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# Real-Time Generation Stability Calculation and Market Modelling Process

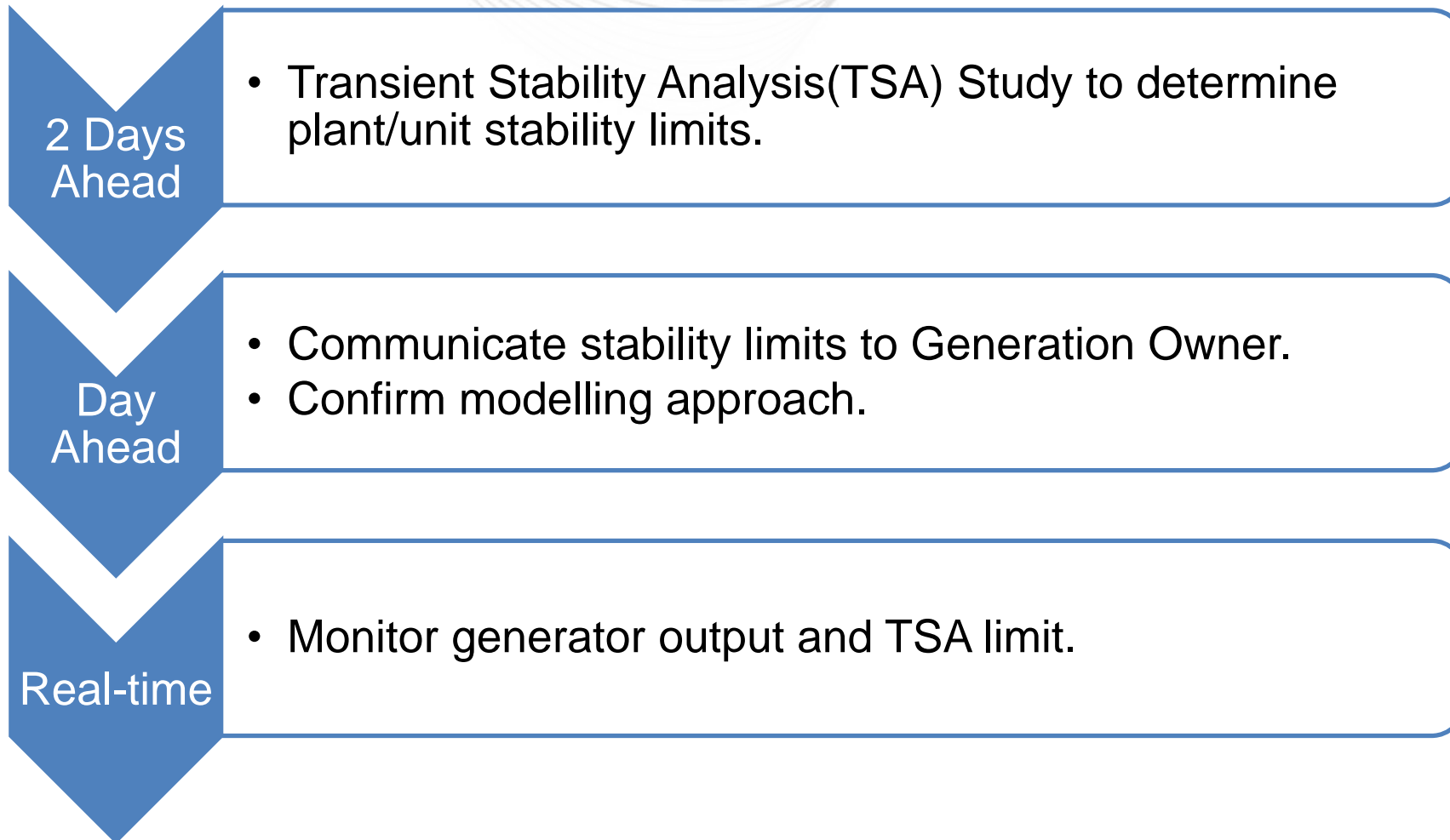
Liem Hoang and Mike Zhang  
October 16, 2019

## Manual-03: Section 3.9.1 Process for Handling Generator Stability Limitations

*“The Reliability Limited Generation Compensation Task Force established the following procedure on how PJM currently handles Stability Issues on the transmission system. When a stability issue is identified and advanced coordination is not possible, PJM will:*

- 1) Confirm/calculate the stability limit and communicate the limit to the generator(s) as quickly as possible and prior to DA market submission when practical.*
- 2) Create an interface that would be used in the Day Ahead and Real Time Market so that LMP will be utilized to reflect the stability constraints.*
  - a) If the generator chooses to reduce their Economic Maximum bid below the stability limit, the constraint would not bind.*
  - b) If the constraint does bind, it would be handled consistent with how PJM handles other transmission constraints on the system. All current market rules regarding Lost Opportunity Cost (LOC) would apply and LOC would be paid as currently defined in the Tariff when a transmission constraint is in effect.”*

- Definition and Impact
  - Transient: Ability to remain synchronized after being subjected to a disturbance
  - Dynamic: Ability to damp oscillations cause by minor disturbances
  - Unstable units may impact other generators on the system
- NERC Standard
  - FAC-011-3 R2.1: *“all Facilities shall be operating within their Facility Ratings and within their thermal, voltage and **stability limits**; and **Cascading or uncontrolled separation shall not occur.**”*



