Renewable Dispatch in Market Clearing Engines

Real-time Market Operations

PJM Interconnection

October 2024

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Contents

I. Introduction

The purpose of this paper is to support renewable dispatch efforts at the Distributed Resource Subcommittee (DISRS), and it will provide background on PJM's current dispatch logic for renewable resources, specifically wind and solar resources. In addition, the paper will explore potential options that can be incorporated into PJM's Real-time Market Clearing Engines (MCE) to improve the dispatch of these resources, especially for constraint control, power balance, and reduction of out-of-market actions to increase system reliability. The solution options outlined in this paper are narrowly focused on the following:

- Reducing the volatility that renewable resources can have on constraint control
- Improving the data PJM's security constrained economic dispatch (SCED) uses to dispatch these resources (to improve overall system dispatch)
- Improving SCED ability to dispatch these resources, thus improving system dispatch and reliability

II. Renewable Resource Challenges in Market Clearing Engines

Renewable resources are making up an increasing portion of the PJM generation mix, with many more projects expected over the next five to 10 years, including significant amounts of wind and solar resources.

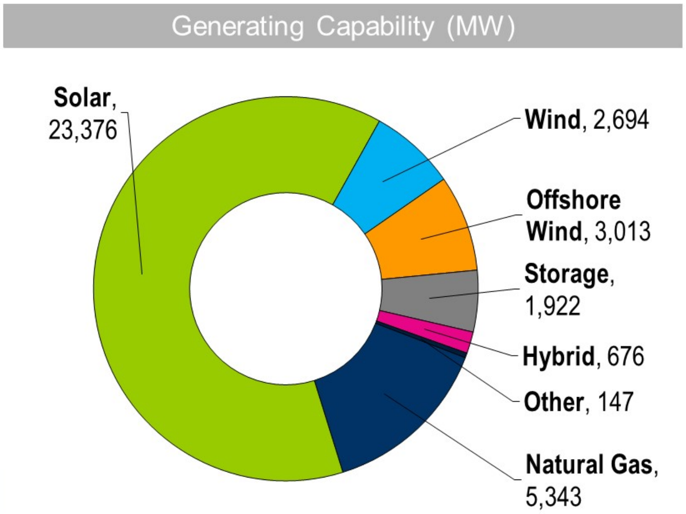
As of June 30, 2024, PJM's existing capacity includes 10,289 MW of wind generation and 12,072.7 MW of solar generation.[1]

Additionally, **Figure 1** highlights the large increase of interconnection requests for new renewable projects, with the majority of the growth coming from new solar projects.

[1] Monitoring Analytics 2024 Quarterly State of the Market Report for PJM: January through June

Figure 1. Interconnection Projects With Final Agreements

Fuel Type	Number of Projects	Generating Capability (MW)
Natural Gas	13	5,343
Solar	347	23,376
Wind	18	2,694
Offshore Wind	7	3,013
Storage	32	1,922
Hybrid	24	676
Other	7	147
Total	**448**	**37,171**



Data as of Sept. 13, 2024

As the amount of renewable resources on the PJM system grows, it becomes increasingly difficult to manage the dispatch of these resources using PJM's real-time MCEs. Several factors contribute to this increased difficulty, including:

1 | Weather-dependent output. The increased variable output of these resource types makes PJM's ability to forecast near-term changes in energy output difficult.

2 | Extremely fast response rates. Not only can these resources ramp fast, they also ramp in different ways when compared to traditional resources. For example, blocks of solar arrays result in short-term generation shifts, which can and frequently do result in generation swings, especially when operators are managing constraints on the system.

3 | Resource's market parameters. Input parameters (e.g., Economic Maximum) of these resources are updated inconsistently by resource owners, which impacts how MCEs are able to dispatch resources.

4 | Inverter technology and characteristics. These resources can exhibit a larger range of different operational characteristics when compared to traditional generation, which makes it more difficult to model and forecast the resources. For example, staffing levels may be different for more traditional resources, tuning parameters (even compared to as built), and different technologies (grid forming/following, winterization packages, tilt/non-tilt solar).

