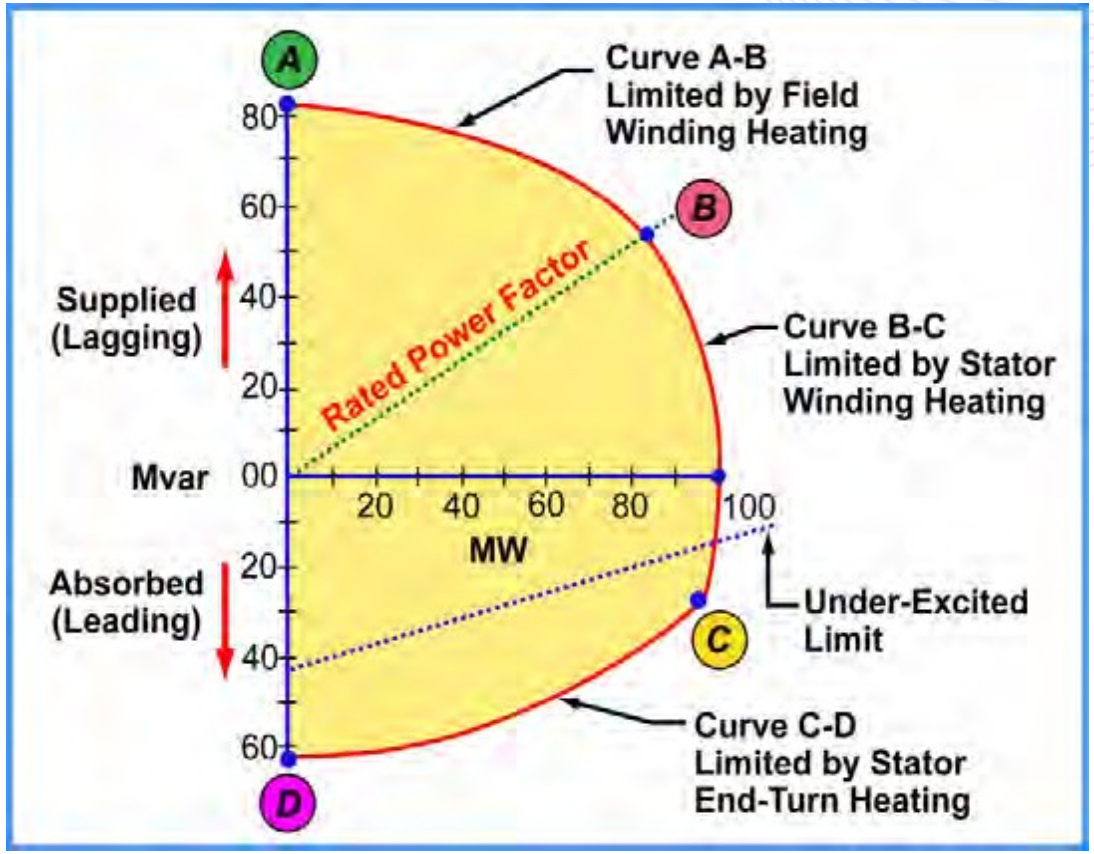
Operational Requirements for Reactive Power

Darrell Frogg
Generation Department
Reactive Power Compensation Task Force
November 5, 2021