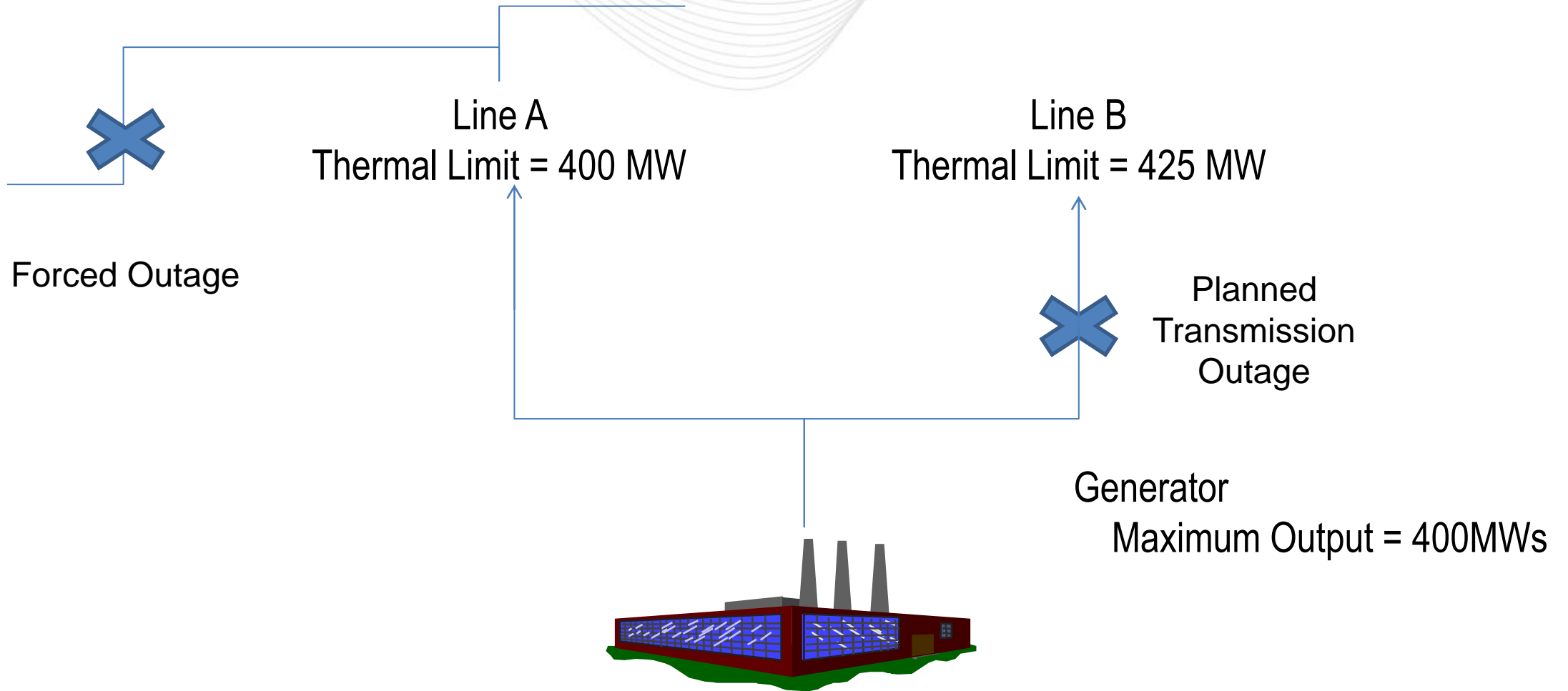
- PJM utilizes a Transient Stability Assessment (TSA) Tool.
  - Manual-03 Section 3.9 defines the uses of TSA.
  - Manual-03 Section 5 contains plant specific limitations of common stability areas
    - Use in case TSA is not available
    - Provide transparency to GO and Market Participants
- For transmission outages, PJM will:
  - Study and determine plant/unit stability limitations.
    - TSA limitations tend to be less conservative than M-03 procedures.
  - 2 Days Ahead of Operating Day (further ahead for nuclear plants)
  - Limitations can be Maximum MW or/and Minimum MVar.

- Communicate the limit to the Generation Owner (GO) prior to Day-Ahead Market (DAM) closure
- Scenario 1: GO opts to reduce maximum output to communicated stability limit
  - GO should submit eDART generator outage ticket
    - Guidelines in place to avoid EFORd impacts
    - Capacity verified as part of Gen Checkout process
  - Surrogate/interface would not be needed
    - Alleviates negative impacts to LMPs at associated busses due to stability
  - Unit(s) committed and dispatched economically up to new Economic Max
    - Other bid in parameters unaffected for Price, Cost, and PLS schedules
  - PJM preferred method



- Communicate the limit to the Generation Owner (GO) prior to Day-Ahead Market (DAM) closure
- Scenario 2: GO opts NOT to reduce maximum output
  - PJM creates thermal surrogate/interface to reflect stability limitation
  - Constraint will bind in DA and/or Real-time when limits are exceeded
    - Impacts LMPs at affected busses up to Marginal Value Limit as defined by Tariff
    - Unexpected price fluctuations from positive to negative when constraint binds/unbinds
      - LMP distortions may cause downstream settlement impacts outside of DA/RT energy market
    - Units electing to must-run in DA above stability limit could create congestion





- Generator:
  - Generator can provide up to 400 MW of energy
- Transmission Lines:
  - After Line A was removed from service for a planned transmission outage, another nearby transmission facility experienced a forced outage

- Situation:
  - With the new system configuration, the plant has a stability limitation
- What are the courses of action:
  - Scenario 1:
    - PJM determined the stability limit to be 350 MW total maximum for plant.
    - Restriction communicated to the Gen Owner prior to the closing of the Day-Ahead Market.
    - Gen Owner decided to submit an eDART ticket and lower maximum limits to 350 MWs.
    - Unit receives basepoint based on updated limits.
    - No thermal surrogate/interface required in Real-time.