PJM has at times experienced operational challenges due to these factors. These challenges include transmission constraint control issues (i.e., constraints becoming volatile as they bind and unbind in upcoming dispatch intervals), volatile Area Control Error (ACE) control and the out-of-market dispatch of resources. Because of the expected continued growth of renewables on the system, PJM will need to seek out the appropriate operational, planning and market reforms in order to address these challenges to support grid reliability.

A. Previous Stakeholder Engagement on Renewable Resources

PJM has previously engaged with stakeholders across several forums to discuss the operational challenges of renewable resources prior to the current DISRS effort.

During the Dec. 2, 2021, meeting of the PJM Operating Committee (OC), PJM introduced an Issue Charge related to renewable dispatch in order to work with stakeholders on potential business rule updates for market parameter submissions and solar Lost Opportunity Cost (LOC). This effort continued in Special OC sessions and regular OC meetings leading to stakeholder-approved changes.

During a Feb. 22, 2022, Special OC, PJM provided further detail on the operational challenges of renewable dispatch. These challenges included:

- The ability to receive and follow a dispatch signal
- The calculated increase of out-of-market dispatches
- Utilizing reactive capability

Following this Special OC, PJM conducted a survey in November 2022 requesting data from solar and wind resources on their ability to receive and follow the PJM dispatch signal. The data from this survey showed that only approximately 45% of solar and wind resources were interconnected with the ability to receive PJM's dispatch signal at that time. Historical data on manual dispatch data from the 2017 to 2022 time frame was also provided that showed a decrease in the need for out-of-market dispatch due to wind resources, but an increase in out-of-market dispatch due to solar resources. PJM found, based on this historical data along with the significant influx of new solar resources coming online in the PJM system, there would be a potentially increased need for dispatchers to control system constraints using out-of-market dispatch.

PJM has also previously discussed communication and control differences between inverter-based resources and traditional thermal resources. The varying controlling agents' setups to site control and inverter settings have led to issues in communications, following PJM instructions, and resilience in responding to disturbances. PJM has noted that addressing these operational concerns may lead to an opportunity to integrate more interconnection process criteria and education to put solar and wind resources in a more optimal position to operate according to PJM requirements and expectations.

Currently, through the Reserve Certainty Senior Task Force (RCSTF), PJM is exploring uncertainty and flexible ramping reserve products to ensure system flexibility needs are met to support the renewable penetration and the overall changing generation mix in the PJM footprint.

III. Overview of Current Real-Time Renewable Dispatch Logic

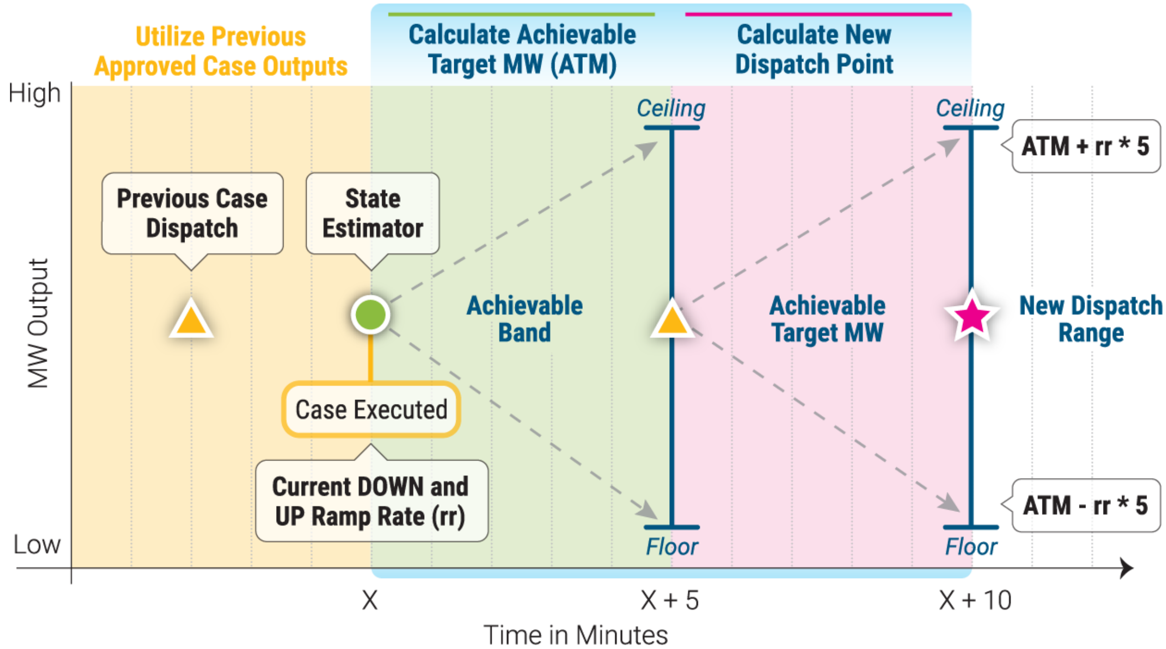
A. Real-Time SCED Dispatch Functionality

