UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Reactive Supply Compensation in Markets Operated by Regional Transmission Organizations and Independent System Operators	)	Docket No. AD16-17-000

COMMENTS OF THE INDEPENDENT MARKET MONITOR FOR PJM

Pursuant to the workshop convened in the above referenced proceeding on June 30, 2016, Monitoring Analytics, LLC, acting in its capacity as the Independent Market Monitor for PJM ("Market Monitor"), offers these comments for the Commission's consideration on issues related to compensation for Reactive Supply and Voltage Control (Reactive Supply) within the Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs).

The Market Monitor supports the Commission's reconsideration of the compensation of Reactive Supply, and specifically the issues associated with what have been termed payments for reactive capability. The best approach to reactive compensation relies on markets. Generating units are required to have reactive capability in order to receive interconnection service and generating units are not designed or built without reactive capability. The cost of new units includes the cost of providing reactive power and generation owners can therefore have the opportunity to recover the costs of new units including reactive costs through markets. The cost of service approach is an anachronistic approach based on a period prior to the introduction of wholesale power markets when reactive was a service provided by vertically integrated transmission companies under cost of service rates, although reactive was not distinguished as a separate ancillary service. With the introduction of wholesale power markets, generation owners have the

opportunity to recover all costs from markets including the costs of reactive. The cost of service rules should be eliminated. If the Commission decides to not eliminate the cost of service rules for Reactive Supply, then the rules should be reformed to ensure that overpayments under current rules are eliminated.

I. COMMENTS

A. Background

Units in PJM are compensated for Reactive Supply in two distinct ways: (i) cost of service rates established under Schedule 2 of the PJM Open Access Transmission Tariff ("OATT") compensate suppliers for reactive capability and (ii) make whole and opportunity costs payments under Section 3.2.3B of Schedule 1 of the PJM Operating Agreement ("OA") compensate market participants for energy costs not covered by energy prices in response to PJM directives related to reactive support. PJM's rules for compensating units for make whole or opportunity cost payments for following PJM dispatch related to reactive support generally work well, but could be improved by calculating lost opportunity costs in the ancillary services markets using the schedule on which the unit was scheduled to run in the energy market.[1]

PJM's rules and related regulations for reactive capability payments need more significant reform.

PJM market participants currently pay units for reactive power capability under cost of service rates. Payment for reactive capability rates constituted 96.35 percent of total reactive compensation in 2015 and 99.59 percent of total reactive compensation in the first six months of 2016 (Table 1).

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[1] *See* 2015 State of the Market Report for PJM, Vol. 2 (March 10, 2016) at 44.

Cost of service rates are established under Schedule 2 of the OATT and may cover rates for single units or a fleet of units.[2] Until the Commission took corrective action, fleet rates remained in place in PJM even when the actual units in the fleet changed as a result of unit retirements or sales of units.[3] New rules require unit owners to give notice of fleet changes in an informational filing or to file a new rate based on the remaining units, but do not yet require unit specific reactive rates.[4] Fleet rates should be eliminated. Compensation should be based on unit specific costs. Fleet rates make it almost impossible to monitor whether compensation for reactive capability is based on actual unit specific performance and costs.

Reactive capability is provided by the same equipment that provides real power. But unlike the market-based payments for real power, reactive power is compensated on an outdated cost of service basis which uses an inaccurate allocation of the share of unit costs associated with providing reactive power and which inappropriately incorporates the variable costs associated with heat losses as fixed costs. The allocator is based on the power factor (PF) which can be based either on theoretical calculations or on the results of actual tests. The power factor is a number between 0.00 and 1.00. The power factor used in the allocation is generally a theoretical value, termed the nameplate power factor or the design power factor, which is specified by the manufacturer. PJM tests for power factor and monitors for power factor.

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2 *See, e.g.*, OATT Schedule 2; *Virginia Electric and Power Company*; 114 FERC ¶ 61,318 (2006).

3 *See PJM Interconnection, L.L.C.*, 149 FERC ¶ 61,132 (2014); 151 FERC ¶ 61,224 (2015); OATT Schedule 2.

4 *Id*.

The allocation method used to allocate unit costs to reactive capability is called the *AEP* Method and is based on a 1999 Commission order.[5] Given a power factor and a real power rating (MW), an apparent power capability (MVA) is calculated as MW/PF. Reactive power (MVAR) is the square root of the difference between the square of the apparent power and the square of the real power.

Example:

Real power (RP): 300 MW

Power factor (PF): 0.85

Apparent power (MVA) = RP/PF

Apparent power = 300 MW / 0.85 = 352.94 MVA

Reactive power capability (MVAR) = $(MVA^2 - RP^2)^{1/2}$

Reactive power capability (MVAR) = $(352.94^2 - 300^2)^{1/2}$ = 185.92 MVAR

Reactive power allocation factor[6] = $MVAR^2 / MVA^2$

Reactive power allocation factor = $185.92^2 / 352.94^2$ = .2775

Based on the *AEP* method, the reactive allocation factor in this example is 27.75 percent. The reactive allocation factor is applied to the value of the unit's Generator/Exciter. The value of the unit's GSU transformer is added. An allocation of accessory electrical equipment and balance of power plant is added. The total is multiplied by a fixed charge

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[5] *See American Electric Power Corp.*, Opin. 440, 88 FERC ¶ 61,141 *mimeo* at 29–33 (1999). In subsequent cases, the Commission determined that a unit's quantity of reactive output or hours online should not be the basis for reactive supply compensation. *See*, *e.g.*, *Bluegrass Generation Company, L.L.C.*, 121 FERC ¶ 61,018, at P 13 (2007); *Calpine Oneta Power, L.P.*, 119 FERC ¶ 61,177, at P 11 (2007) (*AEP*). Staff has in the past characterized the AEP method as providing for "an option payment for the right to call on a generator for reactive power within the required power factor range." Commission Staff Report, Payment for Reactive Power, Docket No. AD14-7 at 12 (April 22, 2014).

[6] *See AEP mimeo* at 30 n6 ("The parties agreed to use the formula $MVAr^2/MVA^2$ to determine the allocation factor.")

factor that incorporates rates of return, capital structure and depreciation in order to develop an annual revenue requirement for reactive capability.

The reactive power allocation factor is a function of the power factor. The lower the power factor, the higher the reactive allocator. Thus the use of understated power factors based on a theoretical nameplate level rather than based on testing significantly overstates the calculated reactive costs under this approach. In this example, the reactive allocator (27.75 percent) resulting from the use of the nameplate power factor of 0.85 is 2.8 times higher than the reactive allocator (9.75 percent) resulting from the use of a power factor of 0.95, which is typical of tested power factors.