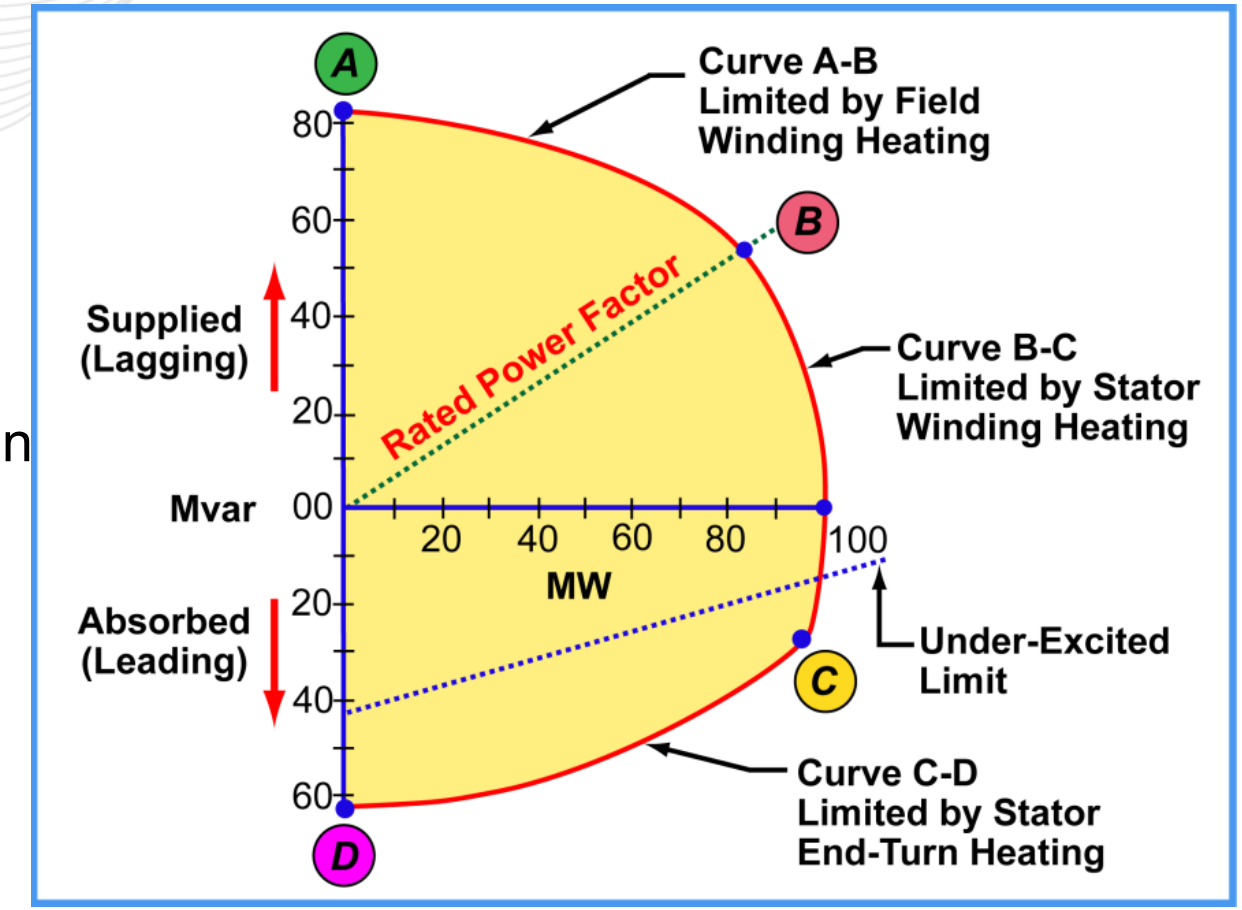
What is Reactive Capability Curve?



- Measurement of the generator reactive power capability
- Defined by the MW versus MVAR points
- Lagging – Providing MVARs to the system
- Leading – Absorbing MVARs from the system

Restrictions and Limitations

- Limitations causing “D” shape
  - Unit Over-excitation
    - Limit on field heating, limits MVAR generation
    - Rotor overheating is I2R heating caused by DC current over-excitation
  - Unit Under-excitation
    - Limit on end turn heating
    - Unit instability
      - Field strength too weak, unit goes unstable