PJM's real-time security constrained economic dispatch tool (RTSCED) co-optimizes energy and reserves, maintains power balance, controls transmission constraints and maintains regulation while producing the least-cost solution to do so. RTSCED automatically executes every five minutes, and each case solves five separate solutions that differ by the level of load forecast solved for the target interval. The load forecast level is adjusted by the amount of "load bias" entered by dispatch for each solution. PJM dispatchers regularly bias (i.e., effectively adding or reducing demand that must be balanced with additional or less supply) their scheduling of supply resources in an attempt to manage the uncertainty inherent in near-term forecasts of load, wind generation, and solar generation (or for unexpected plant outages). If needed, cases can be manually executed by dispatch. Inputs into RTSCED include but are not limited to the following:

- Resource bid-in data
- EMS data (State Estimator Data [SE], unit constraint sensitivities sometimes referred to as distribution factors [Dfax], and loss penalty factors)
- Load forecast
- Fixed Ancillary Service (AS) assignments
- Interchange schedule
- Operator inputs (e.g., load bias, hydro schedules, constraint control percentage, marginal value limit overrides)

RTSCED solves for a 10-minute look-ahead period. The first five minutes in this period are used to calculate an Achievable Target MW (ATM), while the final five minutes of the look-ahead period produce the dispatch basepoint for each resource in the SCED solution. The ATM is a projection on how well a resource is following its previous dispatch instruction. The State Estimator MW (SE MW) is used as the starting point in the calculation of ATM, and RTSCED will determine its achievable band (both a ceiling and a floor) for that resource to meet in the first five minutes. ATM is then used as the starting point to calculate the dispatch basepoint over the second five-minute segment of the 10-minute look-ahead period. The resource will be ramped over the final five minutes to its next dispatch point. The direction of ramp (up/down) for each unit is determined by the RTSCED solution as it takes into account the forecasted system conditions, maintaining power balance and reserve needs, controlling transmission constraints and maintaining regulation. Each segment builds upon the previous segment, based on the projected output of the unit. This dispatch sequence is illustrated in **Figure 2**.

Figure 2. Real-Time Dispatch Sequence



B. Megawatt Calculations in RTSCED

The logic in RTSCED is designed to produce two megawatt calculation solutions. This is a carryover from the legacy Unit Dispatch System (UDS) engine from the early 2000s.The first megawatt solution is referred to as the internal megawatt solution (iMW), which is calculated as part of the optimization logic in the MCE. The internal megawatt solution is where power balance, constraint control, co-optimization of energy and reserves, derivation of LMPs and other logic are performed.

The second megawatt solution is referred to as the Individual Generator Dispatch (IGD) megawatt and is calculated in post process based on the iMW solution locational marginal price (LMP) and the resource's bid-in offer curve and economic limits. The IGD MW is the resource's economic dispatch basepoint that is sent to PJM's AGC application where it is processed and sent to the resource via ICCP or some other data transfer mechanism.

