Transient Stability Analysis and Control (TSA&C) -- An On-line Tool for PJM System Operations

September 9, 2009 – System Operations Subcommittee

September 15, 2009 – Operating Committee

September 16, 2009 – Planning Committee

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Overview - Main functions of TSA&C

- Monitor and determine **transient stability** of the PJM system subject to 3000 contingencies pre-defined.
- Compute **stability limits** by using real time data input and real-time network models.
  Replace the current computation process which uses the tables generated by off-line planning model years ago.
- Provide recommend **transient stability control measures** required to prevent the system from losing transient stability for potentially unstable system condition and/or contingencies

Three systems:

- Production TSA&C system installed on Dec. 2006
- Test TSA&C system installed on July 2006
- OTS TSA&C system installed on March 2007

Real-time models:

- Real-time network model and State Estimation solution
- Operation dynamic generator models (Consistent with PJM Planning Models)
- Contingency models (Each contingency contains common fault and switching events (circuit tripping, generator tripping, shunt switching, etc.))

Technologies:

- Advanced non-linear system technology
- Parallel computation

Assessment cycle

- 15 minutes

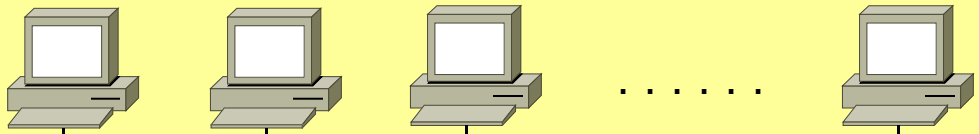
System size

- 13,500 buses
- 2,500 generators
- Must accommodate planned system expansion

Overview - Architecture

User's workstations

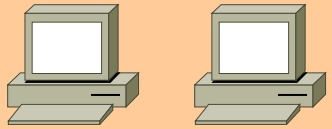
Application Administrator: access **DSA Manager** through Terminal Service
General users: **DSA Monitor** + **Off-line DSATools programs** (local)



Ethernet

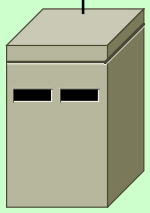
Fiber optics

San storage (**Data server**)



Data server hosts
- Standalone clustered servers

14 IBM blade servers (3.6 GHz dual Xeon CPU per server)
- 2 for TSA&C Clients
- 10 for TSA&C Servers
- 2 for off-line study server



EMS

Overview - Software Engine (TSA vs PSS/E)

- **TSA Algorithm:**
  - **TSA Uses Real-Time System Data to:**
    - Perform transient security
    - Determine preventive control measure
    - Compute stability limits
  - **TSA Employs Nonlinear Time-Domain Simulations**
  - **TSA Use of Early Termination**
    - Early terminate only if the swing margin is within specified thresholds.
    - Can be set to “Off” so simulation is performed for entire duration.

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Overview - Software Engine (TSA vs PSS/E)

Remarks of Comparing Software Engine:

- TSA **produces the same result as PSS/E** on EMS Model.
- TSA **settings can be adjusted to be the same** as PSS/E.
- TSA can **run the same full-time simulation** as PSS/E without early termination.

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Initial Validation - TSA Software and Models

Step 1: Validation of TSA&C software

- Compared with the PSSE transient program by using same cases
- The simulation results of TSA&C and PSSE were same

Step 2: Validation of TSA&C models (Real-time network model, dynamic generator models and contingency models)

- Created same power flow and fault scenarios in both TSA&C real-time models and PJM planning models
- Performed the comparison of the calculation results
- TSA results were consistent with Planning Studies

Note: Results of initial validation provided as addendum to presentation.

Artificial Island Stability Benchmarking Analysis

PU2

Artificial Island Stability Benchmarking Study

- Analysis of the model differences between TSA and Planning
- Internal and External Model Impact

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Analysis of the 9/20/08 03:00 Cases

Study Method	Min MVAr (Total)	Min MVAr (Each)	Difference
Case 0 (PJM EMS Model)	**450**	150	-
Case III (MMWG Planning Case)	**510**	**170**	**-20 (=150-170)**

* Stability criteria is used for Min MVAR computation, ***stability limit regardless of the voltages***