- Scenario 2:
  - PJM determined the stability limit to be 350 MW total maximum for plant.
  - Restriction communicated to the Gen Owner prior to the closing of the Day-Ahead Market.
  - Gen Owner opted not to submit an eDART ticket and not lower maximum limits below the stability limit.
  - Thermal surrogate/interface required in Real-time for stability concern.
  - Surrogate created and controlled as a thermal limit to the stability limitation.
    - » Control percentage may vary as ambient temperatures and stability conditions change

- Scenario 1:
  - Reserve calculations will respect the updated max of 350 MW.
    - » If unit is picked up for reserves, the deployment should not create a stability violation.
- Scenario 2:
  - Reserve calculations will utilize the full output of the plant.
    - » If unit is picked up for reserves, the deployment could violate the stability limitation.
    - » Leads to overestimation for reserves on the unit.

- Scenario 1:
  - No surrogate is used with no resulting pricing impacts from the surrogate in RT.
- Scenario 2:
  - Surrogate is created to best represent the stability limitation.
    - » Depending on the electrical modelling of the unit, an ideal surrogate is not always available.
    - » Based on existing Market rules, surrogate transmission facility must be classified as a Reliability and Markets facility. This eliminates plant side equipment as most are not classified as Reliability and Markets.
    - » May need to use the radial line, which can reveal the marginal unit on the constraint.

- Scenario 1:
  - With no surrogate binding, unit would be dispatched economically between eco limits.
- Scenario 2:
  - When surrogate binds in RT, it could lead to significant LMP difference between intervals.
    - » Depending on the severity of the violation, the surrogate could bind all the way up to the marginal value limit.
    - » An associated ramp-limited basepoint would be sent out. If a unit is unable to follow the basepoint, it maybe deemed to be deviating and logged accordingly.



- Scenario 1:
  - Plant reduces maximum limits and submits associated data in eDART/eGADS.
  - Any outage or derate event for transmission issues are required to be reported to both eDART and eGADS. If, and only if, the events are **scheduled in advance** in eDART as maintenance outages or derates will they be allowed to remain maintenance outage or derates in eGADS.
  - Should not impact EFORd calculations.
    - » Guidelines in proposed Manual 3 language around ticket submission.
- Scenario 2:
  - If outage or derates are not scheduled in advance in eDART, they must be forced outages or derates in eGADS and then they will impact a unit's EFORd.

- Reliability Limited Generation Compensation Task Force (RLGCTF) formed in 2012 to examine generator stability restrictions.
- Task force evaluated multiple design components including communications, method for using interfaces, and compensation.
- Package Summary: After the interface is created and modeled the GO has the option to bid in ECO MAX and bind the constraint in DA or they can place the ECO Max below the Stability Limit and provide eDART Ticket (OMC) and be paid system price.
- With exception of definition of Lost Opportunity cost, status quo was maintained.
- Endorsed by MIC at December 12, 2012 meeting.

