Objective

The objective of reactive capability testing for generators is to improve the transmission system reliability by accurately determining generator reactive capability on a regular basis. Also, this testing could identify any conditions which are limiting the reactive capability of generating units in PJM. PJM encourages testing to be coordinated between PJM, the Generator Owner, and the local Transmission Owner to ensure that the impact on system operations is minimized. Testing is intended to demonstrate reactive capability for those conditions where reactive reserves would be required.

PJM will evaluate the Generator Reactive Capability Testing requirements contained within this document and may expand testing to various MW output levels if experience indicates it is beneficial to do so.

General Requirements

1. Individual units with a nominal capacity greater than 70 MW, wind generating stations connected at a common bus with an aggregate rating greater than 70 MW, and all black start units will be required to perform a reactive capability test.

2. All other individual units with nominal capacity less than 70 MW and non-black start units will verify the reactive capability reported in the PJM e-DART system on a periodic basis consistent with PJM Manual 14D.

3. Generation Owners are required to test approximately 20% of the number of their eligible assets annually, totaling 100% of their eligible assets over a 5-year period. More frequent testing may be done if the Generator Owner so chooses.

4. The PJM generator reactive capability testing period will begin on May 1 and continue through September 30. This testing cycle will repeat on an annual basis, ensuring that all designated units are tested at least once in a five year cycle.

5. Generator reactive capability testing will take place Monday thru Friday, between 0900 and 1100 hours, Eastern Time.

6. The Generator Owner will determine the best time to conduct these tests. This test may be conducted in conjunction with other testing (including the Net Demonstrated Capability testing), provided all other requirements of this test are met. All equipment will be tested with all auxiliary equipment needed for normal operation in service.

7. As an alternative, data collected during routine operation of the unit is acceptable, provided all test requirements are met.

8. The tests required are functional and do not require special instrumentation. They are designed to demonstrate that the ratings can be obtained for the time periods required under normal operating conditions for the equipment being tested.

9. Projected system conditions must permit the unit to operate at full capacity (or at least 50% of nameplate capacity for wind generating stations) without adversely impacting system operations.
10. PJM will consider other test periods on a case by case basis, so long as proposed testing periods do not adversely impact system operations.

Testing Requirements for **both Non-Wind Units Larger-Greater than 70 MW** and Black Start Units

1. The over-excited (lagging) and under-excited (leading) reactive capability outputs (MVAR) is required to be tested at or near-above demonstrated capability (i.e. a single MW point test).

2. A steady active and reactive power output will be maintained during the test.

3. Exception Criteria: Lagging/Leading tests are required depending on unit type. All exceptions must be documented and reviewed by PJM and Transmission Owners. Test requirements are as follows:

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Required Testing</th>
<th>Exception Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>Lagging Test</td>
<td>Documented Exception to Lagging based on impact to System Reliability</td>
</tr>
<tr>
<td>Black Start, Near-term Steam</td>
<td>Lagging Test</td>
<td>Not Applicable</td>
</tr>
<tr>
<td></td>
<td>Leading Test</td>
<td></td>
</tr>
<tr>
<td>All Other</td>
<td>Lagging Test</td>
<td>Documented Exception to Lagging test based on impact to System Reliability</td>
</tr>
<tr>
<td></td>
<td>0 MVAR Test</td>
<td></td>
</tr>
</tbody>
</table>

Note: Near-term Steam units are defined as steam units with a hot start plus (+) notification time of less than 8 hours. The list of units is maintained by PJM and located in Transmission Owners Restoration Plan.

4. The reactive capability curve and minimum excitation limiter settings for each machine unit will be used to determine the expected reactive capability. If a machine unit has been tested previously, the expected reactive capability for a new test should reflect at a minimum the reactive capability that was previously demonstrated.

