.
4. Generators verify checklist is complete (Manual 14D Attachment N).
5. Meet with Interstate Natural Gas Assoc. of America and other grid organizations.
6. Generators participate in cold weather testing.

PREPARATION STEPS FOR BOTH SEASONS

- **Assess** seasonal weather outlook.
- **Review** load and capacity outlook.
- **Check** for manual or rule changes.
- **Coordinate** pre-season meetings with neighbors.
- **Run** Emergency Operations Procedures drill.

** This also may be done to prepare for winter.*

In addition to planning for the peak season, spring and fall have their own operational challenges. Transmission and generation outages are typically scheduled in this time of year, and unseasonably high electricity demand brought on by abnormal weather patterns can stress the system.

When operating the grid day to day or week to week, system operators do not have perfect foresight of what may happen through the next operating period. Load – or demand – on the system, which is a function of many things, including weather, may be higher or lower than forecast. Thermal generators may have mechanical problems and be forced to reduce their output or disconnect from the system entirely. Solar output varies based on the intensity of the sun. Wind turbines' output depends on wind speeds and other factors.

PJM's system operators, with the help of the advanced tools noted above, prepare for the loss of both generation resources and transmission facilities by evaluating thousands of what-if scenarios, and take action to adjust the system if any single contingency would result in a facility operating outside of prescribed limits. Operators act before the event occurs so that if it were to happen, all of the remaining facilities would not exceed applicable power flow or voltage limits. Operating in this way is essential for ensuring reliability and preventing cascading transmission failures.

Coordinating Gas and Electric Operations

With the tremendous growth in natural gas-fired generation over the last decade, it has become increasingly critical to the reliability of the bulk electric system that PJM operations are coordinated with the operators of the interstate pipelines that fuel natural gas generators, many of which share the same pipeline for fuel supply.

PJM prepares for failures that may occur on interstate pipeline facilities, as they can impact generators operating on the bulk electric system. PJM has already taken actions to enhance coordination with gas pipeline systems. PJM's gas electric coordination team monitors conditions on pipeline systems and advises markets and operations of conditions that may impact the availability of resources. In addition, tools have been developed to enhance situational awareness of pipeline conditions and how they may impact operations. In 2018, PJM changed our market-clearing timeline to better align with the gas nomination cycles. In 2019 and 2020, PJM organized exercises with natural gas pipeline operators to simulate pipeline outages and their impacts to the generation fleet. This remains an area of on-going focus for PJM.

Initiating Emergency Procedures

Severe weather, such as tornados, derechos and hurricanes, or extended periods of heat or cold, can cause multiple facilities to be automatically removed from service. Other natural disasters, such as mudslides and earthquakes, can threaten multiple bulk electric system elements at the same time, or in a very short period of time, before system adjustments can be made.

In those cases, system operators may need to rely on emergency procedures to maintain the reliability of the bulk electric system. These emergency procedures can be implemented quickly with little or no advance notice, and in some cases may include disconnecting load, also known as load shedding. The overall reliability of the bulk electric system is of utmost importance, and these emergency procedures are only used as a last resort.

Future of Reliable Operations

Operations will need to continue to evolve as the system evolves.

Coordination with the gas pipeline systems will become increasingly important as the penetration of gas-fired resources continues to increase. The proliferation of intermittent resources will also increase the need for controllable resources such as gas-fired combustion turbines and combined-cycle plants that can ramp and/or start up quickly.

As previously noted in the forecasting section of this paper, behind-the-meter rooftop solar is not visible to PJM but appears as an offset to load, and its output varies based on weather and cloud cover. Their increasing penetration will require PJM to continue enhancing our models, tools and our daily forecasting capabilities.

And there are many other types of distributed energy resources connecting to the system with their own impacts, including combined heat and power, other behind-the-meter generators, and batteries. Recent FERC Order 2222 will ensure that these resources can participate in PJM's wholesale markets through aggregators, which will allow PJM to dispatch them similarly to how we currently dispatch a large power plant connected to the transmission system.

DER also connect to the distribution system, operated by the local utility or other distribution system operators, or DSOs, rather than bulk grid operators. Just as PJM coordinates operations with adjacent transmission system operators, PJM will therefore need to coordinate operation of the DER with the various DSOs that they are interconnected with.

Operations will also need to continue to integrate controllable loads into the operation. Controllable loads have participated in PJM's markets and have been integrated into operations for many years as demand response and price-responsive demand. PJM is also beginning to see distributed energy resources looking to combine into microgrids that may be connected to the system and may operate as an island – apart from the grid – from time to time.

As controllable loads continue to increase on the system, it may be more efficient to control the demand for electricity instead of – or in combination with – controlling generation, which is how the system has traditionally operated. This could provide another tool for system operators to manage intermittency issues with renewable resources.

IV. Next Steps

The PJM system is reliable today. In the future, the emerging trends reshaping the electric industry have the potential to significantly impact the manner in which reliability is maintained.

In this paper, we reviewed some of those trends and highlighted certain areas within PJM where change may be necessary to ensure a reliable future. These areas touched on all four building blocks of reliability and each of PJM's core functions of planning, markets and operations.

In the coming months and years, PJM plans to further explore the topics and areas of change introduced in this paper with policymakers and stakeholders. This process has already begun. PJM set up two four-part stakeholder workshops, one focusing on improvements to the interconnection process, and the other examining potential enhancements to the capacity market. This paper is intended to help facilitate discussions in those areas, as well as others. Additional research will look to dive more deeply into the various topics noted in this paper, providing analysis and potential market design changes for consideration where appropriate.