Voltage Control Background

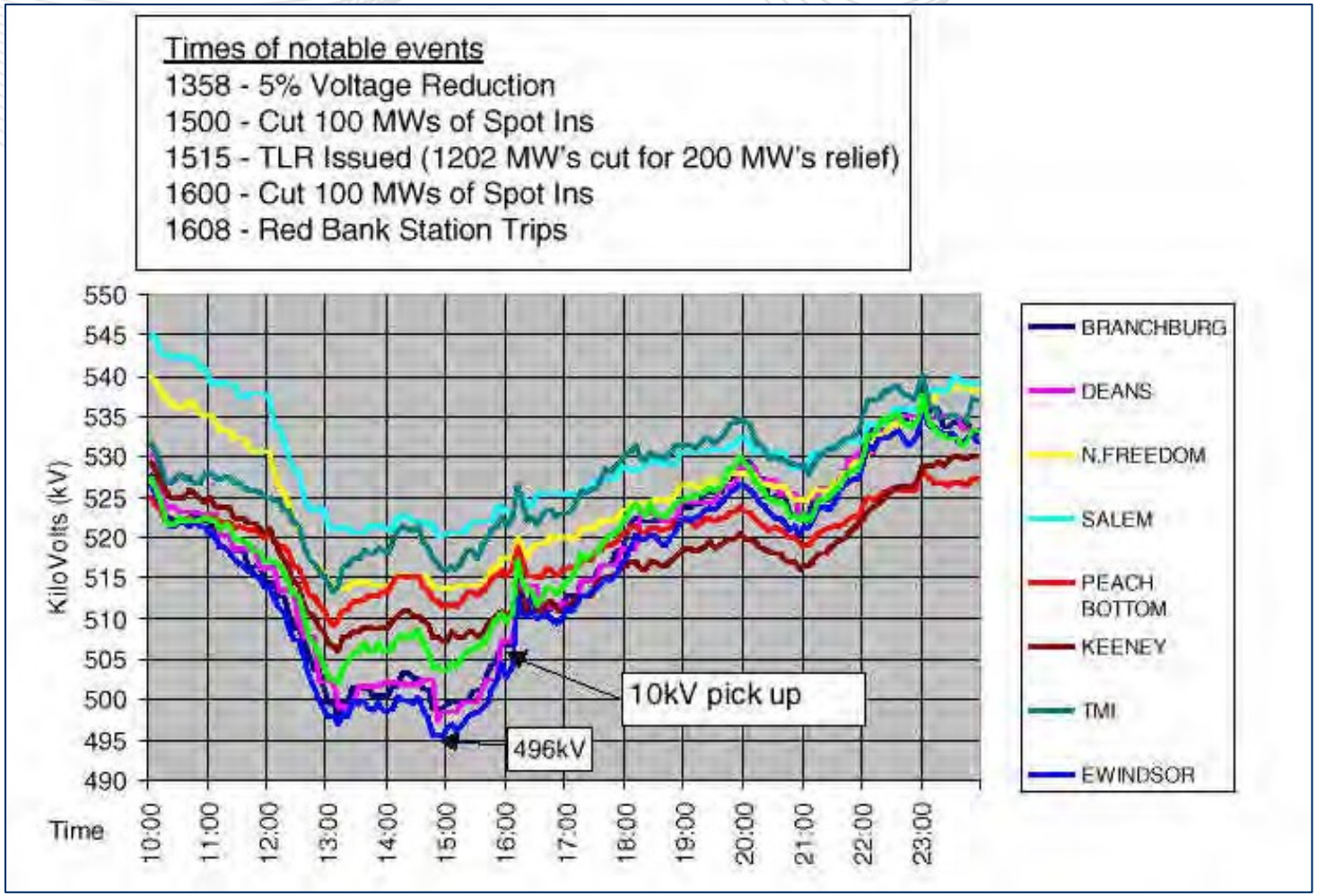
- Generators are a Major Source of MVARs
  - VAR supply controlled by field excitation
  - VARs don't travel well
    - Use units electrically close to the voltage problem
- Response to Generator Excitation Changes
  - Voltage at output of generator controlled by voltage regulator
    - Normally on automatic control (NERC Standard VAR-002-4.1)
      - If Automatic Voltage Regulator is out of service, eDART ticket is required
      - Reporting of Reactive Capability changes via eDART is also related to this standard

Why is D-curve Important?

- Voltage limits are established on the BES to maintain system reliability
- As conditions change, it is important to have a source of reactive power (MVAR) reserves available to maintain voltages within their limits
- Reactive power provided by generating units is a major source of voltage support on the PJM system
- PJM must have data that reflects the true amount of MVAR reserves that are on the system
  - What each unit can *actually* provide vs. theoretical capability

1999 Low Voltage Event in PJM

- Hot, humid, high load day
- PJM at that time had only nameplate D-curve data for capabilities
- Many units had internal or external limitations that prevented the units from providing expected MVAR support



1999 Low Voltage Event in PJM

Root cause investigation indicated PJM narrowly avoided a voltage collapse

If PJM had known reserves available were not realistic, other actions could have been take to stabilize the system

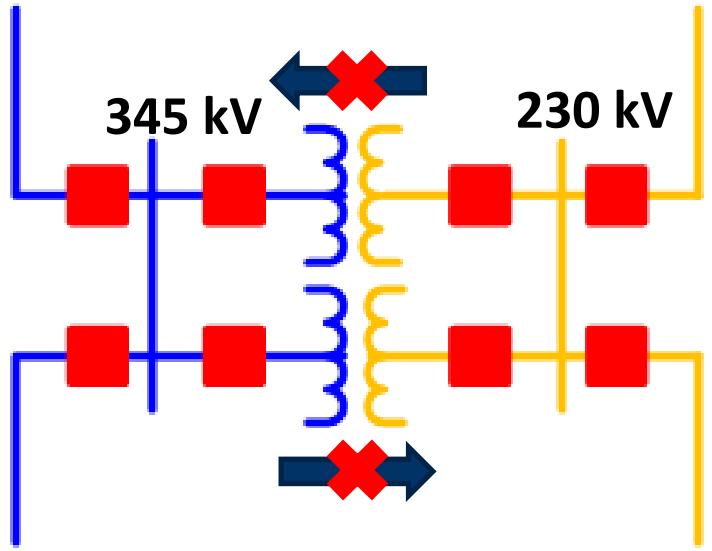
By monitoring MVAR reserves, PJM can develop action plans to maintain or correct system voltages and ensure voltage stability