5. Units are to be tested while maintaining the voltage within normal operating limits on the system bus (pre- and post-contingency voltage limits). This requirement may require a departure from scheduled voltage during the test, provided no adverse effect on the validity of test results can be demonstrated. The Generator Owner will need to coordinate between its designated LCC, PJM, and other units in order to allow the unit being tested to demonstrate its maximum reactive capability while maintaining system voltages within acceptable limits.
6. All reasonable measures shall be taken to ensure the results from the reactive capability test are based upon actual operating conditions. If it is not possible to maintain the system voltage within operating limits, for non-black start unit leading capability tests, then it is acceptable to calculate the non-black start unit leading reactive capability quantities. Calculated test results will not be acceptable on an ongoing basis. Black start units and Near-term Steam units are required to test both leading and lagging reactive capability.

7. For hydrogen-cooled generators, the hydrogen pressure should be raised to the normal operation pressure. If the hydrogen pressure cannot be raised, then the reason for this condition should be documented and the appropriate reactive capability curve should be used.

8. The over-excited reactive capability test should be conducted for a minimum of one hour. Data for the under-excited reactive capability test may be recorded as soon as a limit is encountered.

9. When the maximum sustained over-excited and under-excited reactive output during the test is achieved, the MW and MVAR outputs at the generator terminals (low side gross), auxiliaries, the generator step-up transformer (GSU) primary (low side net, after auxiliaries), and the GSU secondary (high side net) should be recorded. If metering is unavailable, it may be necessary to calculate some of these quantities. A note should be provided in the “Remarks” section of “Lagging and Leading/Zero Form R” for points which are calculated.

10. During the test, the scheduled and actual voltages at the system bus and the generator terminals should also be recorded. In addition, the nameplate GSU impedance, MVA rating, primary and secondary voltage ratings and available tap settings, and the existing GSU tap setting should be provided.

11. The reasons for any limit to unit reactive capability during the test should also be specified (for example, reactive capability curve limit, minimum excitation limiter settings, field current limitation, generator voltage, auxiliary bus voltage, system voltage limits, generator vibration, generator temperatures, hydrogen pressure restriction, shorted rotor turns, etc.) in the remarks section.

For Wind Generating Stations with an Aggregate Nameplate Rating Greater than 70 MW

1. Only wind units of Type 3 (doubly-fed asynchronous) and Type 4 (full converter interface) will be tested for reactive capability, exclusive of static reactive power compensation devices.

2. The over-excited (lagging) and under-excited (leading) reactive capability outputs (MVAR) is required to be tested at 50% or greater of aggregate wind generating station nameplate rating (i.e. a single MW point test).

3. The active and reactive power output shall be maintained as steady as possible during the test.
4. The reactive capability curve and minimum excitation limiter settings for each wind generating station will be used to determine the expected reactive capability. If a wind generating station has been tested previously, the expected reactive capability for a new test should reflect at a minimum the previous reactive capability that was demonstrated.

5. Wind generating stations are to be tested while maintaining the voltage within normal operating limits on the system bus (pre- and post-contingency voltage limits). This requirement may require a departure from scheduled voltage during the test, provided no adverse effect on the validity of test results can be demonstrated. The Generator Owner will need to coordinate between its designated LCC, PJM, and other units in order to allow the unit being tested to demonstrate its maximum reactive capability while maintaining system voltages within acceptable limits.

6. All reasonable measures shall be taken to ensure the results from the reactive capability test are based upon actual operating conditions. If it is not possible to maintain the system voltage within operating limits, for wind generating stations leading capability tests, then it is acceptable to calculate the wind generating station leading reactive capability quantities. Calculated test results will not be acceptable on an on-going basis.

7. When the maximum sustained over-excited and under-excited reactive output during the test is achieved, the MW and MVAr outputs at the aggregated collector bus low side terminals (low side gross), auxiliaries, the generator step-up transformer (GSU) primary (low side net, after auxiliaries), and the GSU secondary (high side net) should be recorded.

If metering is unavailable, it may be necessary to calculate some of these quantities. A note should be provided in the “Remarks” section of “Lagging and Leading/Zero Form R” for points which are calculated.