# Clearing Stability Restricted units in Day Ahead Market

Keyur Patel

Sr. Lead Engineer, Day Ahead Market Operations

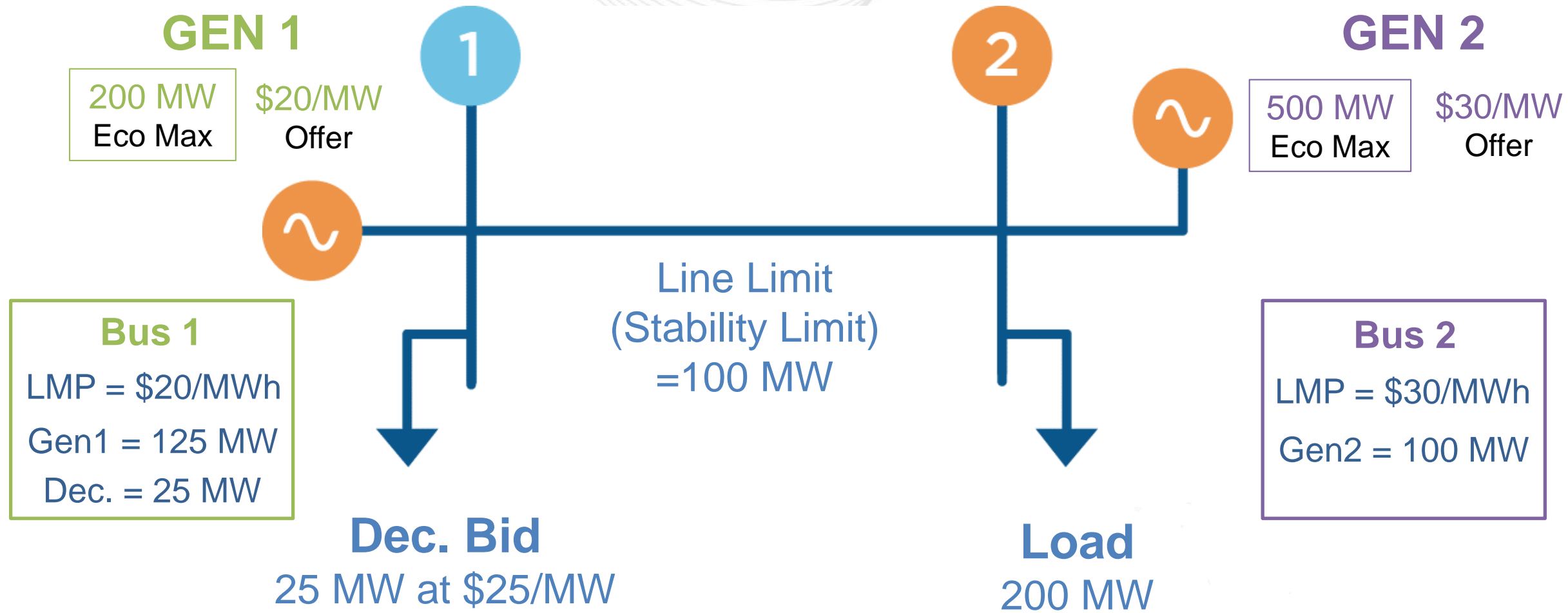
Markets Implementation Committee

November 13, 2019

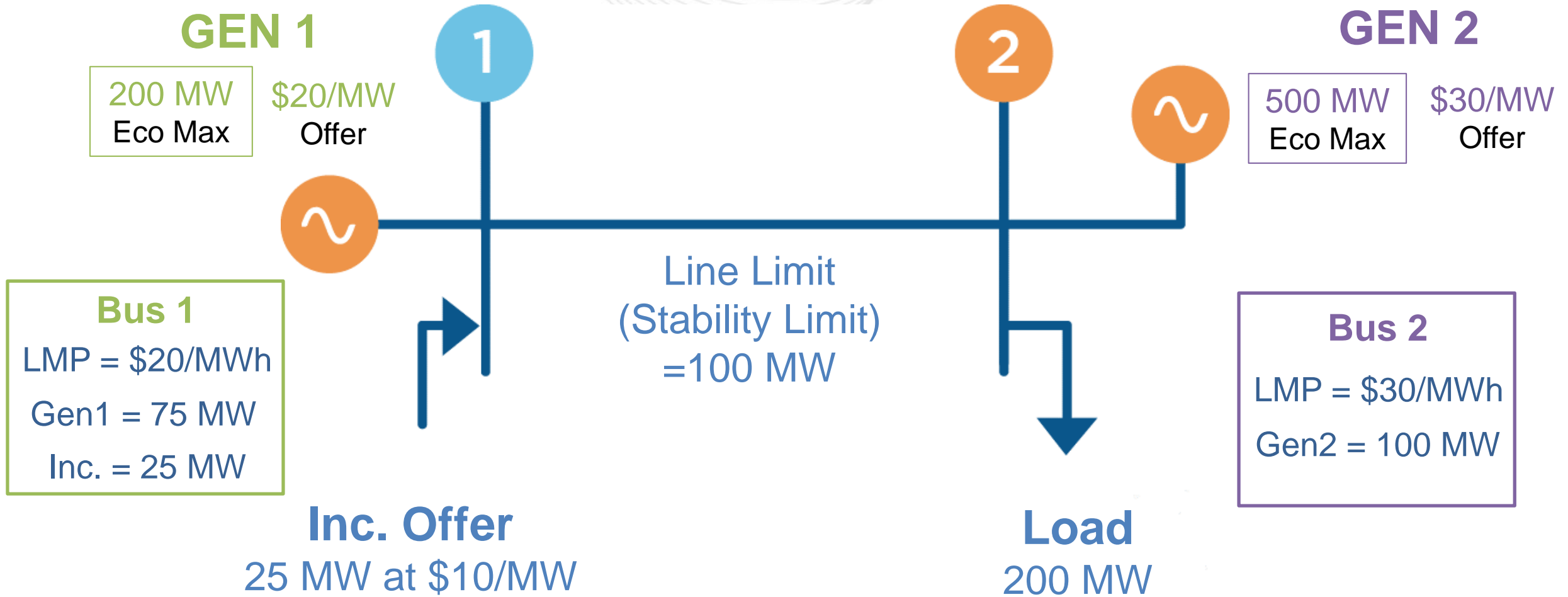
## Modeling Stability Limits in DA

- The stability limits are modeled as thermal constraints.
- Stability restricted unit is cleared the same way as any other unit.
- Stability restricted unit may clear more or less than stability limit under virtual bidding.

# Unit Clearing when Decrement Bid at same location



# Unit Clearing when Increment Offer at same location





# Transmission Planning Stability Study Overview

Byoungkon Choi (BK)  
Transmission Planning Department  
December 11, 2019



- One element of transmission system reliability analysis in regional transmission expansion planning (RTEP) process
  - Power flow, **Stability** and short-circuit analyses
- Ensure bulk electric system (BES) stability in planning horizon.
- Comply with applicable NERC standards (e.g., TPL-001-4).
- Transmission Planning mainly focuses on existing generators and BES stability.

- Establish Transmission system planning performance requirements to BES.
- Stability performance planning events (TPL-001-4, Table 1)
  - Single contingencies (P1, P2)
  - Multiple contingencies: stuck breaker (P4), failure of non-redundant relay (P5) and common structure (P7)
  - N-1-1 contingencies (P3, P6): with the loss of single element due to an N-1 contingency followed by system adjustments and second N-1 contingency is applied.