Under the *AEP* method, units must establish their MVAR rating based on "the capability of the generators to produce VArs."[7] Typically this has meant reliance on manufacturers' specified nameplate power factor.[8] The Commission has noted a difference between tested reactive MVAR ratings and nameplate MVAR ratings and has, in a number of cases, set the issue of MVAR rating degradation for hearing.[9] The Commission has identified a significant issue. There is no reason to use the nameplate MVAR rating to develop a reactive allocation and there is no basis in the *AEP* order for reliance on the nameplate MVAR rating. Nameplate reactive power ratings are generally higher than the actual ratings as defined by the PJM mandated tests of capability because nameplate power ratings are generally calculated using leading and lagging power factors that are lower than are achievable in real world operation. Although this issue is characterized as degradation, the difference between nameplate and tested capability exists when units are new. Testing

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7 *AEP mimeo* at 31.

8 *See*, *e.g.*, *id*.

9 *See*, *e.g.*, *Talen Energy Marketing, LLC*, 154 FERC ¶ 61,087 at P 10 (2016) ("The Informational Filing contains information that raises concerns about the justness and reasonableness of Ironwood's reactive power rate, including, but not limited to, the degradation of the Facility's current MVAR capability as compared with the MVAR capability that was originally used to calculate the revenue requirement for Reactive Service included in Ironwood's reactive power rate.").

will reveal whether the tested capability degrades further. Reliance on tested results would address both the issue of degradation and the issue of theoretical versus actual MVAR ratings.

The estimated capability costs also include estimated heating losses relative to MVAR output.[10] Heating losses are variable costs and not fixed costs and should not be included in the definition of reactive capability costs.[11] Heating losses can be accurately calculated for each hour of operation if each unit had an accurate, recent D-curve test.

B. Compensate Reactive Capability Through Markets.

The best approach for recovering reactive capability costs is through markets when markets are available as they are in RTOs/ISOs. The best approach for recovering reactive capability costs in PJM is through the capacity market. The capacity market already incorporates reactive costs and reactive revenues. The treatment of reactive costs in the PJM market needs to be modified so that the capacity market incorporates reactive costs and revenues in a more efficient manner.

Reactive capability is an integral part of all generating units; no generating unit is built without reactive capability.[12] There is no support for the assertion that the fixed costs of reactive capability either can be or should be separated from the total fixed costs of a generating unit. There is no support for the assertion that reactive capability should be compensated outside the markets when the units participate in organized markets. Reactive

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[10] *See*, *e.g.*, *id*. at P 10 n12 citing *PPL Energy Plus, LLC*, Letter Order, Docket No. ER08-1462-000 (Sept. 24, 2008); *Dynegy Midwest Generation, Inc.*, 125 FERC ¶ 61,280, at P 35 (2008).

[11] *See* Transcript, *Reactive Supply Compensation in Markets Operated by Regional Transmission System Operators Workshop*, AD16-17-000 (June 30, 2016) at 26:21–27:23.

[12] *See Reactive Power Requirements for Non-Synchronous Generation*, Order No. 827, 155 FERC ¶ 61,277 at 9 (2016) ("[T]he equipment needed for a wind generator to provide reactive power has become more commercially available and less costly, such that the cost of installing equipment that is capable of providing reactive power is comparable to the costs of a traditional generator.").

capability is a precondition for participating in organized markets. Resources must invest in the equipment needed to have minimum reactive capability as a condition of receiving interconnection service from PJM and other markets.[13] PJM requires a power factor of at least 0.95 leading to 0.90 lagging for synchronous units and at least 0.95 leading to 0.95 lagging for non-synchronous units.[14] The regulations specify a minimum power factor range of 0.95 leading and 0.95 lagging power factor unless the market operators' rules specify otherwise.[15] The Commission has recently extended the interconnection service requirement to have reactive capability to wind and solar units, which previously had been exempt.[16] Reactive capability is a requirement for participating in organized markets and is therefore appropriately treated as part of the gross Cost of New Entry in organized markets.

There are two ways to address the cost of reactive in the PJM market design.

Under the current capacity market rules, the gross costs of the entire plant, including any reactive costs, are included in the gross Cost of New Entry (CONE) and the revenues

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13 *See* 18 CFR § 35.28(f)(1); *Standardization of Generator Interconnection Agreements and Procedures*, Order No. 2003, FERC Stats. & Regs. ¶ 31,146, Appendix G (Large Generator Interconnection Agreement (LGIA)), *order on reh'g*, Order No. 2003-A, FERC Stats. & Regs. ¶ 31,160, *order on reh'g*, Order No. 2003-B, FERC Stats. & Regs. ¶ 31,171 (2004), *order on reh'g*, Order No. 2003-C, FERC Stats. & Regs. ¶ 31,190 (2005), *aff'd sub nom.* Nat'l Ass'n of Regulatory Util. Comm'rs v. FERC, 475 F.3d 1277 (D.C. Cir. 2007), *cert. denied*, 552 U.S. 1230 (2008); *Standardization of Small Generator Interconnection Agreements and Procedures*, Order No. 2006, FERC Stats. & Regs. ¶ 31,180, Attachment F (Small Generator Interconnection Agreement), *order on reh'g*, Order No. 2006-A, FERC Stats. & Regs. ¶ 31,196 (2005), *order granting clarification*, Order No. 2006-B, FERC Stats. & Regs. ¶ 31,221 (2006).

14 *See* OATT Attachment O Appendix 2 § 4.7.

15 *See*, *e.g.*, *id*. LGIA Article 9.6.1 ("Interconnection Customer shall design the Large Generating Facility to maintain a composite power delivery at continuous rated power output at the Point of Interconnection at a power factor within the range of 0.95 leading to 0.95 lagging, unless Transmission Provider has established different requirements that apply to all generators in the Control Area on a comparable basis.").

16 *Reactive Power Requirements for Non-Synchronous Generation*, Order No. 827, 155 FERC ¶ 61,277 (2016); *see also PJM Interconnection, L.L.C.*, 151 FERC ¶ 61,097 at P 28 (2015).

from reactive service capability rates are an offset to the gross CONE. The result is that, conceptually, the cost of reactive is not part of net CONE.[17] This is logically consistent with the separate collection of reactive costs through a cost of service rate in that there is no double counting if the revenue offset is done accurately. Under this approach there is a separate collection of reactive capability costs.

An alternative approach to the current treatment of reactive costs in the capacity market would be to include the gross costs of the entire plant including any reactive costs in the gross Cost of New Entry (CONE) but to calculate net CONE without a reactive revenue offset for reactive service capability rates. The result of this approach would be that the cost of reactive is part of net CONE. This is logically consistent with the elimination of the separate collection of reactive costs through a cost of service rate in that there is no double counting if done accurately. Under this approach there would be no separate collection of reactive capability costs.

PJM currently uses the first approach. There is no reason that PJM could not easily implement the second approach.

The second approach is preferable. The second approach relies on competitive markets to provide incentives to provide energy, both real and reactive, at the lowest possible cost. The second approach does not require the use of arbitrary, approximate and generally inaccurate allocators to determine the cost of providing reactive. The second approach does not require the use of estimated, average and inaccurate net reactive revenue offsets to calculate Net CONE. It is critical in the PJM Capacity Market that Net CONE be as accurate as possible. Only the second approach assures this.

Units are compensated for reactive capability costs under the second approach. But the compensation is based on the outcome of a competitive capacity market rather than based on current or historical cost of service filings for units or fleets of units.