The main reason for the implementation of the two megawatt solutions was the development and implementation of the Degree of Generator Performance (DGP), which was a measure of how well a resource was following its previous dispatch basepoints. If a resource was not following its dispatch very well, it received a lower DGP value. The DGP value was applied in the iMW solution and lowered a resource's ramp capability. If a resource was following PJM's dispatch basepoints well, then its DGP value would be high, and the resource's ramp capability would not be adjusted. DGP was not applied in the IGD calculation, which caused a split in the iMW and IGD MW for a resource if it was not following dispatch. A split between the iMW and IGD MW is not desirable because it results in a SCED solution inconsistent with actual generation capabilities and real-time system conditions. This inconsistency presents added challenges for PJM dispatchers that can lead to the need for out-of-market actions (e.g., manual dispatching of resources, modified transmission limit control percentages).

The use of DGP was phased out in 2021 with the implementation of five-minute dispatch and, essentially, was replaced with the ATM calculation (as detailed above). This change in logic moved away from a factor approach to level out poor performing resources and introduced logic to utilize the previous dispatch signal, current output, and submitted ramp rates in order to determine a realistic starting point for the unit to ramp from for the next five minutes. This change in logic created a better alignment between the iMW and IGD MW calculations. However, because the IGD MW calculation is limited by the submitted economic/emergency limits of a resource (i.e., the dispatch basepoint cannot be greater than the economic/emergency max or less than the economic/emergency minimum), a misalignment between the iMW and IGD MW can still occur if the unit is operating outside of these submitted limits.

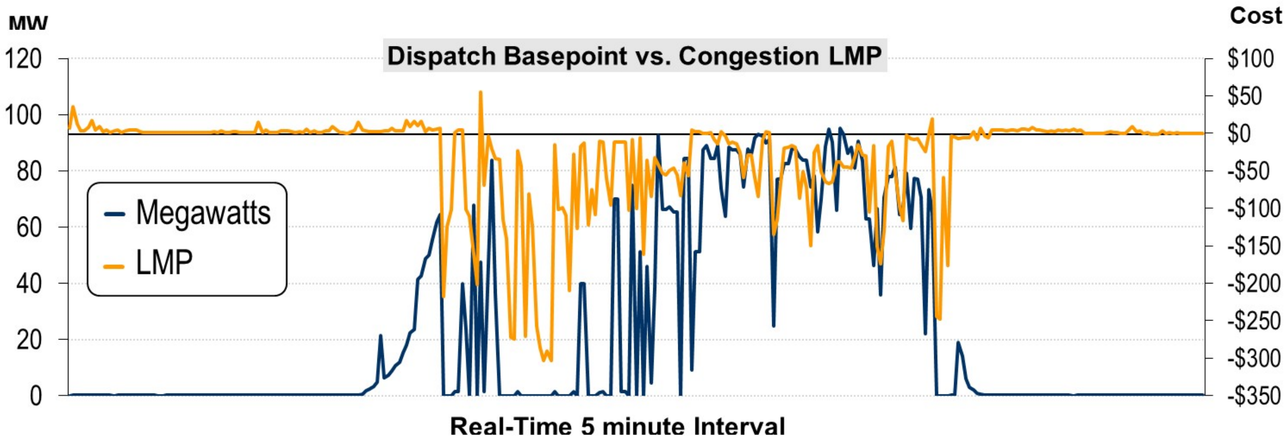
IV. Wind and Solar Logic Limitations

Wind and solar resources are dispatchable (meaning that they can follow PJM's dispatch instructions) in the Real-Time Energy Market if they have bid-in dispatchable parameters and are running for PJM, or are self-scheduled but have indicated a desire to follow PJM dispatch. In RTSCED, wind and solar resources are eligible to set price if they are made dispatchable and follow the rules documented in PJM Manual 14D: Generator Operational Requirements, Attachment M. PJM has observed that in an unconstrained system, because of their typically low bid in offer profile, these facilities will be operating at either Economic Maximum or their current State Estimator MW (SE MW) value if there is no change in environmental factors.

When the system is constrained, a challenge associated with constraint control is the fact wind and solar resources generally have unlimited ramp capability. While fast-ramping resources are usually beneficial to system operations, having a concentrated amount of resources where the total megawatts available for dispatch can be substantial has caused challenges. The lack of the ability for the MCEs to limit ramp rates is compounded by the fact that the dispatch solution is based on a single snapshot in time. This fact, along with the resource's typically low offer profile, may result in the potential movement of a significant level of generation from one five-minute interval to the next five-minute interval, subject to congestion patterns.