- PJM also incorporates Transmission Owners specific stability criteria into stability analyses.
- Some Transmission Owners have more conservative criteria than NERC and PJM criteria in terms of:
  - Fault types for multiple contingencies
  - Generation reactive power dispatch
  - Transient voltage recovery performance
  - Damping performance

- PJM annual system-wide stability study
  - Conduct stability analysis for 1/3 of network each year.
  - Evaluate summer light load and summer peak load conditions.
  - Monitor transient (angle) stability, damping and transient voltage recovery performances.
- Stability study for system changes on an as-needed basis
  - Generating system changes (generator, excitation system, power system stabilizer, etc.)
  - Generator step-up transformer replacements

- Stability study for operational performance issues
  - Conduct stability study for specific system outage conditions upon PJM Operations request.
  - Support PJM Operations to update/develop operating guides for stability limited areas.
  - Provide PJM Operations with potential stability issues identified from Planning stability studies and conduct further necessary studies upon Operations request.

# Interconnection Analysis Stability Study Overview

Brinda Malladi  
Interconnection Analysis  
December 11, 2019



- Enter PJM New Services Queue
- Two queue windows per calendar year
  - April 1<sup>st</sup> – September 30<sup>th</sup>
  - October 1<sup>st</sup> – March 31<sup>st</sup>
- Feasibility Study and System Impact Study identify required transmission enhancements
- ISA or WMPA execution



- One element of Interconnection Analysis (IA) study process
  - Power flow, **Stability** and short-circuit analyses
- IA stability study ensures stability for new Interconnection projects and system-wide stability and identify the need for upgrades, operating guides or Remedial Action schemes (RAS)
- Stability studies are performed for all the queue projects greater than or equal to 20 MW or for generators connecting to areas with known stability concerns
- Comply with applicable NERC standards (e.g., TPL-001-4) and TO stability criteria (FERC 715 Filing)

- Studies performed on Summer Peak and Summer Light load cases
- Fault scenarios included depend on queue project location
- Monitor angle stability, damping and transient voltage recovery performances
- Low Voltage Ride Through tests performed for Inverter based projects
- Reactive Power Requirement Assessment is performed for all new generators

- N-1-1 and SPS scenarios listed in Manual 3 operating guides and N-1-1 scenarios as per TO criteria are considered
- Least cost remedy to N-1-1 outage violations for new generators under study is to allow them to curtail during the event
- Interconnection customers are required to reinforce the system if curtailment is not an option
- PJM operations staff are notified of any changes required to operating guides or any generator curtailments prior to commercial operation of a generator

- IA performs tests on “As built” data submitted by the generator and sends the model along with any required mitigations to PJM Operations
- PJM planning ensures the necessary system upgrades identified in the ISA or WMPA are constructed prior to the commercial operation of the generator, or a mitigation plan is in place
- PJM planning notifies PJM Operations of a generator’s plan to initially synchronize to system and begin initial operations (testing) typically a week prior to the generator synchronizing

# Stability Manual Dispatch Data and Coordination

Mike Zhang  
Markets Implementation Committee  
December 11, 2019

# Stability Driven Manual Dispatch

- Manually dispatching a generator for stability is a last resort option for controlling stability limitations.
  - Unit does not elect to reduce maximum output and no suitable surrogate is available
  - Unit deviating from/not following basepoints with surrogate
- Instances
  - 36 in 2019
  - 28 in 2018

- No existing stability limitations impacting multiple units with different owners.
  - Formalized process discussions ongoing
- Status quo challenges
  - Unit Parameter Reduction – Allocation of MW reduction needed from each unit, manual process without surrogate
  - Thermal Surrogate – May incorporate other unintended units(leakage), dispatch order based on economic merit and not actual impact on stability limitation