For wind generating stations on Lagging Form R, record only the instantaneous value in the “Start of Test” row and Stated Capability (previous tested value if applicable). The 15 min, 30 min, 45 min, and End of Test rows are not applicable.

PJM will evaluate the reported values as compared to the average values consistent with requirements. The average values will serve as the basis for modifying the default reactive curves within eDart.

8. During the test, the scheduled and actual voltages at the system bus and the aggregated collector bus low side terminals should also be recorded. In addition, the nameplate GSU impedance, MVA rating, primary and secondary voltage ratings and available tap settings, and the existing GSU tap setting should be provided.

9. The reasons for any limit to wind generating station reactive capability during the test should also be specified (for example, reactive capability curve limit, minimum excitation limiter settings, field current limitation, generator voltage, auxiliary bus voltage, system voltage limits, generator vibration, generator temperatures, shorted rotor turns, etc.) in the remarks section.
Notification and Reporting Requirements

If non-cost operations (the adjustment of generator MVAR output or the movement of PAR or LTC transformer taps) or off-cost operations are required to accommodate the test, PJM will communicate these requests directly to the appropriate LCCs and MOCs.

**MOC Actions:**

- Proposed testing dates/times should be communicated via eDart to the PJM Dispatch, PJM Reliability Engineer and LCC no later than noon 3 business days prior to the test, ensuring testing impacts are incorporated into day-ahead studies. PJM and LCCs will consider shorter notification times and try to accommodate reactive testing while ensuring that operating limits are not violated.
- The test notification will be submitted using a “MVAR Test” Ticket in which the test duration should be provided, as well as any additional relevant information for the test within the description field.
- Prior to the test scheduling, the MOC (Generation Owner) shall confirm with PJM Reliability Engineer that MW and MVAR data is being provided to PJM via ICCP. If issues are identified, they are required to be resolved before proceeding with the test scheduling of the unit.
- Any scheduled or unscheduled maintenance work on the unit scheduled for testing must be complete and all eDART tickets cleared prior to contacting PJM for the purpose of initiating the study process.
- The MOC will contact PJM Reliability Engineer at least three hours prior to the start of the scheduled testing in order to initiate the real-time study process.
- Real-time testing should be coordinated with LCC and PJM Transmission dispatchers. At least 30 minutes notice should be provided to allow PJM and LCC operators to adjust the system to ensure testing does not result in voltage limit violations.
- The MOC will coordinate any required transmission mitigation steps to resolve internal plant limitations with PJM Reliability Engineer.
- If testing must be canceled or rescheduled, the MOC will inform PJM Reliability Engineer as soon as possible.
- The MOC will coordinate the implementation of their portion of the exit strategy with PJM, if required.
- Generator Owner shall submit complete PJM Leading and/or Lagging Test Form R to reactivetesting@pjm.com within 30 calendar days after completion of the testing.
- The MOC will coordinate all actions with PJM dispatch.

**LCC Actions:**

- The appropriate LCCs will conduct studies in accordance with established company procedure in order to determine the effect of scheduled testing on their systems.
- LCC should contact PJM Reliability Engineer with any possible concerns regarding the scheduled testing.
- LCC support staff will ensure that the LCC operators are aware of scheduled reactive capability tests and communicate the pre-studied mitigating action plan.

- Prior to studying the test, the LCC will verify, with the PJM Reliability Engineer and the generating station, the expected MW and MVAR output levels of the unit during testing, and ensure that the AVR is in service.

- The LCC will contact the PJM Reliability Engineer no later than two hours and 15 minutes prior to the scheduled test start time in order to discuss the results of their studies and the mitigating steps required, if any.

- The LCC will discuss, coordinate, and implement any actions necessary as required by mitigation strategies with PJM prior to the start of testing.

- The LCC will communicate MVAR output step changes to the testing unit in coordination with PJM. In general, MVAR step changes should be no greater than 100 MVAR increments.

- If testing must be canceled or rescheduled, the LCC will inform PJM Reliability Engineer as soon as possible.