For example, in the next immediate set of cases after the resources have moved quickly in response to PJM's dispatch basepoints, the constraints will unbind as the constraint flow has significantly changed in the next EMS snapshot. This unbinding of the constraint will then drastically alter the bus prices in the subsequent set of cases, causing the resources to be dispatched back into a range that has an impact on the transmission constraint. This cycle repeats continuously as the quick resource movements, based on price, cause the constraint to flip from binding to unbinding. Each instance in turn affects prices and results in significant resource swings. At times, these megawatt swings can result in a violation of the actual transmission constraint line limit as reflected in the PJM EMS, which requires immediate dispatcher intervention, often in the form of out-of-market manual dispatch instructions. An example of this binding/unbinding cycle is shown in **Figure 3**.

Figure 3. Real-Time Constraint Volatility



This plot compares dispatch basepoint versus congestion LMP. When the constraint binds, the dispatch basepoint is lowered toward Economic Minimum, and when the constraint unbinds or binds at a low level, the dispatch basepoint is raised toward Economic Maximum. As illustrated in the figure, this can happen very quickly. Existing SCED dispatch logic and input parameters create volatile real-time pricing and control issues for PJM operators. This pattern on a larger scale can lead to ACE swings.

As noted previously, because of the current logic, there can be scenarios where the iMW is not aligned with IGD MW for both wind and solar resources. A driving factor for this inconsistency is inaccurate economic limits in relation to where the resource is currently operating. The result is the internal MW logic utilizing an SE MW greater than the Economic Maximum, whereas the IGD MW will follow economic dispatch based on LMP/incremental curve/economic limits. Two examples are provided in **Table 1**.

In the examples, it is assumed the renewable resources are dispatchable and have unlimited ramp capability, both resources have a raise help distribution factor (Dfax) on any active constraints criteria, and the resource is operating above its submitted Economic Maximum. Therefore, the iMW will reflect current SE MW, and IGD MW will follow economic dispatch based on LMP/incremental curve/economic limits.

Table 1. iMW Versus IGD MW Misalignment Examples

	MARGINALCOST	LMP	SE MW	iMW	IGD MW	ECONOMIC MIN BID IN	ECONOMIC MAX BID IN
A	$0	$10	150	150	90	0	90
B	$0	$10	125	125	100	0	100

Here we see the misalignment between iMW and IGD MW. For renewable resource A and B, the iMW solution reflects SE MW, but the IGD MW (dispatch basepoint sent to the resource) is dispatched down to its bid-in Economic Maximum of 90 MW and 100 MW, respectively. Here the total megawatt discrepancy between the megawatts accounted for in the iMW and IGD MW calculations is 85 MW.

The discrepancies outlined in these scenarios create uncertainty in the PJM dispatch basepoint. Renewable resource A and B may be uncertain as to why PJM is dispatching the resource down from its current operating level when the LMP is indicating to produce as much as possible.

V. Wind and Solar Logic Approaches

A. Wind and Solar Logic Approaches in Other ISO/RTOs

ISOs/RTOs employ different logic approaches to control both wind and solar resources. For example, some ISOs/RTOs limit the ramp capability of wind and solar resources. Others use a forecasted output as the resources dispatch basepoint unless the resource is being reduced to control a transmission constraint. Some ISOs/RTOs utilize Dfax filters to dispatch more cost-effective resources to control constraints. Most ISOs/RTOs use forecasted values in some fashion in the unit commitment process and real-time dispatch. The logic approaches are summarized in **Table 2**.