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[17] *See* OATT Attachment DD § 5.10(a)(iv).

The first approach, although internally logically consistent, relies on unnecessary and inaccurate approximations. The reactive allocator is such an approximation. The reactive revenue offset is an inaccurate estimate based on historical data from reactive revenue requirement filings. The reactive revenues used in the net CONE calculation are based on an average of reactive filings over the three years from 2005 through 2007 and therefore do not reflect even the allocated reactive costs and revenues for a new unit, as would be required to be consistent with the CONE logic.[18] To the extent that the reactive portion of the Net Energy and Ancillary Services Offset is inaccurate, the net CONE is inaccurate.

The reactive revenue offset is set equal to $ 2,199/MW-year in the PJM OATT.[19] This figure is the average annual reactive revenue for combustion turbines from 2005 through 2007, based on the actual costs reported to the Commission in reactive service filings of CTs, as developed by the Market Monitor.

The Net Cost of New Entry is a key parameter in the PJM Capacity Market as it affects the location of the VRR or demand curve and thus has a direct impact on capacity market prices.[20]

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[18] OATT Attachment DD § 5.10(a)(v)(A) ("The Office of the Interconnection shall determine the Net Energy and Ancillary Services Revenue Offset each year for the PJM Region as (A) the annual average of the revenues that would have been received by the Reference Resource from the PJM energy markets during a period of three consecutive calendar years preceding the time of the determination, based on (1) the heat rate and other characteristics of such Reference Resource; (2) fuel prices reported during such period at an appropriate pricing point for the PJM Region with a fuel transmission adder appropriate for such region, as set forth in the PJM Manuals, assumed variable operation and maintenance expenses for such resource of $6.47 per MWh, and actual PJM hourly average Locational Marginal Prices recorded in the PJM Region during such period; and (3) an assumption that the Reference Resource would be dispatched for both the Day-Ahead and Real-Time Energy Markets on a Peak-Hour Dispatch basis; plus (B) ancillary service revenues of $2,199 per MW-year.").

[19] *Id*.

[20] *Id*.

If revenues for reactive capacity were removed from the Net Energy and Ancillary Services Revenue Offset, then the fixed costs for investment in reactive capability would be recoverable through the capacity market. By employing a simple and direct approach using CONE with no offset, the rules for cost of service compensation included in Schedule 2 could be eliminated and the requirement for cost of service filings would be eliminated.

As a result of the nature of reactive filings, it is not possible to identify the reactive capability revenues for all individual units that receive reactive capability revenues. As a result, the offer caps in the capacity market are not as accurate as they should be.

Relying on capacity markets instead of cost of service allocations would enhance competition and efficient pricing.

Actual experience with the cost of service approach suggests that customers would be better off under a competition based approach. The Commission's recent investigations into particular rates raises questions about the accuracy and basis of rates currently charged for reactive capability.

Cost of service ratemaking creates unnecessary monitoring difficulties. Because service providers do not have to file rates periodically, suppliers have no incentive to adjust reactive capability rates except when they increase. Suppliers have direct access to information about the costs for their own units; the Commission and other parties do not have such access. When rates are established on a fleet basis or result from a black box settlement, the ability of parties to review and challenge rates is further reduced.

This proceeding provides an excellent opportunity to discard an anachronistic cost of service approach that has not been working well and that is inconsistent with markets and is unnecessary in organized markets. Increased reliance on markets for the recovery of reactive capability costs would promote efficiency and consistency. Customers, market administrators and regulators will be better served by a simpler and more effective competition based approach.

C. An Improved Cost of Service Method Should Be Implemented if the Commission Decides to Retain Approach.

To the extent that the Commission decides that PJM and other markets should continue to rely on a cost of service method to compensate reactive capability, the rules should be modified to improve the accuracy of the calculations of reactive capability cost. Rates that do not accurately reflect the cost of the service provided are not just and reasonable.

Manufacturers' nameplate MVAR ratings and the corresponding theoretical power factors should not be relied upon to define the allocator used to calculate the costs of reactive capability. Current performance and testing show significant disparities between nameplate MVAR output and actual output. This is significant regardless of whether the cause is degradation of power factors or simply the difference between theoretical and tested power factors.[21] PJM determined in 1999 that nameplate MVAR and power factor ratings do not reflect the value to the system operator of a units' reactive output after it is interconnected at a specific location.[22] Only operator evaluation of reactive capability can provide a meaningful measure of reactive capability.

The information for MVAR ratings should come from data on the MVAR output provided. System operators can evaluate the usefulness and value of reactive capacity based on the actual availability and use of such capability.

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[21] In response to a 1999 low voltage event, PJM performed a root cause analysis. The analysis concluded that "PJM narrowly avoided a voltage collapse" and the "if PJM had realized that the MVAR reserves that the EMS indicated were available were not realistic, other action could have been take [sic] to stabilize the system." PJM State & Member Training Dept., Slides, Reactive Reserves and Generator D-Curves at 13 (included as an Attachment), which can be accessed at: <http://www.pjm.com/~/media/training/nerc-certifications/gen-exam-materials/gof/20160104-reactive-reserves-and-d-curve.ashx>

[22] *Id*., including Attachment.

Data from periodic testing for reactive capability is another approach to measuring MVAR output. Testing at relatively long intervals is not likely to be as accurate as actual market operations data, but it is more reliable than an untested and dated manufacturers' nameplate rating.

Fleet rates should be eliminated. Compensation should be based on unit specific costs. Fleet rates make it almost impossible to monitor whether compensation for reactive capability is based on actual unit specific performance and costs.

Heating losses are variable costs and should not be included in the cost of reactive capability. The production of reactive power slightly reduces the MWh output of the generator as the generator follows its D-curve. The value of this heating loss component is generally estimated based on estimated operation and associated estimated losses and estimated market prices, treated as a fixed cost, and included in the cost of reactive capability. Losses are minimal and occur during normal operations and should not be treated as a fixed cost. Losses can be better and more accurately accounted for as a variable cost based on actual unit operations and market conditions.

D. Costs of Reactive Service in PJM Markets.

The Market Monitor includes analysis of reactive power and the costs of reactive power in the PJM State of the Market Report.[23] The costs of reactive power for 2015 and January through June of 2016 are included in Table 1. In Table 1 the Revenue Requirement Charges column include the cost of reactive capability as approved by the Commission.[24] The Reactive Service column includes the costs for units dispatched by PJM Market

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[23] *2015 State of the Market Report for PJM,* Vol. 2 (March 10, 2016) at 4, Table 10-4 (History of ancillary services costs per MWh of Load: 2004 through 2015).

[24] A full list of these provider/zonal requirements is published each month on the PJM website: Reactive Supply and Voltage Control from Generation or Other Sources Service Revenue Requirements for June, 2016, <*http://www.pjm.com/~/media/markets-ops/settlements/reactive-revenue-requirements-table-june-2016.ashx*>.

Operations in the Day-Ahead Energy Market specifically for the purpose of providing Reactive Service in real time, plus uplift costs for resources whose dispatch is adjusted outside of their normal operating range in real time for the purpose of providing reactive service. Such decisions are made by PJM dispatch and logged.