- PJM Planning model was modified to become Case III (**MMWG Planning Case**) with following adjustments:
  - Voltage values and shunts
  - Line and transformer impedances
  - Load level and power factor
- Adjustments were made to reflect real-time conditions of PJM EMS Model Case 0.
- **After adjustment the results have a difference of -20 MVAR for each unit**

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Internal and External Model Impact– EMS vs Planning Model

The Four Cases:

Case	PJM Inside	PJM Outside
Case 0 (PJM EMS Model)	EMS Data	EMS Data
Case I (PJM EMS External Model Inserted into the MMWG Case)	Planning Data	EMS Data
Case II (PJM EMS Internal Model Inserted into the MMWG Case)	EMS Data	Planning Data
Case III (MMWG Planning Case)	Planning Data	Planning Data

- EMS Model (Case 0) is Merged with the MMWG Planning Model (Case III) > Case I & Case II.
- Compare four those different cases.

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Internal and External Model Impact– EMS vs Planning Model

- Result for **2b** Contingency (SLG on 5015 near Hope Creek, 1-3 SB at Hope Creek) :

	Case	Min MVAR* (Total)	Min MVAR (each)	Delta from Case 0
PJM (EMS)	Case 0 (PJM EMS Model)	450	150	
	Case II (PJM EMS Internal Model Inserted into the MMWG Case)	435	145	-5
PJM (Planning)	Case I (PJM EMS External Model Inserted into the MMWG Case)	450	150	0
	Case III (MMWG Planning Case)	510	170	+20

* Stability criteria is used for Min MVAR computation, ***stability limit regardless of the voltages***.

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Internal and External Model Impact– EMS vs Planning Model

Remarks of Model Impact Study for 2b:

1. Highest difference was only 20 MVAR for each unit.
2. Impact of using PJM EMS or MMWG internal model is minimal.
3. Impact of using PJM EMS or MMWG external model is minimal.

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Lessons Learned - EMS Model Verification

- **Ensure PJM EMS Model Parameters Accuracy:**
  - The EMS was updated with latest transmission line impedances from PSEG.
  - The EMS was updated with latest GSU impedances from PSEG.
  - The EMS network topology is updated seasonally to reflect system changes.

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Lessons Learned - Contingency Definitions

- **Single Phase Fault with CB Stuck –> Worst Contingency**
- **Implementation of Contingency Models in TSA**
  - Three Phase Fault Contingency Model.
  - Automated system wide single phase fault with CB stuck contingency model to be implemented in November 2009.
    - Currently implemented as a manual process for a subset of recognized stability areas.
    - Internal PJM Process for TSA to Automatically Obtain the Latest Short Circuit Model from Planning will be Developed.

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Lessons Learned – Fault Clearing Time

- Fault Clearing Time Significantly Impacts Stability Results
- Fault Clearing Times Provided by TOs. TSA Sets Default Fault Clearing Times If No Fault Clearing Times Defined
- PJM Internal Process to Ensure Implementation of Fault Clearing Time in TSA consistent with PJM Planning Stability Study

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Propose Next Steps

1. **Move TSA Project Forward.**
   - Present the TSA Tool to the Planning and Operating Committees
   - Present the TSA Tool to the System Operations Subcommittee
   - Address Concerns from the Committees
   - Develop Operating Procedures
   - Perform Individual Area Benchmarking Studies as Needed with Other TOs to Address Concerns

2. **Transition the TSA Tool into Real-Time Operations on a Stability Area by Stability Area basis.**

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Questions?

Supplementary Analysis

NEPA Interface Studies and Additional Stability Area Validation Analysis

Example - Validation of NEPA Interface

Table. 1 Susquehanna Units

Stability Validation Study -- Transfers out of NEPA

Study	Base Case (MW)	Limit A (MW) Reduction Only at Susquehanna	Delta	Limit B (MW) Reduction at non Susquehanna Units	Delta (MW)
TSA	3571	3181	390	2881	690
Planning	3572	3172	400	2636	936
Difference	1		10		244

Continue Example - Validation of NEPA Interface

Table. 2 Montour Units

Stability Validation Study -- Transfers out of NEPA

Study	Base Case	Limit A Reduction at Montour Units Balanced by PJM units	Delta	Limit B Reduction at non Montour Balanced by remote	Delta
TSA	3571	2911	660	2881	454
Planning	3572	2644	928	2636	830
Difference	1		268		376

Note: The table 2 was shown the MW reduction in Montour units: Limit A indicated sink generators in PJM areas and Limit B indicated sink generators in remote area.