Lessons Learned

- Reactive Power Testing and Notification Requirements
  - NERC added MOD-025
  - PJM added detailed guidance in Manual 14D

Coordination with Transmission Equipment

- Should coordinate generation voltage adjustments with switchable sources (capacitors, reactors, manual load tap changers, and line switching)
  - Do not remove all VAR reserve from a generating unit
- Use voltage schedule to determine need to change voltage
- Coordinate tap changes
  - Transformers in parallel must be balanced to prevent unwanted VAR flows



Coordination of Generators

Coordinate shifts of multiple units together

Otherwise, voltage regulators of other units may increase or decrease excitation to compensate for desired change

- Results in unwanted VAR flow

Result of not adjusting all units

- Voltage does not change as planned
- Units may shift to absorbing VARs
- Units may become under or over-excited

Typical Reactive Power Detractors

MVAR output limited by D-curve

May be limited by auxiliary bus voltage limits

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

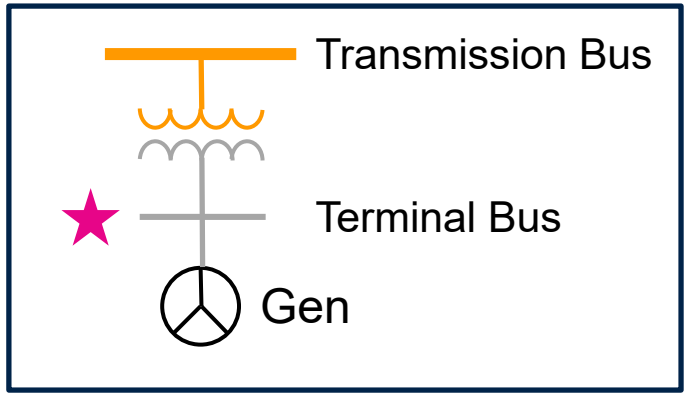
MW tradeoff

- Above certain MVAR output, MW must be traded to get additional MVAR output

Transmission Level Voltage Regulation

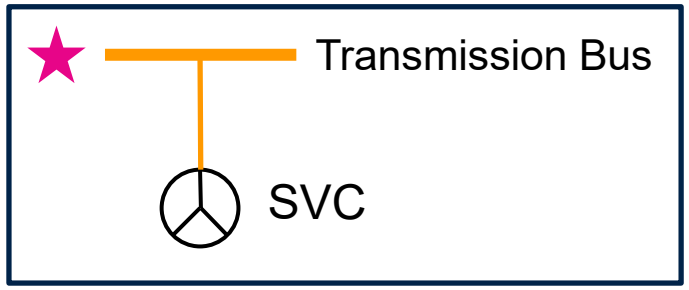
Indirect Voltage Regulation Devices

- Generators, Synchronous Condensers
- Modeled with GSU
- Regulation of local terminal bus



Direct Voltage Regulation Devices

- SVCs, STATCOMs
- Step-up transformer not modeled
- Direct regulation of transmission bus



