



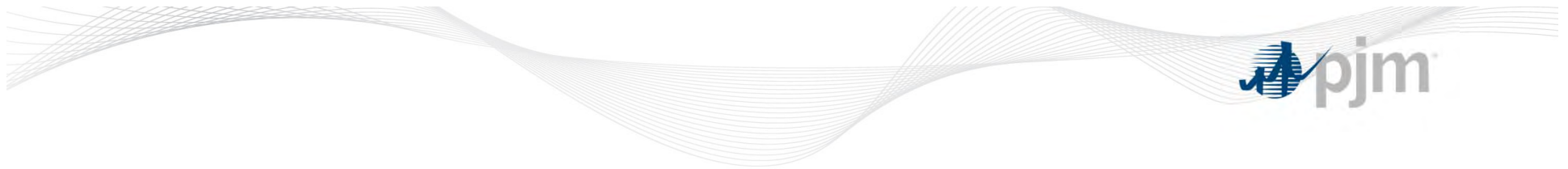
# Reactive Reserves and Generator D-Curves

PJM State & Member Training Dept.



## Objectives

- Identify the process for monitoring and maintaining reactive reserves



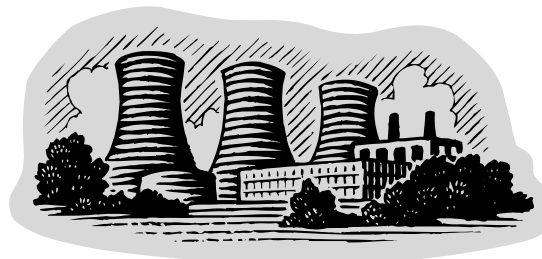
# Reactive Reserves

## 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

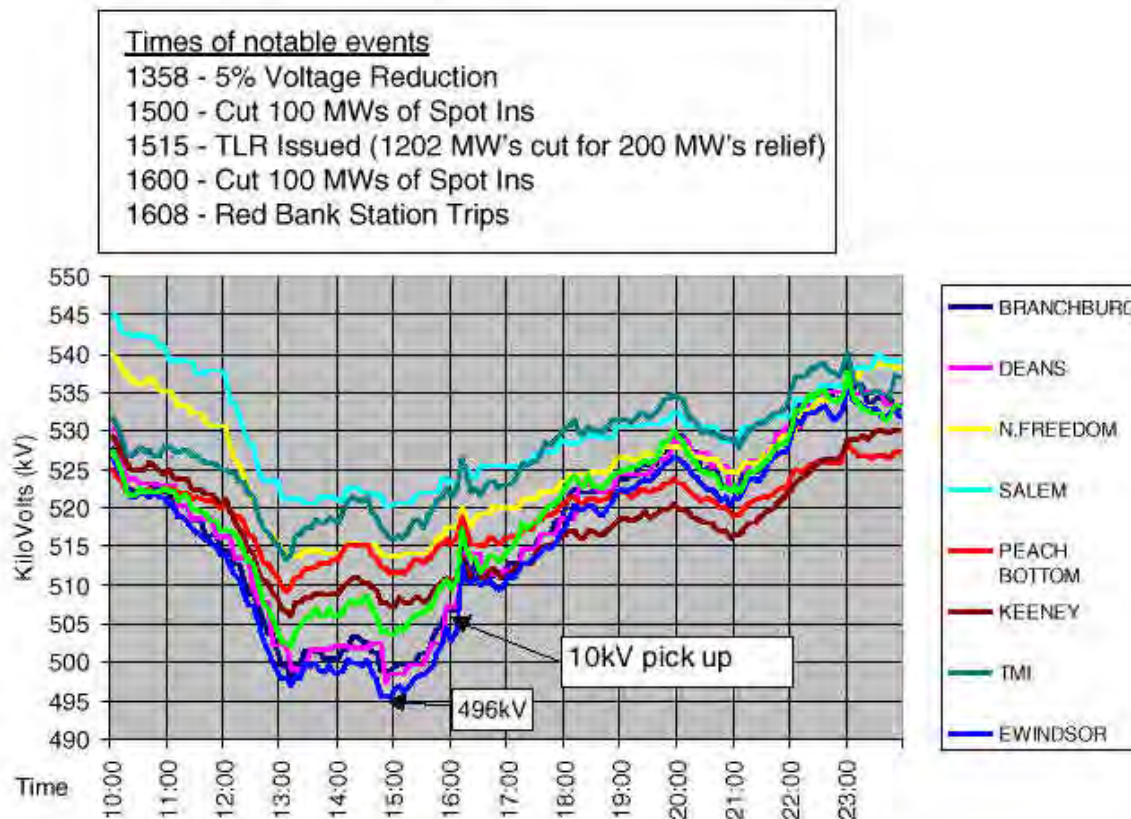


## 1999 Low Voltage Event in PJM....

- 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?