Continue Example - Validation of NEPA Interface

Table. 3 Montour Units

Stability Validation Study -- Transfers out of NEPA

Study	Base Case	Limit A Reduction at Montour	Delta	Limit B Reduction at non	Delta
		Units Balanced by PJM units		Montour Balanced by remote	
TSA	3571	2911	660	2881	454
Planning	3572	3093	479	2636	404
Difference	1		181		50

Note: When we changed planning case more close to the operation case in term of the transient stability. The simulation results were more close each other shown in Table 3.

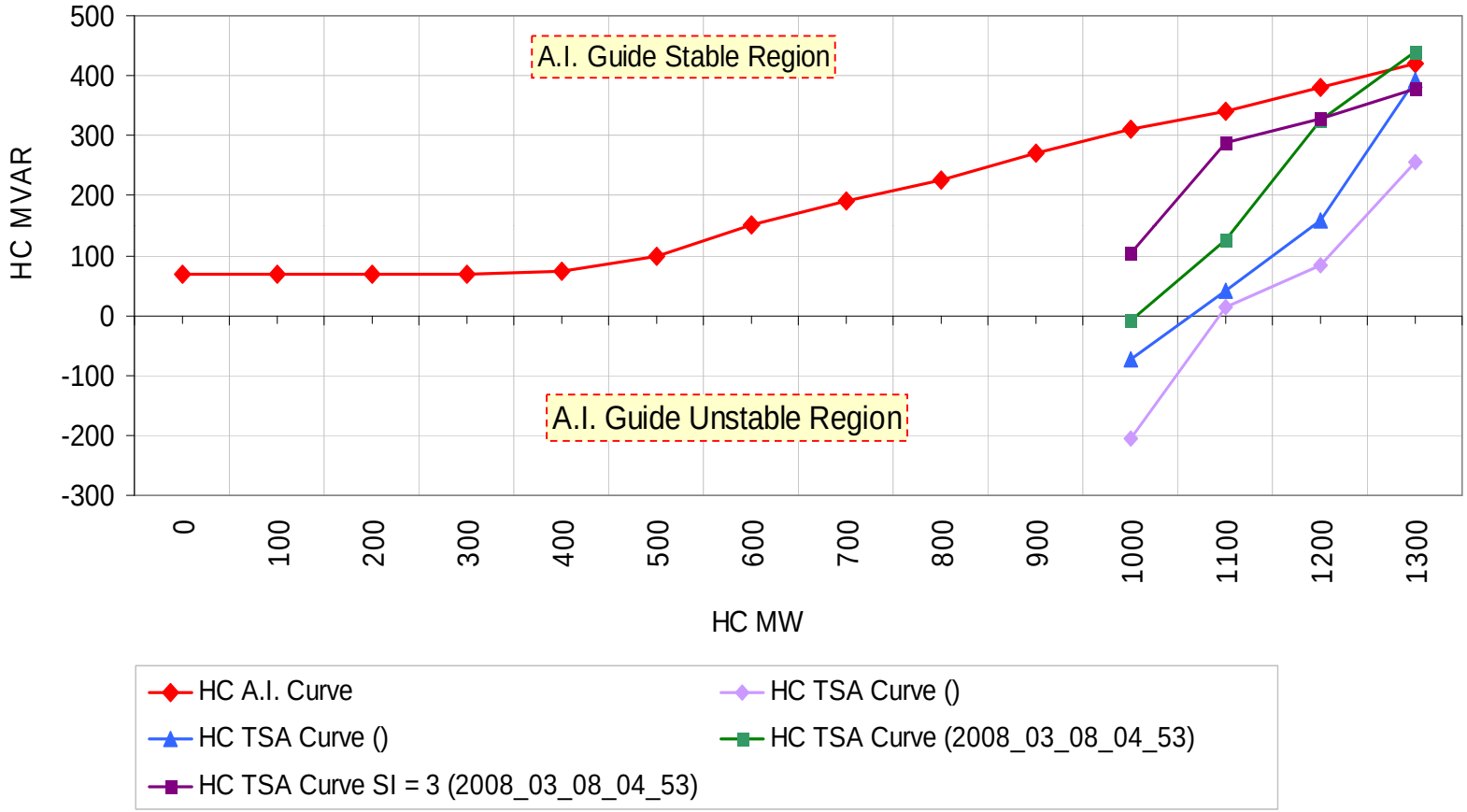
Supplemental analysis and comparisons between TSA and existing Planning limits