Table 2. ISO/RTO Logic Comparison

	CATEGORY			
	Impact of Forecast on Economic Maximum limit	**Ramp Rate Restrictions for Renewables**	**Renewable Resource Specific Real-Time Dispatch Logic**	**Resource Specific Curtailment Indicator**
PJM	Market Participant bid-in Economic Maximum limit.	No ramp rate restrictions. Market Participant may enter default and/or segmented ramp profile. If no ramp rate entered, then ramp rate is defaulted to 9999 (unlimited ramp capability) in SCED.	No special logic for dispatch megawatt calculation. Basepoint limited to be within submitted economic limits.	Currently, PJM provides a curtailment flag for wind resources, expected to retired by end of 2024.
CAISO	Forecast megawatt is used as the Economic Maximum limit.	No ramp rate restrictions. Market Participant may enter default ramp rate and will be applied by clearing engine on dispatch.	No special logic for dispatch megawatt calculation.	A flag is provided with the dispatch basepoint to indicate whether to produce to their full capability or not.
ERCOT	Forecast megawatt is used as the Economic Maximum limit.	20% per min of nameplate rating applied as a ramp rate restriction when the resource is responding to or released from a curtailment instruction.	No special logic for dispatch megawatt calculation.	Special curtailment logic exists. Only wind and solar resources that impact on transmission constraints are issued a curtailment instruction and expected to generate at or below their SCED issued basepoint.
ISO New England	Forecast megawatt is used as the Economic Maximum limit.	For units under 200 MW, the limit is 100 MW over five minutes. For units larger than 200 MW, the limit is 50% of nameplate over five minutes.	Do Not Exceed (DNE) dispatch megawatt points are calculated and communicated electronically at least every five minutes. DNE limit calculation to account for volatility and resources moving to their set points at varying ramp rates.	None

	CATEGORY			
	Impact of Forecast on Economic Maximum limit	**Ramp Rate Restrictions for Renewables**	**Renewable Resource Specific Real-Time Dispatch Logic**	**Resource Specific Curtailment Indicator**
MISO	Market Participant can select either Market Participant forecast or MISO forecast as Economic Maximum.	No ramp rate restrictions. Market Participant may enter default ramp rate and will be applied by clearing engine on dispatch.	No special logic. A dispatchable resource will be restricted by bid-in ramp rate and effective forecast maximum.	None.
SPP	Bid-in information and forecast used to calculate Economic Maximum limit.	Ramp rate restrictions applied only when the resource is responding to or released from a curtailment instruction. Submitted ramp rates must not exceed 40 MW in a five-minute RTBM interval (8 MW/min) if resource EmerMax is less than 200 MW. If the resource EmerMax is >= 200 MW, then the ramp rate must be limited to no more than 20% of the EmerMax in a five-minute interval (so a 400 MW EmerMax resource could submit ramp rates up to 16 MW/min, or 80 MW in a five-minute interval).	No special logic for dispatch megawatt calculation.	SPP will provide a dispatchable flag to the renewable resource indicating whether or not the resource should “follow” or “ignore” its set point instruction.

B. Design Discussion for Modification to PJM's Wind and Solar Logic

Use of Dfax Filters

A Dfax filter on wind or solar resources could be implemented to identify "effective" resources, which would then be used to determine if a resource should be dispatched for constraint control. This would minimize resource curtailment for small constraint impacts, and by extension minimize the volatility that has been observed with binding and unbinding constraints.

Pros	Cons
• A Dfax filter provides a more targeted dispatch approach. • A Dfax filter limits constraint control to a smaller set of resources deemed effective.	• It is difficult to establish level of Dfax filter. What may work now may not work in the future based on active constraints and system conditions. • If the Dfax filter is set globally, then the logic may cause conflict when multiple constraints are binding. • If the Dfax filter is set on an individual constraint basis, then maintaining the threshold level may become challenging. • A Dfax filter may cause disconnect between dispatch and pricing for unfiltered resources.

PJM's Perspective: PJM does not support the use of Dfax filters in wind and solar dispatch logic. A proper filter level is hard to establish and may need to be updated over time. PJM's preference is to dispatch these resources in the same manner as traditional resources.

Use of Wind and Solar Forecasts

In order to replace solar and wind resources' bid-in Economic Maximum value, PJM's dispatch algorithm would use the solar and wind forecast value. PJM produces a wind and solar forecast for each resource, and that can be provided into SCED for dispatch. Although there is uncertainty in the forecasted values, this would eliminate outdated values being used to dispatch the system.