Table 1 Reactive zonal charges for network transmission use: 2015 and January through June, 2016

	2015			2016 (Jan - Jun)		
Zone	Reactive Service	Revenue Requirement Charges	Total Charges	Reactive Service	Revenue Requirement Charges	Total Charges
AECO	$17,555	$6,341,664	$6,359,219	$0	$2,714,981	$2,714,981
AEP	$458,265	$38,198,374	$38,656,639	$14,106	$18,494,486	$18,508,592
AP	$98,666	$16,666,745	$16,765,411	$0	$8,390,866	$8,390,866
ATSI	$3,844,142	$15,692,347	$19,536,489	$0	$12,690,250	$12,690,250
BGE	$63,849	$7,825,069	$7,888,919	$0	$3,827,063	$3,827,063
ComEd	$180,977	$26,029,698	$26,210,675	$1,091	$13,169,277	$13,170,367
DAY	$34,107	$8,487,449	$8,521,555	$0	$4,273,003	$4,273,003
DEOK	$53,426	$5,153,000	$5,206,427	$0	$2,876,239	$2,876,239
Dominion	$2,682,636	$29,848,959	$32,531,595	$0	$15,021,534	$15,021,534
DPL	$2,338,443	$11,292,982	$13,631,425	$570,320	$6,471,457	$7,041,776
DLCO	$25,334	$0	$25,334	$0	$0	$0
EKPC	$28,701	$2,154,987	$2,183,688	$0	$1,084,927	$1,084,927
JCPL	$39,781	$7,175,487	$7,215,268	$0	$4,871,900	$4,871,900
Met-Ed	$63,281	$7,730,837	$7,794,118	$15,071	$3,892,087	$3,907,158
PECO	$73,554	$17,744,319	$17,817,873	$0	$8,933,370	$8,933,370
PENELEC	$313,316	$7,406,799	$7,720,115	$10,366	$4,006,158	$4,016,524
Pepco	$69,105	$5,293,901	$5,363,006	$0	$3,307,039	$3,307,039
PPL	$81,863	$18,969,092	$19,050,955	$15,263	$9,735,841	$9,751,104
PSEG	$73,686	$28,937,473	$29,011,159	$0	$18,512,827	$18,512,827
RECO	$2,499	$0	$2,499	$0	$0	$0
(Imp/Exp/Wheels	$0	$17,324,901	$17,324,901	$0	$8,415,863	$8,415,863
Total	$10,543,187	$278,274,084	$288,817,271	$626,216	$150,689,166	$151,315,382
Percent of Total	3.65%	96.35%	100.00%	0.41%	99.59%	100.00%

II. CONCLUSION

The Market Monitor respectfully requests that the Commission afford due consideration to these comments as the Commission considers the issues raised in this proceeding.

Respectfully submitted,

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Dated: July 29, 2016

Attachment

Reactive Reserves and Generator D-Curves

PJM State & Member Training Dept.

Objectives

- Identify the process for monitoring and maintaining reactive reserves

Reactive Reserves

Why Monitor Reactive Power Reserves?

- Voltage limits are established on the BES to maintain system reliability
  - High voltage limit protects equipment from damage
  - Low voltage limit protects system from voltage instability and equipment damage
  - ANSI Standards provide basis for voltage schedules, including those for Generator Buses
  - As conditions change, it is important to have a source of reactive power (MVAR) reserves available to maintain voltages within their limits

Why Monitor Reactive Power Reserves?

- As the NERC registered Transmission Operator, PJM is responsible for making sure that there are adequate supplies – and reserves – of both “Real Power” (MW) and Reactive Power (MVAR)
- Reactive Power provided by generating units is a primary method of providing voltage support on the PJM system

Why Monitor Reactive Power Reserves?

- PJM's EMS models the available Generating Unit Reactive Power on a minute-by-minute basis
- To maintain adequate system control, PJM must have EMS data that reflects the true amount of MVAR reserves that are on the system
  - What each unit can actually provide –vs- "D"-curve theoretical capability for the unit
- Unrealistic values of reactive reserves can result in PJM system reliability problems including voltage collapse

1999 Low Voltage Event in PJM….

- PJM learned this lesson in July of 1999;
  - Hot and humid conditions led to heavy loads on the interconnection
  - The system loads at that time were ~55,000 MW
  - Sufficient MWs were available (real time and reserves) to supply that load
  - Transmission Voltages were decaying due to insufficient reactive reserves available
    - Gradual decay throughout the day, as demand increased
    - Noted by several member company operators

1999 Low Voltage Event in PJM….

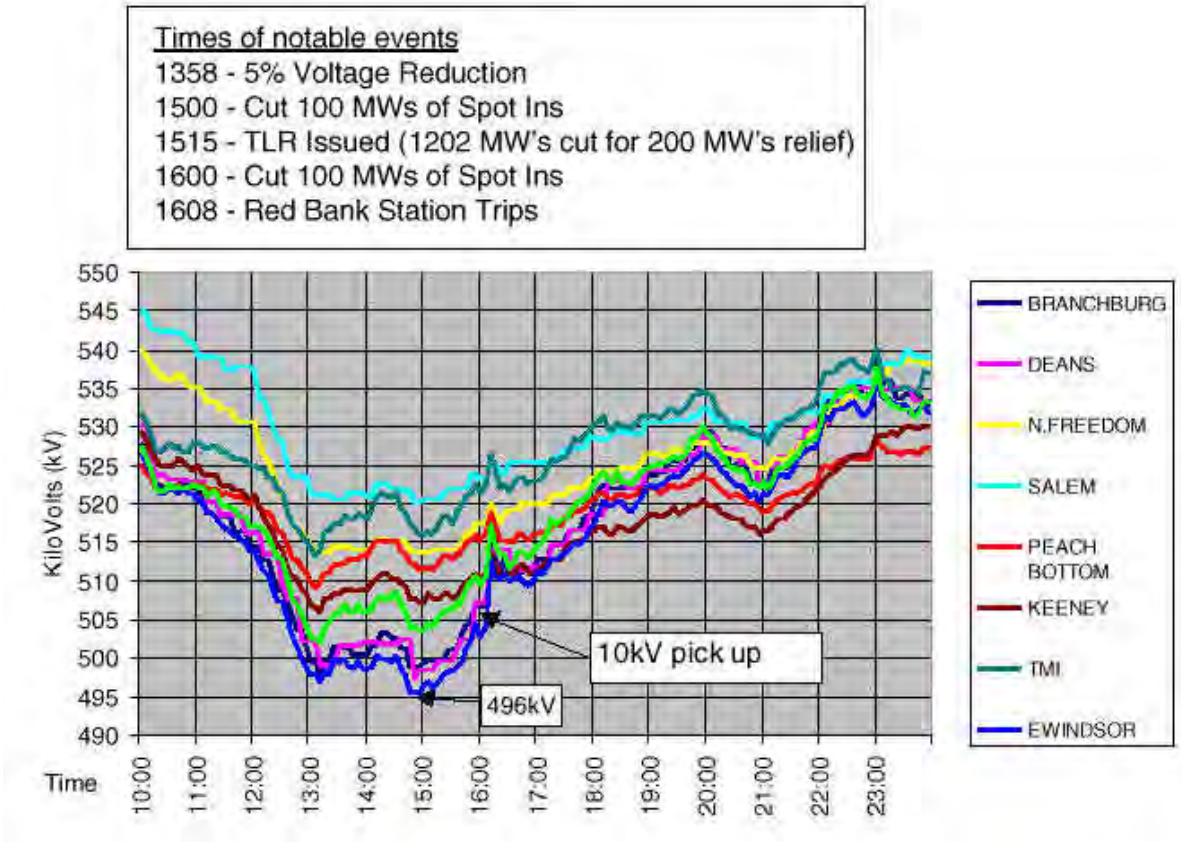
- PJM's EMS at that time had only nameplate "D"-curve data for generating unit reactive capabilities
  - PJM EMS was indicating to the PJM Operators that there were plenty of reserves available to correct the voltage issues
  - In reality, many units had internal or external limitations that prevented the unit from providing that level of MVAR support
- Looking at real-time data on voltages, PJM takes some controlling actions;
  - Issued 5% voltage reduction
  - Curtailed transactions/issued TLR