# An approach to model Stability Limits on units in Markets

Keyur Patel

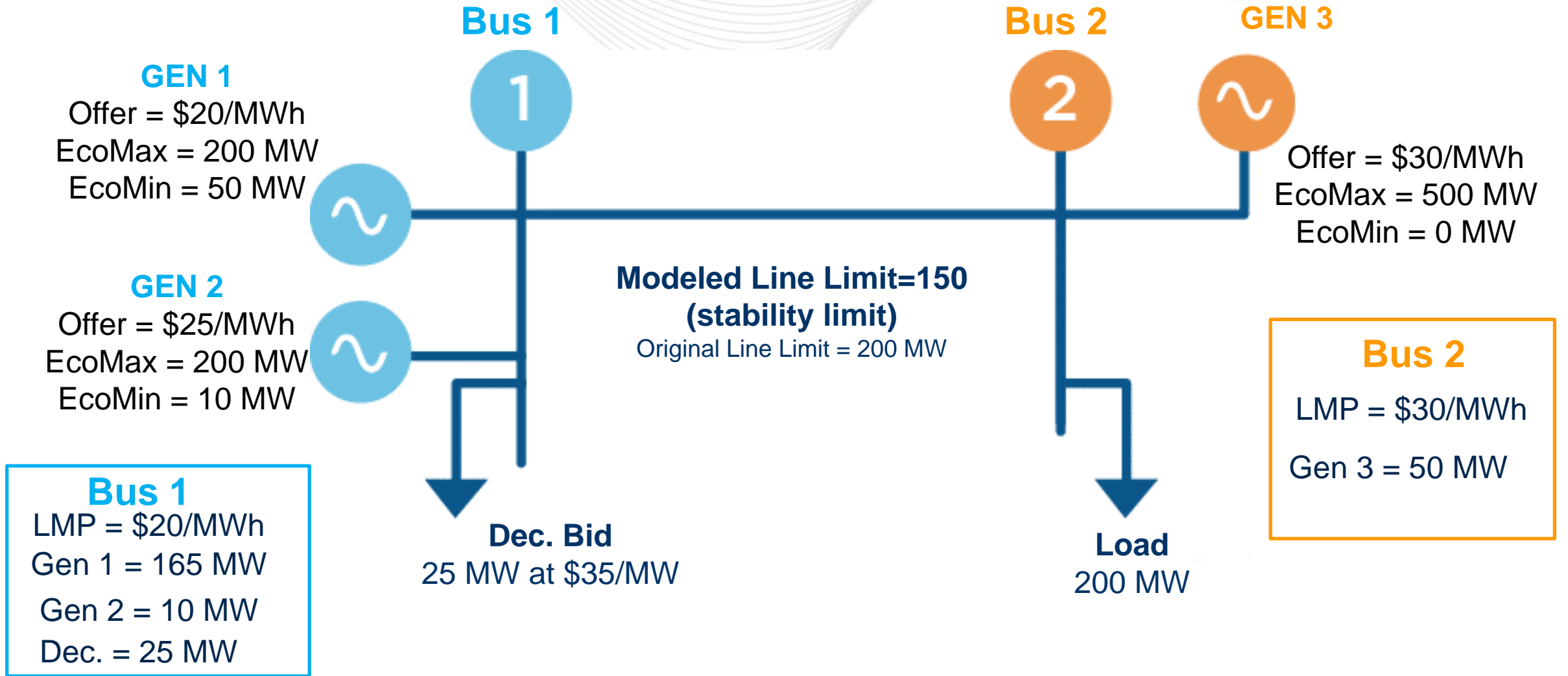
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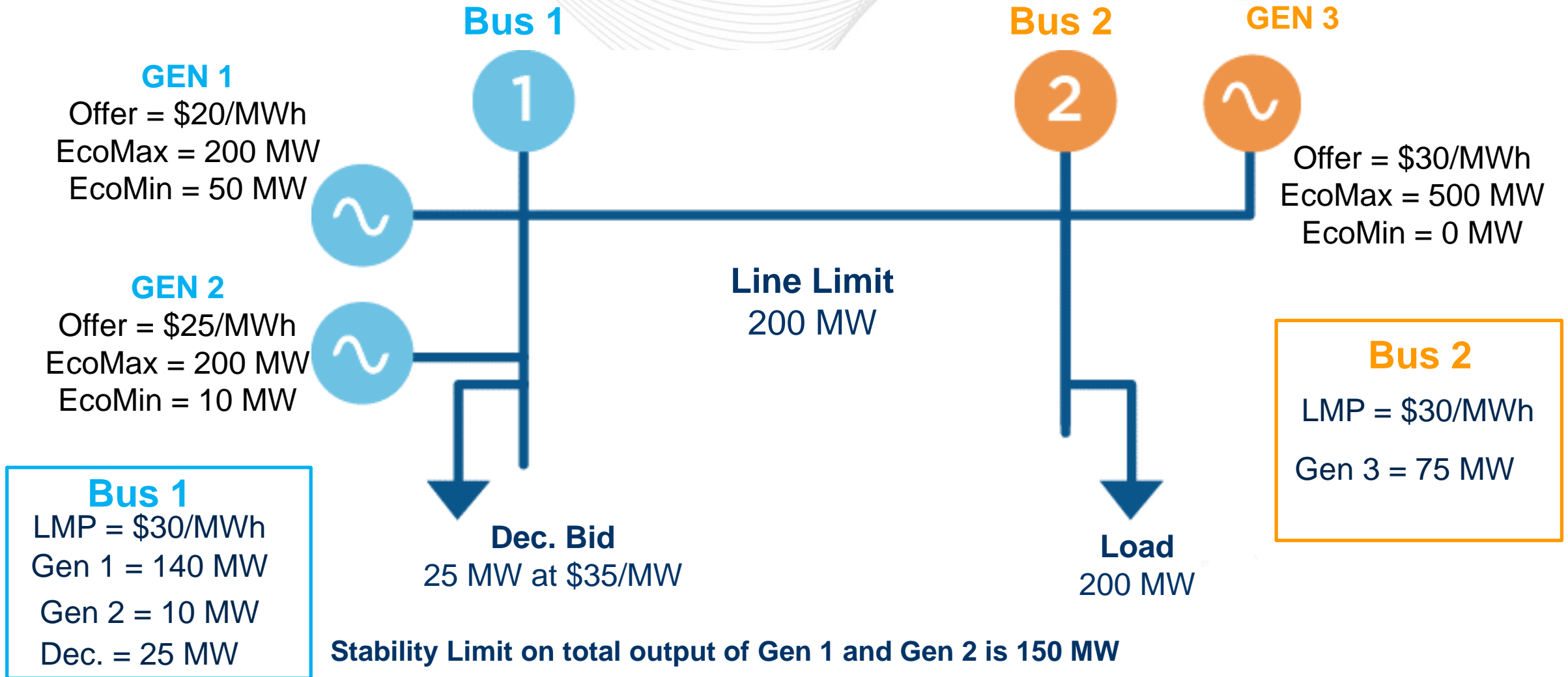
Markets Implementation Committee