Pros	Cons
• Using a forecast value as an Economic Maximum eliminates the issue of outdated bid-in parameters, such as Economic Maximum. • Forecast values can help during extreme weather situations when resources' outputs could be significantly impacted.	• It may not make sense to use a forecast value for a real-time dispatch five-minute or 10-minute look-ahead period. Using the current State Estimator value is the best indicator of the resources' current output, which might not change significantly in the next five to 10 minutes. Using a combination of bid-in Economic Maximum and forecast may make more sense.

PJM's Perspective: PJM is supportive of further discussing the use of a wind and solar forecast as a dispatch maximum replacing a Market Participant entry of Economic Maximum. Using a five-minute forecast value eliminates the stale Economic Maximum observed for many of these renewable resources.

Calculation of a Do Not Exceed Limit

The Do Not Exceed (DNE) limit represents the maximum amount of economical wind and solar generation that the system can safely accommodate without creating any reliability issues. This calculation can be performed as an additional optimization solve in the real-time dispatch engine after the dispatch basepoint has been determined or by a separate application. Inputs into the DNE optimization solve would include the dispatch basepoint along with active transmission constraints and a set of reliability constraints. The DNE MW value is sent to the resource instead of the SCED basepoint for wind and solar resources. The SCED basepoint would always be less than or equal to the DNE MW limit.

Pros	Cons
• This logic provides a dispatch guideline for wind resources. • It ensures reliable system operation. • It may allow low-cost wind resources to provide as much energy as possible.	• A new optimization algorithm may need to be developed. • Additional processing time would be required to calculate the DNE limit, impacting overall RTSCED case solution time. • Resources would need to be able to adhere to the DNE limit, communication signal via ICCP or other data transfer mechanisms. Resources without such capability could continue to contribute to the issues mentioned. • Additional settlement rules may need to be derived or updated based on new DNE MW limit (for example LPOC).

PJM's Perspective: PJM is supportive of further discussion to explore the use of a "DNE-style" logic feature to manage constraint volatility.

Use of a Curtail Flag

A curtail flag is a separate indicator flag provided to the resource indicating the resource is to follow and not exceed its current dispatch basepoint. This indicator is provided when the resource is being lowered to control a transmission constraint. PJM currently provides a "curtail" flag to wind resources when they are dispatched lower to control a transmission constraint. The curtail flag is provided via telemetry.

Pros	Cons
• A curtail flag provides the resource with an indicator that the resource basepoint is being lowered and the resource must follow its dispatch basepoint. • It provides additional layer of communication with such resources.	• The wind/solar resource would need to process this additional megawatt point on their end and reconcile it with the dispatch basepoint they received. • The flag does not help resources that do not have the capability to receive a PJM signal (such as ICCP). • The current IGD MW calculation can serve similar purpose.

PJM's Perspective: PJM currently provides a curtail flag to inform wind resources their output is being reduced for constraint control. PJM will discontinue sending a curtail flag via telemetry by the end of 2024. PJM is not supportive of providing this flag in future designs.

Limiting Ramp Rate

PJM could implement a limit on how much ramping capability a wind and solar resource can offer into the market. This ramp limitation can be used in two ways:

1 | The ramp limitation is always in effect to calculate a wind and solar resource's dispatch basepoint.

2 | The ramp limitation is only applied when a dispatchable wind or solar resource is being lowered to control a transmission constraint and after the constraint has been cleared to increase the resources output to its unconstrained output (controlled release).

Pros	Cons
• Ramp rate limits reduce constraint volatility.	• Ramp rate limits restrict the actual capability of the resource. • It is difficult to establish a good limit that works for different scenarios. For example, a 5 MW limit would still move a lot of generation for a constraint where there is a large amount of available generation. • Ramp rate limits would restrict the ramp for a "raise help" resource. • Ramp rate limits may require additional regulation or reserves as growth in solar and wind continues. • Existing resources may not have installed the technology needed to follow dispatch signals.

PJM's Perspective: PJM's preference is to dispatch these resources using their bid-in parameters. Fast-responding resources are beneficial in responding to changing system conditions.