- The LCC will coordinate the implementation of their portion of the exit strategy with PJM, if required.

- The LCC will coordinate all actions through PJM Reliability Engineer.

**PJM Actions:**

- All testing requests will be reviewed by PJM Reliability Engineers and Power Directors to ensure that there is no conflict between the testing and any planned transmission outage. PJM will give the MOC a suggestion for a more appropriate date and time to conduct the test, if necessary.

- PJM Reliability Engineer shall verify the accuracy of the telemetry data with the generation owners prior to commencing the test. If issues are identified, they are required to be resolved before proceeding with the test scheduling of the unit.

- PJM Reliability Engineer and Power Director will review and approve the test in accordance with the established PJM procedure.

- PJM Reliability Engineer will ensure that PJM dispatch is aware of scheduled reactive capability tests and communicate the pre-studied mitigating action plan via the PJM Transmission Log.

- Once the PJM Reliability Engineer is contacted by the MOC, they will contact the LCCs of all regions concerned in order to initiate the transmission operator’s study process. They will verify the expected unit output levels with the LCC and ensure that the AVR is in service.

- PJM Reliability Engineer will re-evaluate the pre-studied mitigating action plan prior to test commencement and communicate any necessary adjustments to the impacted parties.

- PJM Reliability Engineer and/or Dispatch will discuss possible mitigation strategies with the appropriate LCCs.
PJM Reliability Engineer will contact the MOC no later than two hours prior to scheduled testing to inform them whether mitigation steps will be required.

PJM Reliability Engineer will coordinate with the appropriate MOCs and LCCs in order to implement the selected mitigation strategy.

PJM Reliability Engineer will coordinate with the LCC in making MVAR output step changes with the testing unit.

If the testing must be cancelled or rescheduled, PJM Reliability Engineer will contact the MOC and LCCs as soon as possible.

PJM Reliability Engineer will coordinate the implementation of the exit strategy with the MOC and LCCs, if required.

PJM Reliability Engineer will coordinate all actions and communications between the MOC and LCCs.

**Test Cancellation**

PJM dispatch and/or the impacted parties may cancel the generator reactive capability testing for the following reasons:

- Internal planning issues.
- Emergency procedures.
- Inability to control actual or post-contingency voltage issues created by scheduled testing.
- Any operating issues created on LCC equipment not monitored by PJM.

Cancellation of the generator reactive capability test will be communicated to all impacted parties.

PJM will document all cancellations and terminations including the party responsible and the reason for the cancellation or termination.

**Voltage Schedules**

Adjustments may need to be made to local voltage schedules in order to accommodate the scheduled testing. These adjustments will be considered and studied on a case by case basis.

**Note:** Deviate from voltage schedule to demonstrate reactive capability while monitoring impacts to limits using SA packages.

PJM will discuss the changes with the appropriate LCC and if the recommendation does not cause a violation of a defined limitation, the LCC should implement the PJM request.

PJM will retain its control of the reactive facilities, such as transmission capacitors, LTCs, and generator MVAR output.

If internal plant or LCC limits restrict the request, PJM dispatch will study the limitations and recommend changes to plant facilities if appropriate.

If the recommended changes cannot be implemented due to equipment or facility limitations, other options will be considered, including test cancellation or rescheduling.
Exit Strategy

Risk

PJM will not allow scheduled generator reactive capability testing to place the system in an unacceptable state. However, there is always the possibility of equipment failure resulting in unplanned situational constraints that would require immediate remedial action.

Requirements

The following are steps that will be considered and agreed upon prior to allowing the scheduled generator reactive capability testing;

Each scheduled test will be studied and approved on a case by case basis.

All required mitigation steps will be agreed to and coordinated with all concerned parties, to include PJM Reliability Engineer, the responsible MOC, and the appropriate LCCs, prior to the scheduled testing.

Parameters

PJM will NOT allow operation over any applicable post-contingency STE or LTE ratings.
PJM will NOT allow operation over any applicable pre-contingency normal rating.