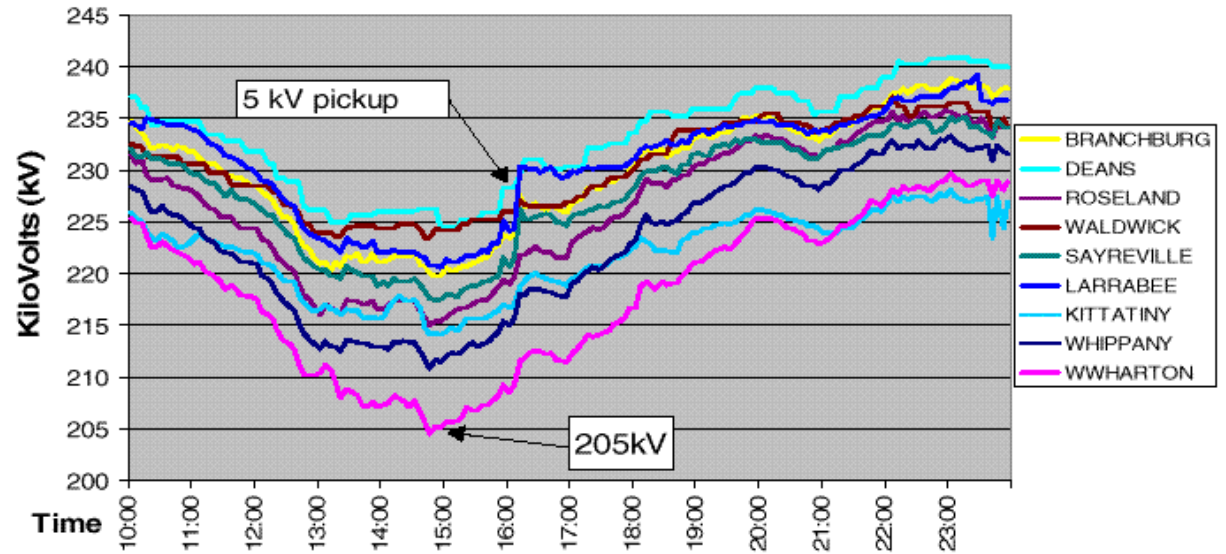
- PJM Voltages – July 6, 1999



# Why Monitor Reactive Power Reserves?

- PJM Voltages – July 6, 1999

Times of notable events  
1358 - 5% Voltage Reduction  
1500 - Cut 100 MWs of Spot Ins  
1515 - TLR Issued (1202 MW's cut for 200 MW's relief)  
1600 - Cut 100 MWs of Spot Ins  
1608 - Red Bank Station Trips



## 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 19<sup>th</sup>
  - 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 6<sup>th</sup> and July 19<sup>th</sup> 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 Power 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