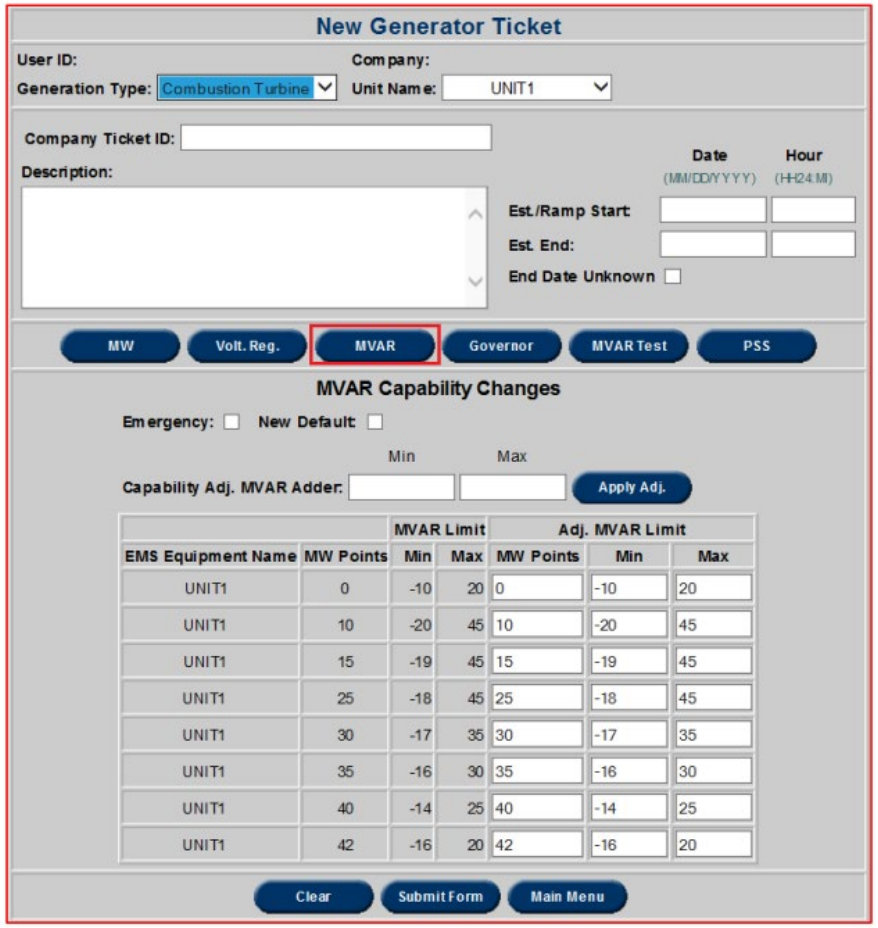
Reactive Testing

Roger Cao
PJM Performance Compliance Department
RPCTF
November 5, 2021

Reactive Capability and Testing Requirements

- NERC added MOD-025
  - Generators test at least once every 5 years
  - Submit test results to transmission planner
- PJM added detailed guidance in Manual 14D
  - MOC/GO must provide reactive capability curve information to PJM via eDART MVAR ticket
  - MOC/GO must review/confirm their unit reactive capability data on a bi-annual basis (April/October)
  - Generators must perform reactive capability test at least once every 5 years and adjust the D-curves if suggested by test results.

Manual 14D Attachment D: D-Curve Reporting



- 8-point curve submitted in eDART as MVAR Ticket, consistent with the PJM EMS model
- Realistic, usable capability that is sustainable during continuous long-term unit operation
- Based on actual operating experience or testing
- Take into consideration any normal unit or plant restrictions at 95 degrees Fahrenheit ambient or above

Example:

	MW Points	Minimum MVAR	Maximum MVAR	
Point 1	50	-80	250	EcoMin
Point 2	100	-75	240	
Point 3	150	-70	230	
Point 4	200	-65	220	
Point 5	250	-60	210	
Point 6	300	-55	200	
Point 7	350	-50	190	EcoMax
Point 8	400	-45	180	Maximum Possible