In the event of a facility rating discrepancy between PJM and the LCC that cannot be resolved, PJM will default to the most conservative limit.

In the event that the testing results in an unexpected thermal or voltage violation, standard mitigation steps will be taken to return the facilities in violation back to normal limits within fifteen minutes.

The mitigation steps taken will not cause limit violations on any other company’s equipment or facilities.

Post-Test Evaluation

PJM will provide feedback on a periodic basis to generation owners on the status of their reactive capability test results. PJM will also provide the results of generation reactive capability tests to the appropriate LCC operator.

PJM will analyze the reactive capability test results in the same calendar year in which the reactive capability test was performed for the unit.

PJM Staff will conduct periodic audits of generator reactive capability test results and will provide summary report information to the PJM System Operations Subcommittee and the PJM Operations Committee on a periodic basis.

Test Evaluation

PJM will evaluate each unit’s reactive capability test results against its stated reactive capability limits modeled within the PJM EMS. This evaluation will determine which units performed over, under, or within 5% of their stated limits, as well as what follow-up steps are necessary to ensure that the correct information is modeled within the PJM EMS.
Units Testing Within 5% of Stated Limits

Units or wind generating stations with test results within 5% of their stated limits will be considered as having fully demonstrated their stated reactive capability.

PJM will notify the MOC that their units achieved their reactive capability, and no further action will be required.

Units Testing Over 5% of Stated Limits

Units or wind generating stations with test results over 5% of their stated limits will be considered as having fully demonstrated their stated reactive capability.

PJM will notify the MOC that their units exceeded their stated reactive capability and will propose that they increase the reactive capability modeled within the PJM EMS by entering New-Default eDART MVAR ticket.

Units Testing Below 5% of Stated Limits

Units or wind generating stations with test results under 5% of their stated limits will not be considered as having demonstrated their stated reactive capability.

PJM will determine which units have not demonstrated due to either internal or external operational limitations based on reasons documented within the submitted test results.

For units that claimed external operational limitations,

A. PJM will perform further analysis to confirm external limitations and possible remedial measures in the event of future attempts by the MOC to demonstrate the unit’s reactive capability.

B. If an external limitation is confirmed, PJM will provide confirmation to the MOC that their units performed below their stated reactive capability due to external limitations and will not require any further action.

C. If no external limitation is confirmed, PJM will require that the MOC either permanently reduces the reactive capability modeled within the PJM EMS by entering a “New Default” eDART MVAR ticket or retest to demonstrate the stated capability of the unit.

D. If the MOC chooses to retest the unit, PJM will require that a temporary eDART MVAR ticket be submitted that will remain active until the unit demonstrates the original stated capability.

For units that claimed internal operational limitations,

A. PJM will notify the MOC that their units performed below their stated reactive capability

B. PJM will require that the MOC either permanently reduces the reactive capability modeled within the PJM EMS by entering a “New Default” eDART MVAR ticket or retest to demonstrate the stated capability of the unit.

C. If the MOC chooses to retest the unit, PJM will require that a temporary eDART MVAR ticket be submitted that will remain active until the unit demonstrates the original stated capability.
Glossary

Scheduled Voltage—The voltage level normally maintained at the system bus during peak load conditions.

Gross Reactive Capability—The maximum sustained overexcited and under-excited reactive output, which generating equipment is expected to produce under normal operating conditions.

Net Reactive Capability at the GSU Primary—The maximum sustained overexcited and under-excited reactive output exclusive of auxiliary usage expected to produce under normal operating conditions.

Net Reactive Capability to the System—The maximum sustained overexcited and under-excited reactive output exclusive of auxiliary usage and GSU reactive power losses expected to produce under normal operating conditions.

GSU (Generator Step-Up Transformer)—An Inductive stationary device that transfers electrical energy from generator voltage to a higher transmission voltage.