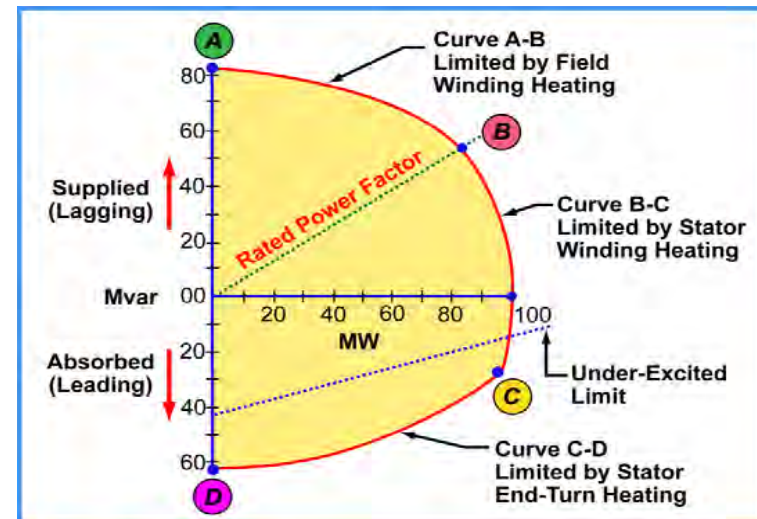
## Reactive Capability Curve

- 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



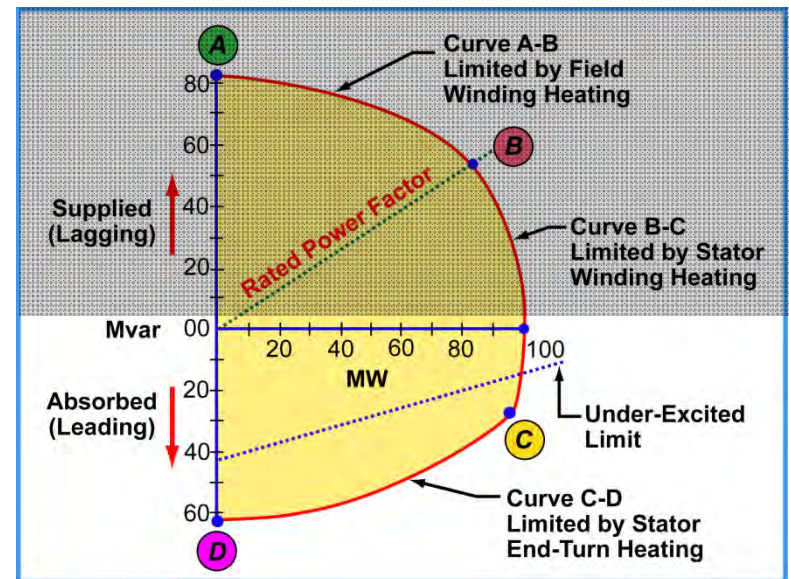
# Reactive Capability Curve

- 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



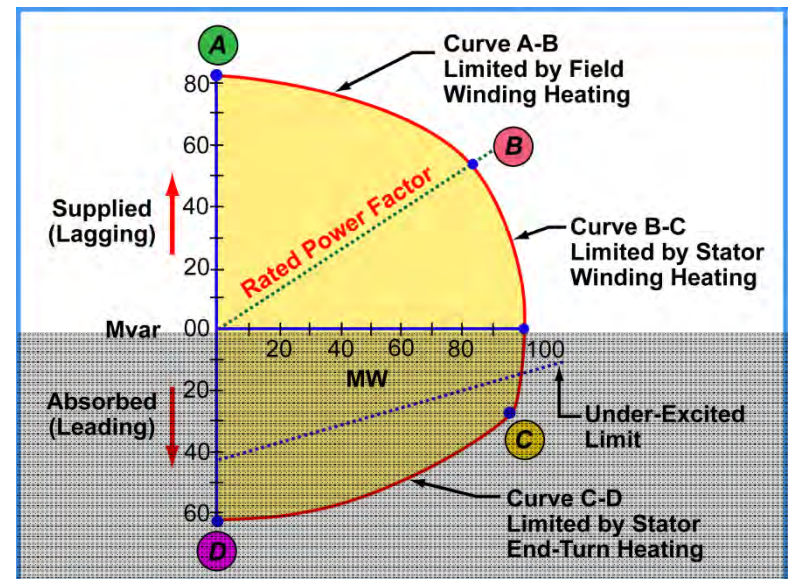
# Reactive Capability Curve

- 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

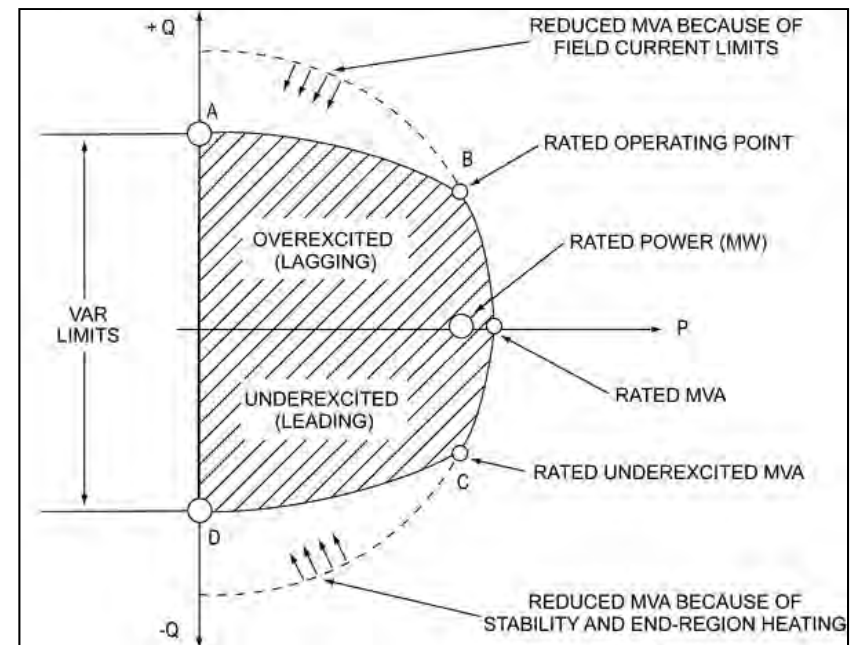


## Reactive Capability Curve

- 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**

Test Type:  Reactive Loading Full Load  Reactive Loading Minimum Load  Star Power Measurement

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 Temperature: \_\_\_\_\_

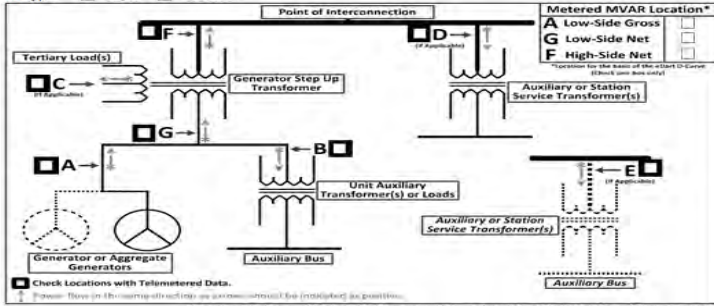
Ambient Temperature, F: \_\_\_\_\_ Ambient Relative Humidity: \_\_\_\_\_

Normal Hydrogen Pressure, PSIG: \_\_\_\_\_ Actual Hydrogen Pressure, PSIG: \_\_\_\_\_

Blackstart:  Yes  No  N/A Test Results Limited by System Conditions:

Data Type:  Steady  Operational

Submission Date: \_\_\_\_\_



Check Locations with Telemetered Data.

Notes: None in this category or refer to the measurement file (available) in 2015/15/15.

Telemetry Verified with PJM on: \_\_\_\_\_ (MM/DD/YY) \_\_\_\_\_ (MM/DD/YY)

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

\*\*Use the Average of all Test Data for Reactive Loading 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

## 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

**New Generator Ticket**

User ID: studentgen90    Company: SBT Gen Comp 0

Generation Type: Combined Cycle    Unit Name: External 4

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Company Ticket ID:

Date (MM/DD/YYYY)    Hour (HH:MM)

Description:

Est./Ramp Start:    

Est. End:    

End Date Unknown

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MW
Volt. Reg.
MVAR
Governor
MVAR Test
PSS

**MVAR Capability Changes**

Emergency:     New Default:

Min                      Max

Capability Adj. MVAR Adder:         Apply Adj.

EMS Equipment Name	MW Points	MVAR Limit		Adj. MVAR Limit		
		Min	Max	MW Points	Min	Max
EXTERNAL GEN 4 UNIT	100	-268	430	<input type="text" value="100"/>	<input type="text" value="-268"/>	<input type="text" value="430"/>
EXTERNAL GEN 4 UNIT	200	-140	200	<input type="text" value="200"/>	<input type="text" value="-140"/>	<input type="text" value="200"/>
EXTERNAL GEN 4 UNIT	250	-131	187	<input type="text" value="250"/>	<input type="text" value="-131"/>	<input type="text" value="187"/>
EXTERNAL GEN 4 UNIT	300	-122	174	<input type="text" value="300"/>	<input type="text" value="-122"/>	<input type="text" value="174"/>
EXTERNAL GEN 4 UNIT	350	-114	163	<input type="text" value="350"/>	<input type="text" value="-114"/>	<input type="text" value="163"/>
EXTERNAL GEN 4 UNIT	400	-105	150	<input type="text" value="400"/>	<input type="text" value="-105"/>	<input type="text" value="150"/>
EXTERNAL GEN 4 UNIT	450	-97	138	<input type="text" value="450"/>	<input type="text" value="-97"/>	<input type="text" value="138"/>
EXTERNAL GEN 4 UNIT	500	-89	126	<input type="text" value="500"/>	<input type="text" value="-89"/>	<input type="text" value="126"/>

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Clear
Submit Form
Main Menu

# 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>