1999 Low Voltage Event in PJM….

- Voltages stabilized somewhat, and began to recover, but remained low going into the evening peak
- At 1608 - due to heavy loads and overheating a large power transformer at Red Bank (NJ) trips out of service
  - ~ 500 MW of load was shed when the transformer tripped
- Voltages on the 500 kV system immediately jumped by as much as 10 kV
  - A 5 KV rise in voltage was seen on the 230 kV system…

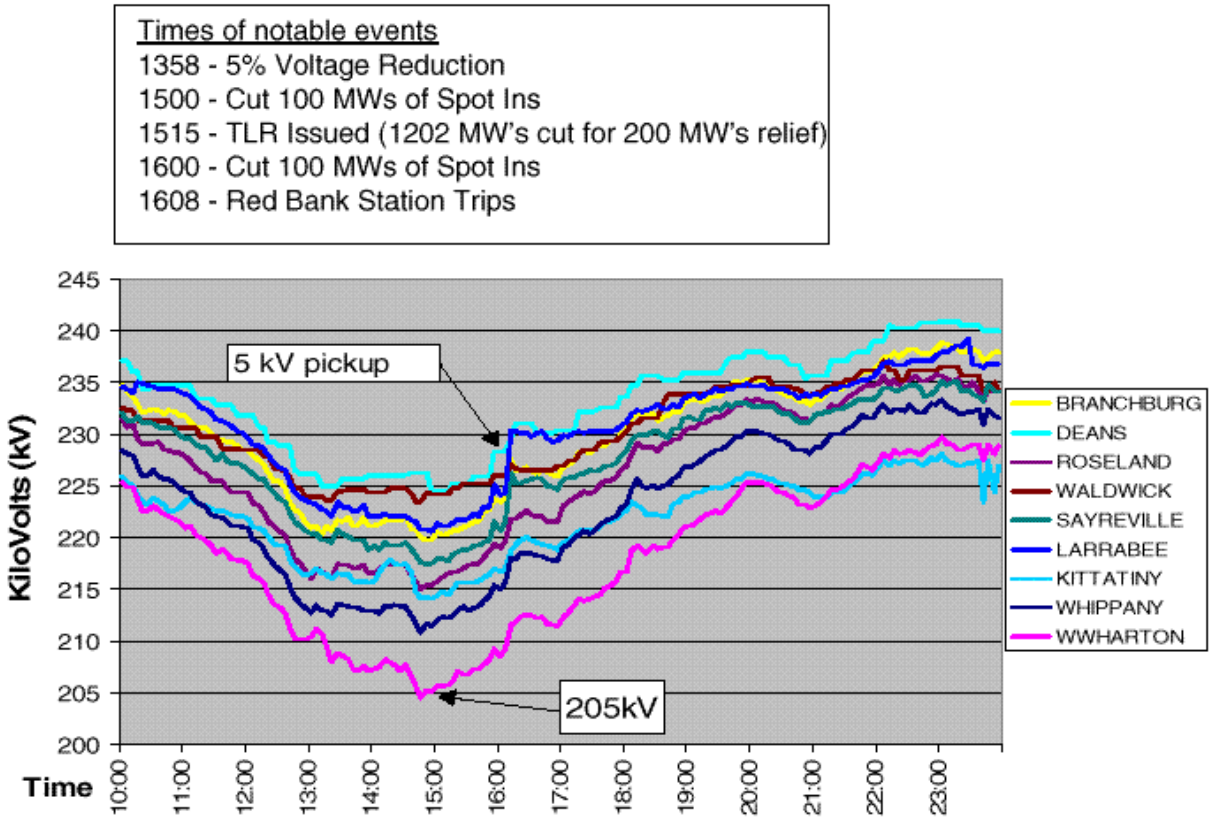
Why Monitor Reactive Power Reserves?

- PJM Voltages – July 6, 1999



Why Monitor Reactive Power Reserves?

- PJM Voltages – July 6, 1999



1999 Low Voltage Event in PJM….

- A textbook indicator of voltage instability is when voltages change drastically when system loads change by small amounts
  - 500 MW of PJM's ~55,000 MW load was a relatively small change (1%)
  - A 10 kV change on the 500 kV system is drastic
- While PJM was still analyzing the results of this day's operation, a similar occurrence occurred again on July 19th
  - Another slow, sustained decrease in system voltages even though the PJM EMS said plenty of reactive reserves were available

1999 Low Voltage Event in PJM….

- Once again, an equipment failure caused a relatively small amount of load to be shed from the system, and voltage recovered dramatically

- These events led PJM to do a Root Cause analysis to determine the cause of the problem
- The Root cause investigation indicated that during these 2 events PJM narrowly avoided a voltage collapse
- The investigation also showed that if PJM had realized that the MVAR reserves that the EMS indicated were available were not realistic, other actions could have been take to stabilize the system

1999 Low Voltage Event in PJM….

- Since plenty of MW reserves were available, some generators could have had their MW output reduced so that they could provide additional MVARs

- One of the recommendations that came out of the Root Cause report was for PJM to develop a method of determining realistic values for MVAR capability for each unit
  - Replace the default "D"-curve data in the PJM EMS with actual capabilities, determined under real conditions.

Why Monitor Reactive Power Reserves?

Heatwave 1999 July Low Voltage Condition Root Cause Analysis Report

Recommendation 3: Investigate the development of a generator MVAR/voltage monitoring process to determine when generators may not be following reported MVAR limits.

Background: Some reactive capability curves that were modeled in the PJM Security Analysis Applications were unachievable, resulting in overly optimistic Transfer Limit Calculations. An investigation of the events surrounding July 6th and July 19th operations indicated that the absence of a policy to validate reactive capability curves was causal to the low voltages that were encountered. The development of a semi-annual review and monitoring process will assist PJM and Local Control Centers (LCCs) in identifying invalid inputs to security analyses and generators that are not adhering to their reported reactive capabilities.