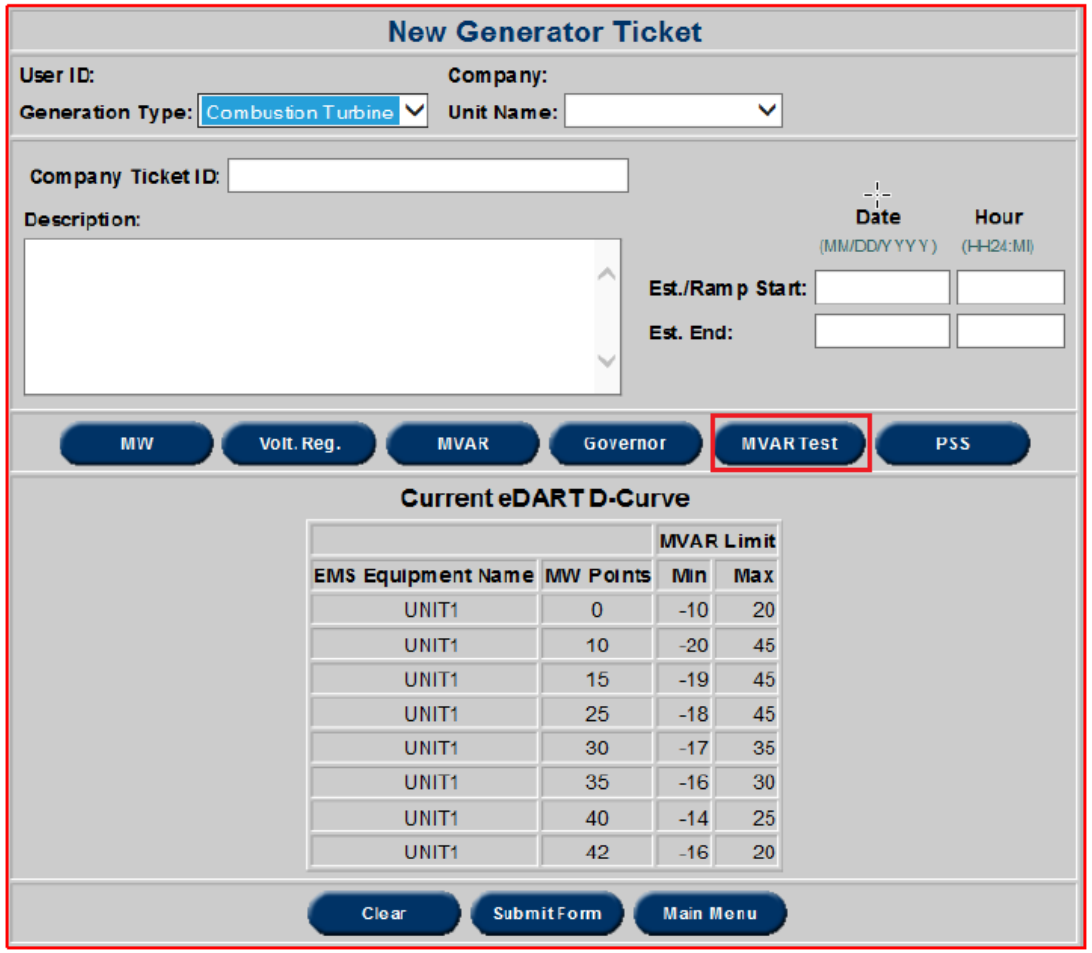
Manual 14D Attachment E: Reactive Testing

- Objective: demonstrate unit's reactive capability
  - Whether D-curve adjustment needed
- Applicable facilities:
  - Individual unit > 20 MVA directly connected to BES
  - Aggregated units > 75 MVA directly connected to BES
  - All Black Start Service resources
- Testing Frequency: Required to test approximately 20% of their applicable facilities annually, totaling 100% of their applicable facilities over a 66 month period. More frequent testing may be done if the owner so chooses.

Testing Requirements Summary

UNIT TYPE	MW Output	MVAR OUTPUT	TEST DURATION
Fossil, Hydro, Blank Start	MAX MAX MIN MIN	MAX LAG MAX LEAD MAX LAG MAX LEAD	ONE HOUR WHEN LIMIT REACHED WHEN LIMIT REACHED WHEN LIMIT REACHED
Sync Cond	- -	MAX LAG MAX LEAD	ONE HOUR WHEN LIMIT REACHED
Nuclear	MAX MAX	MAX LAG MAX LEAD	ONE HOUR WHEN LIMIT REACHED
Variable (Wind and Solar) (Testing done with at least 90% of turbines or inverters on line)	VARIABLE VARIABLE	MAX LAG MAX LEAD	WHEN LIMIT REACHED WHEN LIMIT REACHED
Inverter-Based ESR Max MW Output = fully discharging Min MW Output = fully charging	MAX MAX ZERO ZERO MIN MIN	MAX LAG MAX LEAD MAX LAG MAX LEAD MAX LAG MAX LEAD	WHEN LIMIT REACHED WHEN LIMIT REACHED WHEN LIMIT REACHED WHEN LIMIT REACHED WHEN LIMIT REACHED WHEN LIMIT REACHED