March 11, 2020

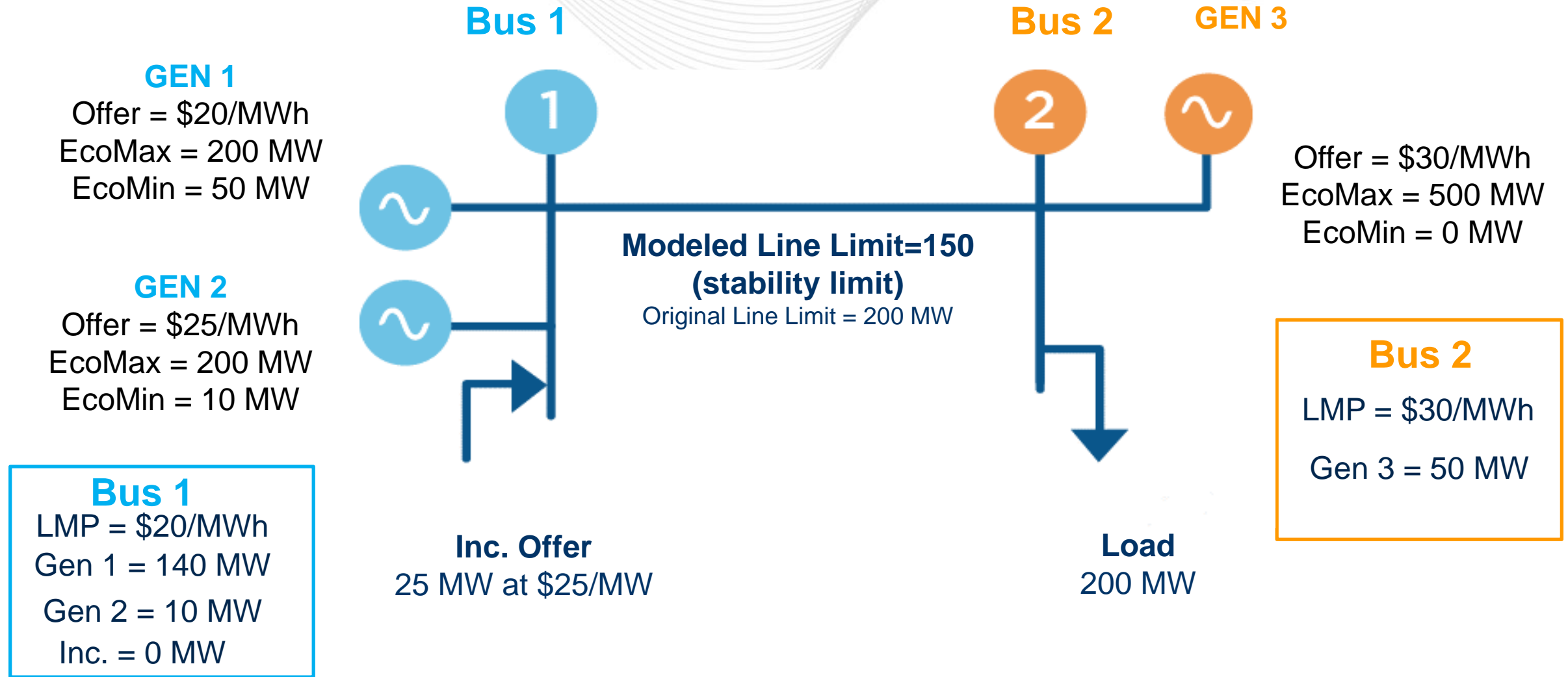
- The stability limits can be modeled as “capacity constraint” for Stability restricted units.
- The sum of MWs from stability restricted units will not be more than stability limit regardless of virtual bidding. This constraint can also be modeled such that sum of energy MWs plus reserve MWs from stability restricted units will not be more than stability limit.
- This type of constraint doesn’t directly affect the LMP.
- The output of stability restricted units will be determined based on their offer curve and LMPs.