1999 Low Voltage Event in PJM….

- By monitoring MVAR reserves, PJM can develop action plans to maintain or correct system voltages and ensure voltage stability on our part of the Interconnection

What Reactive Reserve information is reported?

- The MOC/GO must provide reactive capability curve information to PJM via eDART
  - The TO for the Transmission Zone where the unit is located will be automatically notified via eDART
    - Also any other TOs with eDART authority to receive automatic notification for the unit
- For real-time changes, each MOC/GO should also notify PJM and the respective TO via phone

What Reactive Reserve information is reported?

- PJM Manual 14-D definition;
  - *Continuous Unit Reactive Capability Curve* - data that provides the realistic usable reactive output that a generating unit is capable of delivering to the PJM Interconnection and sustaining over the steady state operating range of the unit
- Planned modifications (tap changer adjustment, GSU replacements, turbine modification, etc) that impact generator reactive capability should be communicated to the impacted TO and PJM as far in advance as possible but no later than the return of the unit from the outage

What Reactive Reserve information is reported?

- MOC's/GOs must also review and confirm their unit reactive capability data via eDART on a bi-annual basis
  - Pre-Summer Review: From April 1 through April 30
  - Pre-Winter Review: From October 1 through October 31
- PJM and the TOs will then verify accuracy of unit reactive capabilities modeled in their respective EMS systems

What Reactive Reserve information is reported?

- Whenever a unit's Automatic Voltage Regulation (AVR) or Pwer System Stabilizer (PSS) status is off (or is planned to be off) longer than 30 minutes, the MOC/GO must immediately enter a ticket via eDART
  - This requirement is exempted when the Unit starting up and shutting down
- For real-time changes, the generator's owner/operator must also notify the PJM Power Dispatcher (PD) and the respective TO by phone
  - PJM and the TO will change the status in their EMS systems

What Reactive Reserve information is reported?

- Upon the request of PJM, all TOs will provide a Reactive Reserve Check (RRC) report to PJM
  - PJM generally requests a RRC during capacity deficient conditions or when a Heavy Load Voltage Schedule Warning is implemented
  - RRCs are also done periodically for testing purposes
- TOs must report MVAR reserve for all units connected to their system
  - MVAR Reserve is the difference between the present operating points, leading or lagging, and the actual lagging MVAR capability

What Reactive Reserve information is reported?

- MOCs/GOs must report to the TO any limitation or restriction on their unit which would prevent it from being able to follow it's reactive capability curve as recorded in eDART
  - Unless an eDART ticket already exists documenting the condition
- This ensures the TO is submitting accurate information for the RRC

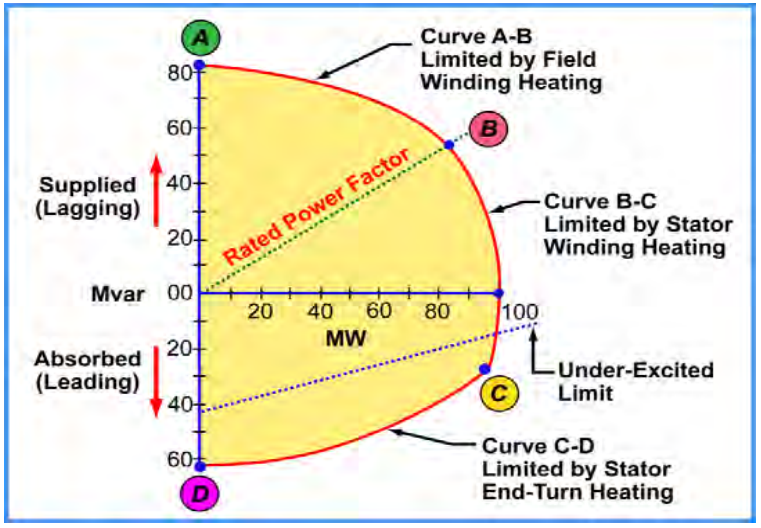
Reactive Capability/D-Curve

Reactive Capability Curve

- Generating Unit Reactive Capability is a measurement of the reactive power able to be delivered by a generating unit to the transmission system
- It is defined by the MW versus MVAR points of a generator capability curve
- For real-time changes, each Generation Owner should also notify PJM and the respective Transmission Owners via phone

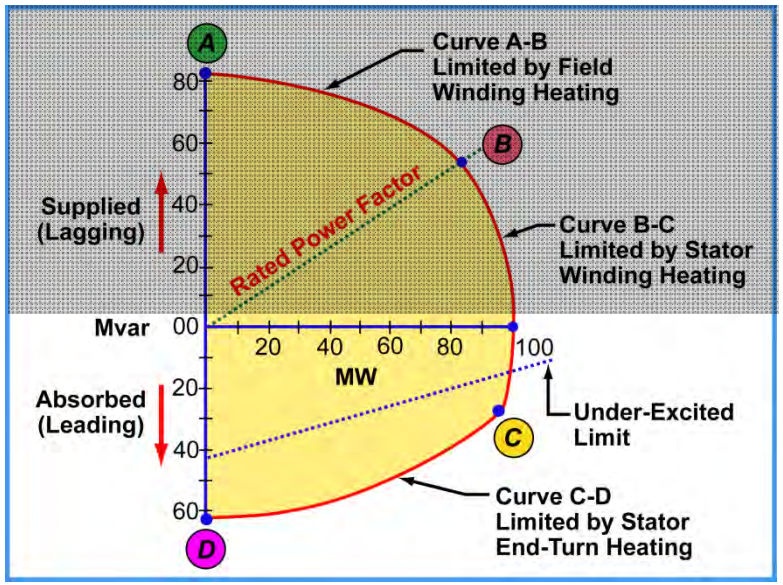
Reactive Capability Curve

- Reactive Capability (or “D”) Curves
  - Generators Report "Continuous Unit Reactive Capability Curve"
    - Realistic usable capability sustainable during continuous unit operation
    - Should be based on actual operating experience (or testing)
    - Takes into consideration any normal unit or plant restrictions at 95˚ F ambient or above



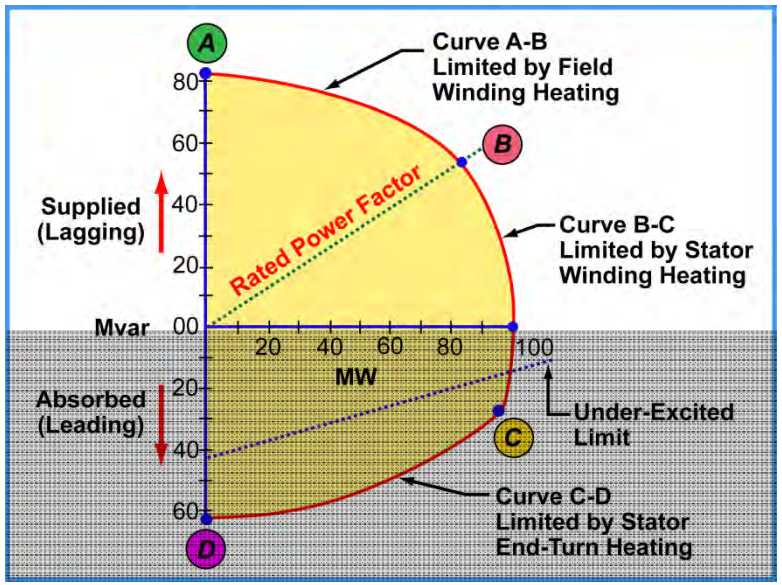
Reactive Capability Curve

- Generating Unit
  - Unit Over-excitation
    - Limit on field heating, limits MVAR generation
    - Rotor overheating is I^2R heating caused by DC current overexcitation