Pre-testing: MVAR Test Ticket



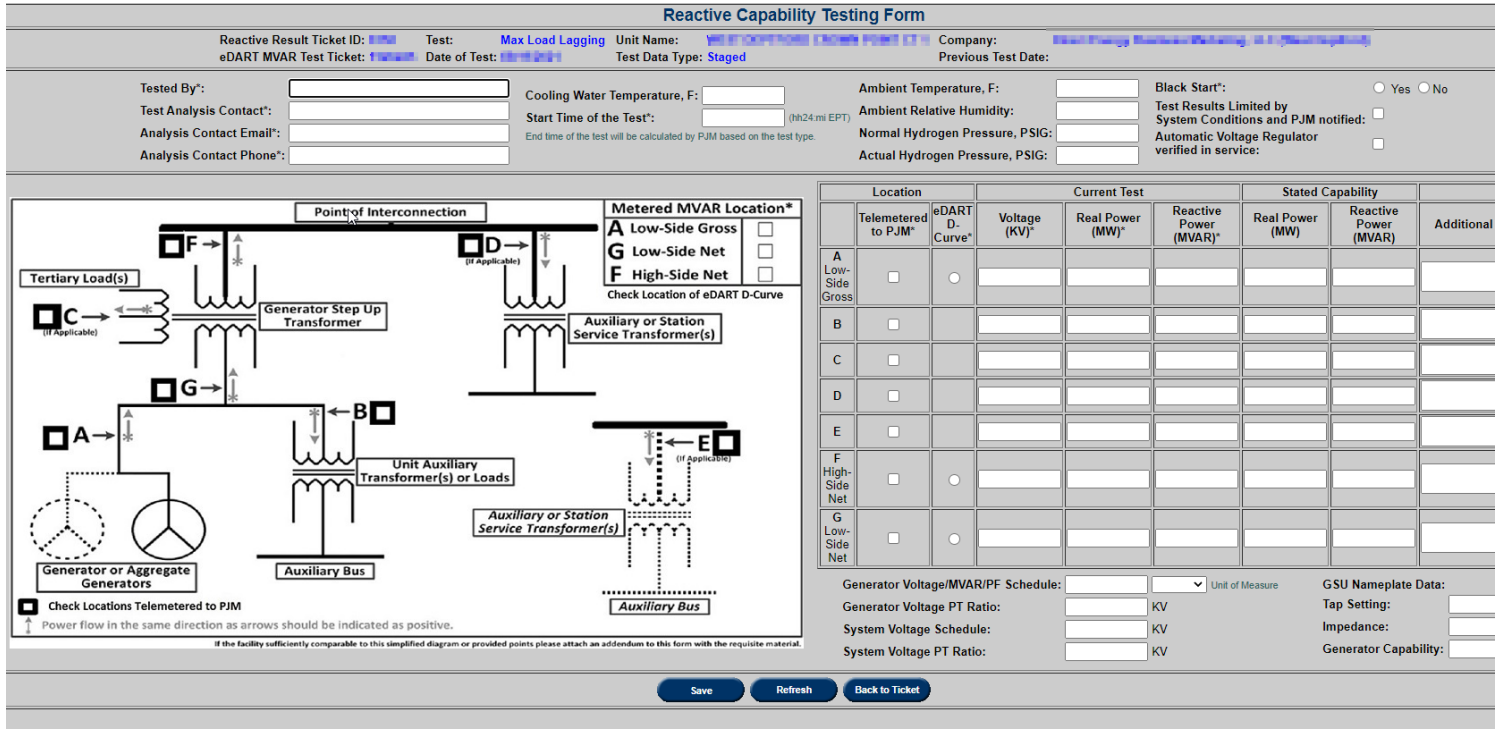
- Submit at least 3 days in advance with date/time and test type (max load lag, max load lead, min load lag, min load lead) with desired MVAR output
- Verify telemetry with PJM and Obtain PJM approval
- During the testing: Coordinate with TO and PJM if internal or external limitations occurred

During the testing

- Communicate to TO and PJM if experiencing external limitations or internal limitation caused by external condition prior to completing the test
- The TO and PJM shall work together and attempt to mitigate the external limitation or condition if confirmed.
- If the mitigation is unsuccessful, no further actions will be required of the GO/MO, PJM will log the external limitation or condition on the MVAR Test ticket

Post-testing: Reactive Result Ticket

- Submit within 30 days from the testing in eDART
- Review analysis files and update D-curve if needed (MVAR ticket)
- Download and Review test letters



Reactive Capability Testing Form

Reactive Result Ticket ID: [redacted] Test: Max Load Lagging Unit Name: [redacted] Company: [redacted]
eDART MVAR Test Ticket: [redacted] Date of Test: [redacted] Test Data Type: Staged Previous Test Date:

Tested By*:
Test Analysis Contact*:
Analysis Contact Email*:
Analysis Contact Phone*:

Cooling Water Temperature, F:
Start Time of the Test*: (hh24:mi EPT)
End time of the test will be calculated by PJM based on the test type.