# Clearing Stability Restricted units with Dec in current Thermal Surrogate approach

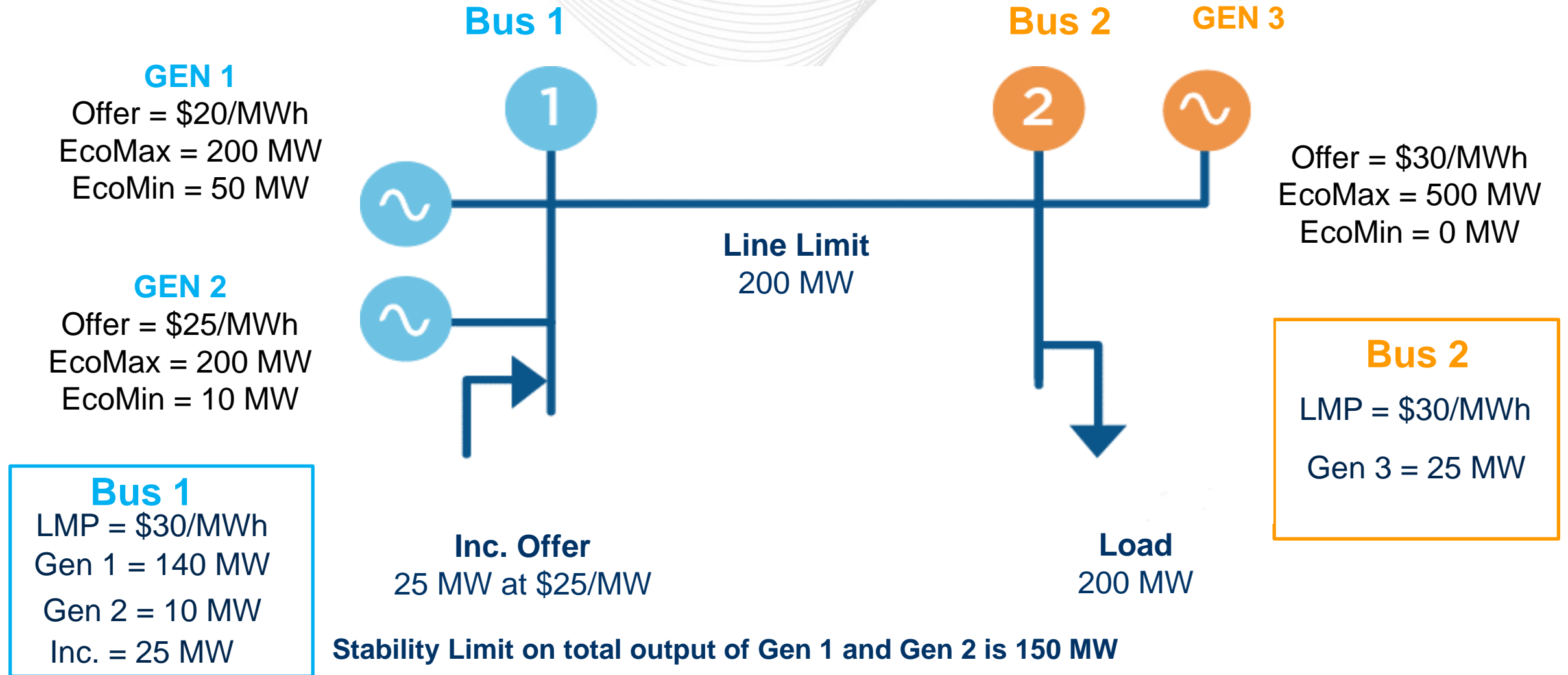




# Clearing Stability Restricted units with Inc in current Thermal Surrogate approach



# Clearing Stability Restricted units with Inc in new approach





# Stability Limits Update

Markets Implementation Committee  
May 13, 2020



- At April MIC, PJM presented a potential approach to model stability limits
  - Model as “generator output constraint” for Stability restricted units
- After PJM further review, stakeholder feedback, and collaboration, PJM can still jointly sponsor the existing package with IMM but can also support the status quo
  - Package does not fully resolve gaps such as reflecting action in LMPs
  - Current rules provide flexibility
- PJM will review existing transparency, modeling, and communication under the existing construct
- Stakeholders may propose additional packages
  - If no additional packages offered then PJM can support status quo

## Planning

## Markets/Operations Method 1: Unit Reduction

## Markets/Operations Method 2: Thermal Surrogate

Modeling	Stability studies which also include N-1-1 scenarios listed in Manual 3 operating guides and per TO criteria are considered	Reduce Emergency and Economic Max to stability limit	Engineers develop a MP1 'thermal surrogate' consisting of a transmission element or elements
Transparency	Manual 14B	Manual 3: Section 3.9.1	Manual 3: Section 3.9.1
Compliance and Notification	<ul style="list-style-type: none"> <li>Comply with applicable NERC standards (e.g., TPL-001-4) and TO stability criteria (FERC 715 Filing)</li> <li>Interconnection customers are required to reinforce the system if curtailment is not an option</li> </ul>	<ul style="list-style-type: none"> <li>Maintenance Ticket needs to be submitted in eDART and eGADS</li> <li>Market Seller notified</li> </ul>	<ul style="list-style-type: none"> <li>MP1 thermal surrogate developed</li> <li>Market Seller notified</li> </ul>
Compensation	<ul style="list-style-type: none"> <li>Least cost remedy to N-1-1 outage violations for new generators under study is to allow them to curtail during the event</li> </ul>	<ul style="list-style-type: none"> <li>Unit receives LMP for MWs               <ul style="list-style-type: none"> <li>Higher LMP w/o thermal surrogate</li> </ul> </li> <li>No LOC</li> </ul>	<ul style="list-style-type: none"> <li>Unit receives LMP for MWs               <ul style="list-style-type: none"> <li>Lower LMP with thermal surrogate</li> </ul> </li> <li>LOC paid if dispatch and price do not line up and unit following dispatch</li> </ul>

## 3.9.1 Process for Handling Generator Stability Limitations

- The Reliability Limited Generation Compensation Task Force established the following procedure on how PJM currently handles Stability Issues on the transmission system. When a stability issue is identified and advanced coordination is not possible, PJM will:
  - Confirm/calculate the stability limit and communicate the limit to the generator(s) as quickly as possible and prior to DA market submission when practical.
  - Create an interface that would be used in the Day Ahead and Real Time Market so that LMP will be utilized to reflect the stability constraints.
    - If the generator chooses to reduce their Economic Maximum bid below the stability limit, the constraint would not bind.
    - If the constraint does bind, it would be handled consistent with how PJM handles other transmission constraints on the system. All current market rules regarding Lost Opportunity Cost (LOC) would apply and LOC would be paid as currently defined in the Tariff when a transmission constraint is in effect. For previously identified stability constraints already documented in Manual 03 Section 5, the generation owner may have already agreed to limit its output to ensure the stability constraint is mitigated. In such cases, an interface constraint in the Day Ahead and Real Time markets is not necessary

Key Takeaway:  
Process already exists and developed through previous stakeholder group

- Solicit additional packages
  
- PJM review existing construct to determine if enhancements can be made in the following areas:
  - Transparency
  - Modeling
  - Communications