Reactive Capability Curve

- Generating Unit
  - Unit Under-excitation
    - Limit on end turn heating
    - Unit instability
      - Field strength too weak, unit goes unstable
      - Area Stability concerns
        - Salem
        - PS South

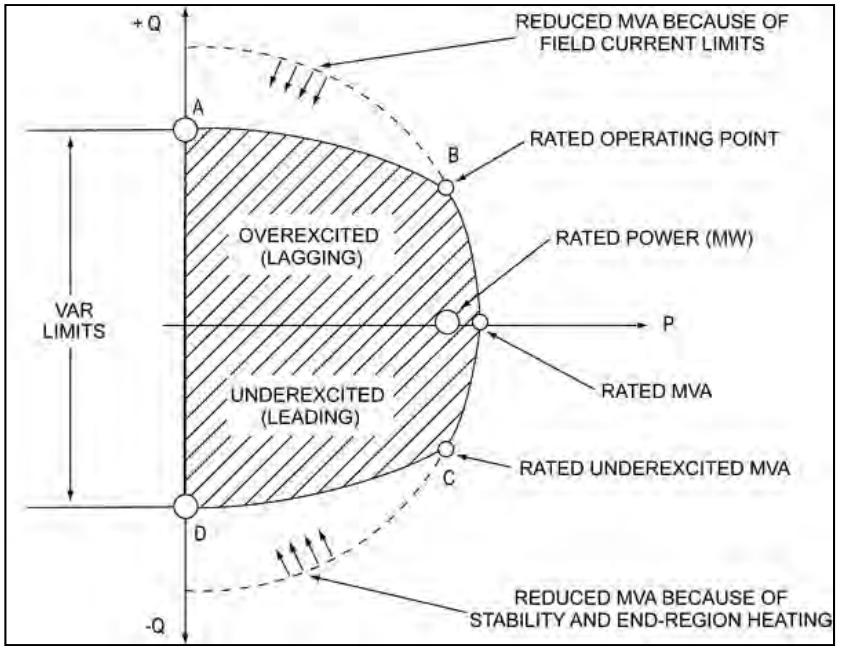


Reactive Capability Curve

- To help maintain a reliable transmission system, each Generation Owner/Operator must provide initial or updated capability curve information to PJM via eDART as soon as the information is available
  - The Transmission Owner for the Transmission Zone where the unit is located will be automatically notified via eDART, as well as any other Transmission Owners with eDART authority to receive automatic notification for the unit

Reactive Capability Limitations

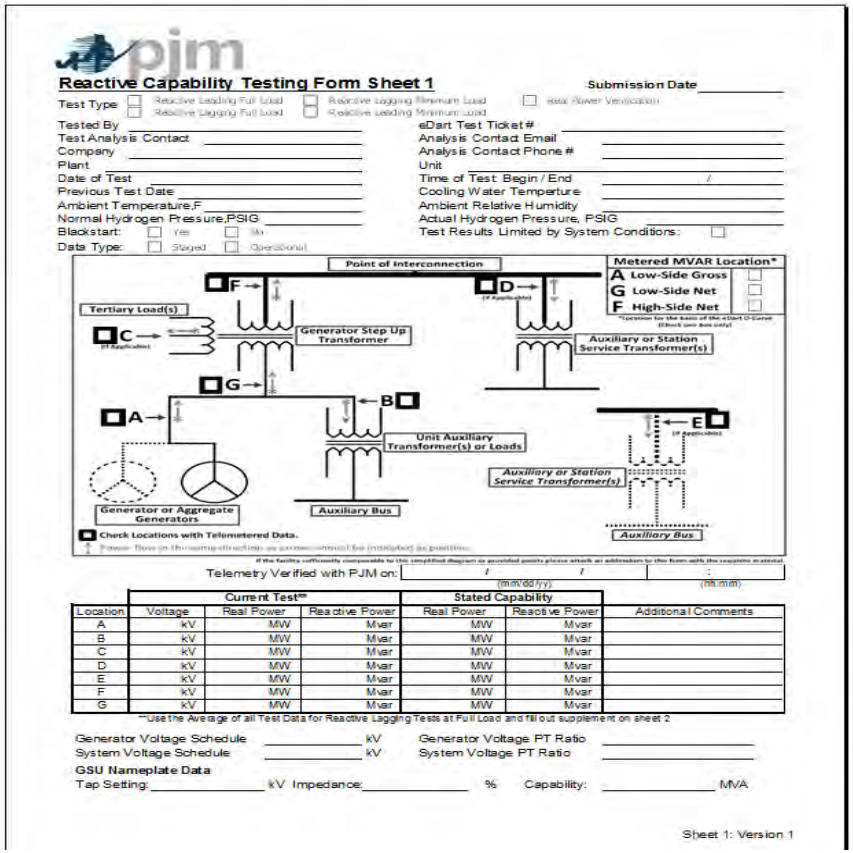
- Generating Unit
  - MVAR output limited by D-curve
  - Voltage regulator limits
    - Voltage regulator operates only within designed voltage limits
    - Designed to limit amount of MVARs that can be generated
  - Power factor limits
    - Units are limited to operating within certain pf limits
  - MW tradeoff
    - Above certain MVAR output, MW must be traded to get additional MVAR output



Restrictions and Limitations

- Affects on the surrounding Power System:
  - Must coordinate shifts in generation to obtain desired MVAR flows and voltage adjustments
  - Should coordinate generation voltage adjustments with switchable sources (capacitors and reactors)
  - Do not remove all VAR reserve from a generating unit

Reactive Capability Test Form



Reactive Capability Testing Form Sheet 1

Submission Date _____

Test Type ☐ Reactive Leading Full Load ☐ Reactive Lagging Minimum Load ☐ Real Power Verification
☐ Reactive Lagging Full Load ☐ Reactive Leading Minimum Load

Tested By _____ eDart Test Ticket # _____
Test Analysis Contact _____ Analysis Contact Email _____
Company _____ Analysis Contact Phone # _____
Plant _____ Unit _____
Date of Test _____ Time of Test: Begin / End _____ / _____
Previous Test Date _____ Cooling Water Temperture _____
Ambient Temperature,F _____ Ambient Relative Humidity _____
Normal Hydrogen Pressure,PSIG _____ Actual Hydrogen Pressure, PSIG _____
Blackstart: ☐ Yes ☐ No Test Results Limited by System Conditions: ☐
Data Type: ☐ Staged ☐ Operational