Wind Generating Stations – an aggregate of multiple wind turbines connected at a common bus (a.k.a. collector bus) with the outlet through a common GSU.
### Lagging Form R

**Net Demonstrated Lagging Reactive Capability Test Data**

<table>
<thead>
<tr>
<th>eDaT Ticket #</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td></td>
</tr>
<tr>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td>Date of Test</td>
<td></td>
</tr>
<tr>
<td>Time of Test: Begin / End</td>
<td></td>
</tr>
<tr>
<td>Ambient Temperature, °F</td>
<td></td>
</tr>
<tr>
<td>Ambient Relative Humidity</td>
<td></td>
</tr>
<tr>
<td>Normal Hydrogen Pressure, PSIG</td>
<td></td>
</tr>
<tr>
<td>Actual Hydrogen Pressure, PSIG</td>
<td></td>
</tr>
<tr>
<td>Blackstart: [ ] Yes [ ] No</td>
<td></td>
</tr>
<tr>
<td>Near-Term Steam: [ ] Yes [ ] No [ ] N/A</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time of Measurement</th>
<th>Gross Gen. Instantaneous</th>
<th>Aux. Power Instantaneous</th>
<th>Net Gen @ GSU Low-Side</th>
<th>Net Gen @ GSU High-Side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW ✗</td>
<td>MVAR ✗</td>
<td>MW ✗</td>
<td>MVAR ✗</td>
</tr>
<tr>
<td>Start of Test</td>
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</tr>
<tr>
<td>Average of Test</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Please check boxes for telemetered data

**Stated Capability**

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator Bus Voltages</td>
<td>kV</td>
<td>kV</td>
</tr>
<tr>
<td>Auxiliary Bus Voltages</td>
<td>kV</td>
<td>kV</td>
</tr>
<tr>
<td>System Bus Voltages</td>
<td>kV</td>
<td>kV</td>
</tr>
</tbody>
</table>

**GSU Nameplate Data**

| Generator Voltage Schedule | kV | Generator Voltage PT Ratio |  |
| System Voltage Schedule | kV | System Voltage PT Ratio |  |

**Remarks:** (Plant Limitations)

**Remarks:** (System Limitations)

**Remarks:** (Other Limitations)
**Leading / Zero Form R**

Not Demonstrated Leading / Zero Reactive Capability Test Data

(leading / zero form may not be necessary, depending on unit type)

- **#Dart Ticket #**
- **Company**
- **Plant**
- **Date of Test**
- **Ambient Temperature, °F**
- **Normal Hydrogen Pressure, PSIG**
- **Blackstart**
  - Yes
  - No

- **Unit**
- **Time of Test: Begin / End**
- **Ambient Relative Humidity**
- **Actual Hydrogen Pressure, PSIG**
- **Near-Term Steam**
  - Yes
  - No
  - N/A

Readings are to be recorded as soon as leading / zero limit is encountered

<table>
<thead>
<tr>
<th>Time of Measurement</th>
<th>Instantaneous Gross Gen.</th>
<th>Instantaneous Aux Power</th>
<th>Net Gen @ GSU Low-Side</th>
<th>Net Gen @ GSU High-Side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW</td>
<td>MVAR</td>
<td>MW</td>
<td>MVAR</td>
</tr>
</tbody>
</table>

- **Instantaneous**
- **Average of Test**
- **Stated Capability**

* Please check boxes for telemetry data
** Average of all test data

** Generator Bus Voltages**
- **Phase 1**
- **Phase 2**
- **Phase 3**

** Auxiliary Bus Voltages**
- **Phase 1**
- **Phase 2**
- **Phase 3**

** System Bus Voltages**
- **Phase 1**
- **Phase 2**
- **Phase 3**

** Generator Voltage Schedule**
- **Galv Voltage PT Ratio**

** System Voltage Schedule**
- **System Voltage PT Ratio**

** GSU Nameplate Data**
- **Tap Setting**
- **Impedance**
- **Capability**

** Remarks: (Plant Limitations)**

** Remarks: (System Limitations)**

** Remarks: (Other Limitations)**