Ambient Temperature, F:
Ambient Relative Humidity:
Normal Hydrogen Pressure, PSIG:
Actual Hydrogen Pressure, PSIG:

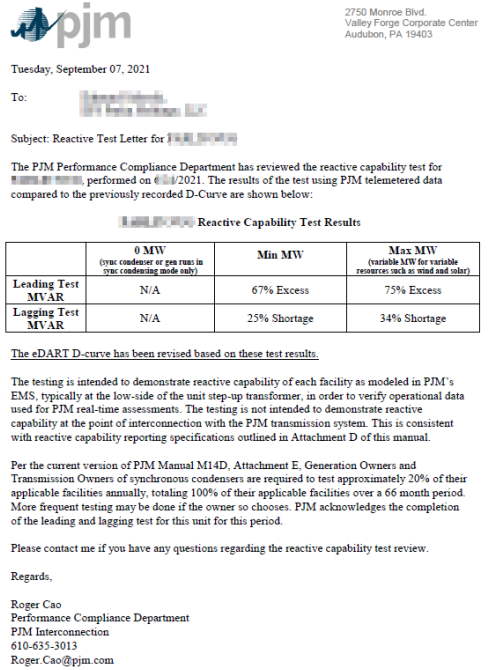
Black Start*: Yes No
Test Results Limited by System Conditions and PJM notified:
Automatic Voltage Regulator verified in service:

	Location		Current Test			Stated Capability		
	Telemetered to PJM*	eDART D-Curve*	Voltage (KV)*	Real Power (MW)*	Reactive Power (MVAR)*	Real Power (MW)	Reactive Power (MVAR)	Additional
A Low-Side Gross								
B								
C								
D								
E								
F High-Side Net								
G Low-Side Net								

Generator Voltage/MVAR/PF Schedule: Unit of Measure
Generator Voltage PT Ratio: KV
System Voltage Schedule: KV
System Voltage PT Ratio: KV

GSU Nameplate Data:
Tap Setting:
Impedance:
Generator Capability:

Save Refresh Back to Ticket



pjm
2750 Monroe Blvd.
Valley Forge Corporate Center
Audubon, PA 19403

Tuesday, September 07, 2021

To: [redacted]

Subject: Reactive Test Letter for [redacted]

The PJM Performance Compliance Department has reviewed the reactive capability test for [redacted], performed on [redacted]/2021. The results of the test using PJM telemetered data compared to the previously recorded D-Curve are shown below:

[redacted] Reactive Capability Test Results

	0 MW (sync condenser or gen runs in sync condensing mode only)	Min MW	Max MW (variable MW for variable resources such as wind and solar)
Leading Test MVAR	N/A	67% Excess	75% Excess
Lagging Test MVAR	N/A	25% Shortage	34% Shortage

The eDART D-curve has been revised based on these test results.

The testing is intended to demonstrate reactive capability of each facility as modeled in PJM's EMS, typically at the low-side of the unit step-up transformer, in order to verify operational data used for PJM real-time assessments. The testing is not intended to demonstrate reactive capability at the point of interconnection with the PJM transmission system. This is consistent with reactive capability reporting specifications outlined in Attachment D of this manual.

Per the current version of PJM Manual M14D, Attachment E, Generation Owners and Transmission Owners of synchronous condensers are required to test approximately 20% of their applicable facilities annually, totaling 100% of their applicable facilities over a 66 month period. More frequent testing may be done if the owner so chooses. PJM acknowledges the completion of the leading and lagging test for this unit for this period.

Please contact me if you have any questions regarding the reactive capability test review.

Regards,

Roger Cao
Performance Compliance Department
PJM Interconnection
610-635-3013
Roger.Cao@pjm.com

Testing Evaluation

Test Type	within 5%	Excess More than 5%	Shortage More than 5%
Max Lagging at Max Output Max Leading at Min Output	None Required	Request New D-curve Reflecting Tested Capability	None Required if an external limitation or an internal operational limit caused by an external condition is confirmed; Otherwise, Request New D-curve Reflecting Tested Capability
Max Leading at Max Output Max Lagging at Min Output	None Required	Request New D-curve Reflecting Tested Capability	Request New D-curve reflecting Expected Operational Capability
Max Lagging at Sync Cond Max Leading at Sync Cond	None Required	Request New D-curve Reflecting Tested Capability	Request New D-curve Reflecting Tested Capability

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Operational Requirements for Reactive Power

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