Telemetry Verified with PJM on: ___/___/___ (mm/dd/yy) ___:___ (hh:mm)

	Current Test**			Stated Capability		
Location	Voltage	Real Power	Reactive Power	Real Power	Reactive Power	Additional Comments
A	kV	MW	Mvar	MW	Mvar	
B	kV	MW	Mvar	MW	Mvar	
C	kV	MW	Mvar	MW	Mvar	
D	kV	MW	Mvar	MW	Mvar	
E	kV	MW	Mvar	MW	Mvar	
F	kV	MW	Mvar	MW	Mvar	
G	kV	MW	Mvar	MW	Mvar	

**Use the Average of all Test Data for Reactive Lagging Tests at Full Load and fill out supplement on sheet 2

Generator Voltage Schedule _____ kV Generator Voltage PT Ratio _____
System Voltage Schedule _____ kV System Voltage PT Ratio _____

GSU Nameplate Data
Tap Setting: _____ kV Impedance: _____ % Capability: _____ MVA

Sheet 1: Version 1

Reporting Reactive Capability Data to PJM

- The following data for each point on the curve must be specified:
  - "Unit Net MW Output" provided to the system, as measured at the low-side of the unit step-up transformer, excluding any station service load fed of the unit terminal bus, consistent with the PJM EMS model
  - Leading or lagging "Unit Minimum Net MVAR Limit" at the specified "Unit Net MW Output", consistent with the PJM EMS model
  - Leading or lagging "Unit Maximum Net MVAR Limit" at the specified "Unit Net MW Output", consistent with the PJM EMS model

Reporting Reactive Capability Data to PJM

- The “Unit Minimum and Maximum Net MVAR Limits” must indicate the realistic, usable capability that is sustainable during continuous long-term unit operation
  - This sustainable continuous capability is based on actual operating experience (or testing) and takes into consideration any normal unit or plant restrictions at 95 degrees Fahrenheit ambient or above
- A sufficient number of curve points must be provided to accurately model the full operating range and capability of the unit as described above

Reporting Reactive Capability Data to PJM

1. A minimum of two curve points must be provided
2. A maximum of eight curve points may be provided
3. The “Unit Maximum Net MVAR Limit” must be greater than (or equal to) the “Unit Minimum Net MVAR Limit” for each curve point
4. The “Unit Minimum Net MVAR Limit” may be equal for any number of adjacent curve points
5. The “Unit Maximum Net MVAR Limit” may be equal for any number of adjacent curve points
6. The “Unit Net MW Output” must be increasing from the first to the last point
7. Company can either test or apply the best engineering judgment to construct D-curve at min load points

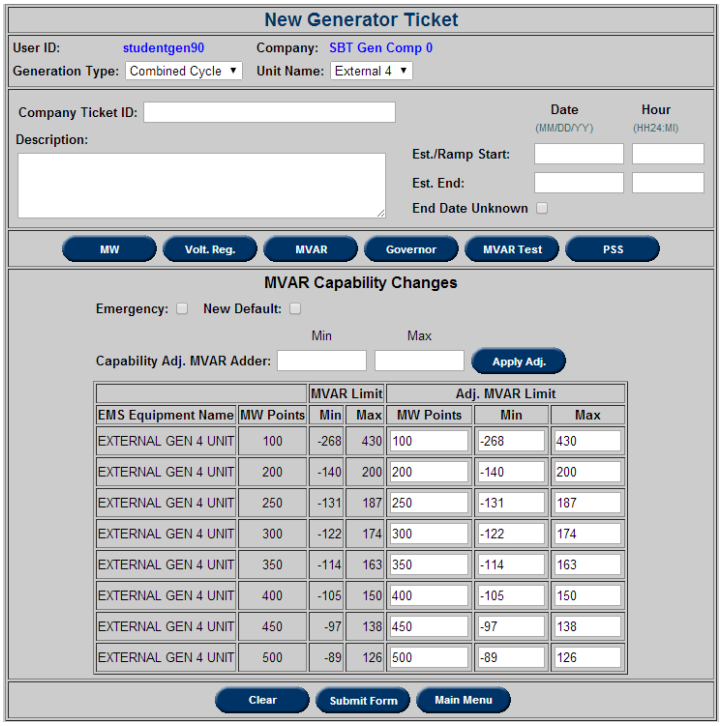
Reporting Reactive Capability Data to PJM

- Data should be provided to PJM in the format shown in the exhibit below via eDART

	MW	Minimum MVAR	Maximum MVAR
Point 1			
Point 2			
Point 3			
Point 4			
Point 5			
Point 6			
Point 7			
Point 8			

*Note that if a unit's current default curve in eDART has less than eight points, a revised curve with more points can be entered in the eDART "Description" field

Reporting Reactive Capability Data to PJM



Reporting Reactive Capability Changes to PJM

For ***Permanent*** Changes

1. Each Generation Owner/Operator must continually provide accurate permanent capability curve changes to PJM via eDART ***as soon as the information is available***. The "New Default" field should be checked in eDART

2. Once the accuracy of the submitted reactive capability curve is verified, PJM will permanently update the PJM Unit Reactive Capability Curves in use by PJM Operating/Planning Studies and PJM EMS Network Applications programs

Reporting Reactive Capability Changes to PJM

For ***Temporary*** Changes

1. Whenever a PJM unit's reactive capability is limited or reduced (or is planned to be limited or reduced) for any reason, the generator's owner/operator must ***immediately enter a temporary ticket via eDART***. For real-time changes, the generator's owner/operator must also notify the PJM Power Dispatcher (PD) and respective LCC by phone

2. The PJM PD will receive the ticket and either temporarily update the unit's reactive capability curve in use by the PJM EMS Network Applications, or will temporarily set the unit's AVR status in use by the PJM EMS Network Applications to "OFF" for the specified time period

Reporting Reactive Capability Changes to PJM

For ***Temporary*** Changes (cont.)

3. The generator's owner/operator must immediately modify the eDART ticket and notify the PJM PD and respective LCC by phone whenever the unit's normal reactive capability is (or is anticipated to be) restored

4. The PJM PD will either restore the unit's normal reactive capability curve in use by the PJM EMS Network Applications. The PJM PD will then close the unit reactive ticket

Summary

- Explained why PJM monitors reactive reserves
- Identified what reactive reserve information has to be reported to PJM&TOs
- Explained the derivation and use of a generator D-curve
- Described how to provide D-curve data to PJM & TO
- Explained timelines for entering/validating D-curve data

Questions?

Resources and References

- PJM. (2014). PJM Manual 14-D: Generation Operational Requirements (rev. 30). Retrieved from http://www.pjm.com/~/media/documents/manuals/M14D.ashx

CERTIFICATE OF SERVICE

I hereby certify that I have this day served the foregoing document upon each person designated on the official service list compiled by the Secretary in this proceeding.

Dated at Eagleville, Pennsylvania,
this 29th day of July, 2016.

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