List of Stability Areas

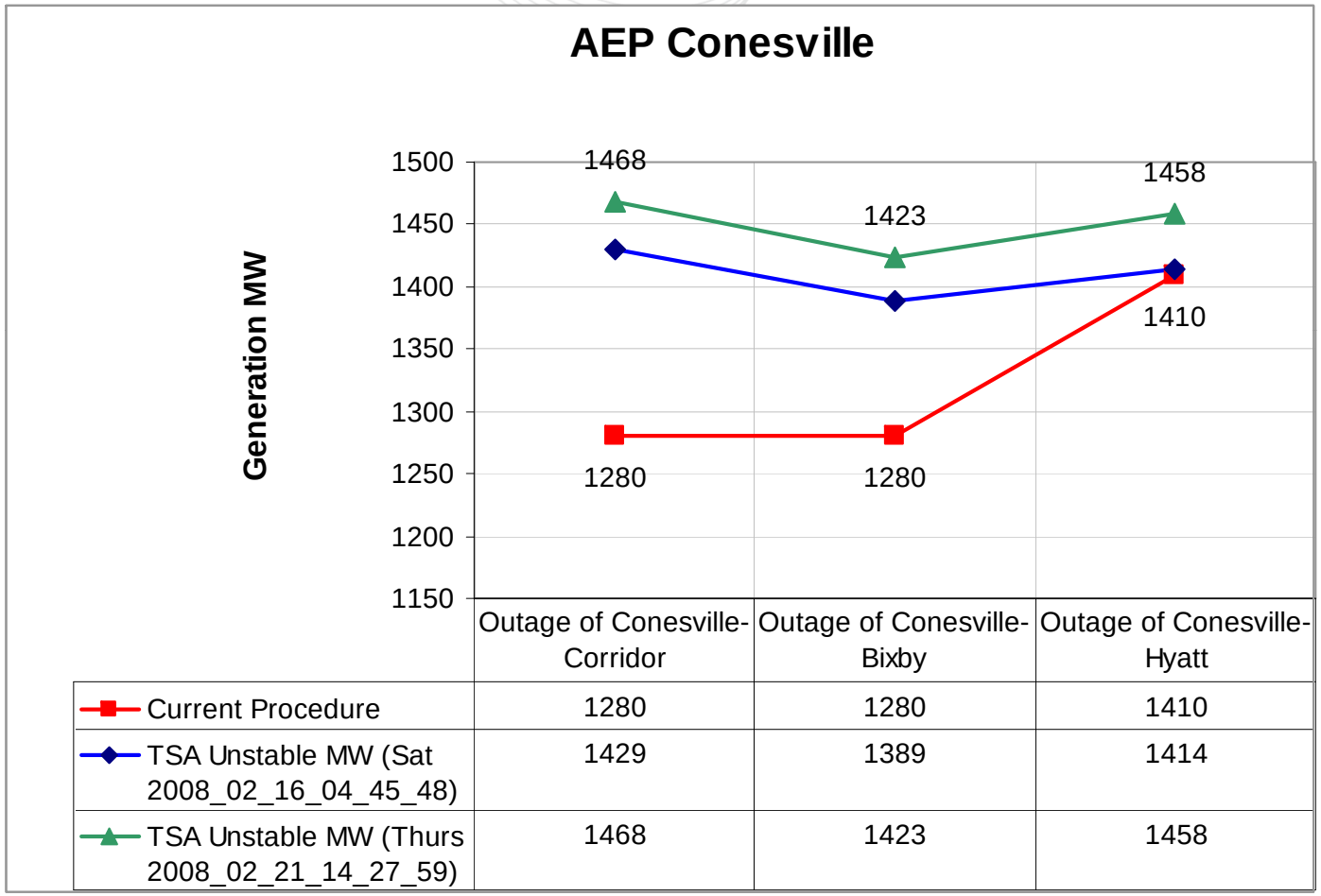
Mid-Atlantic: *Artificial Island, NEPA, Muddy Run, Homer City, Conemaugh*
Dominion: *Clover*
Allegheny: *Belmont/Pleasants, Ronco*
AEP: *Rockport, Conesville, Smith Mountain, Gavin-Mountaineer, Kanawha River – Matt Funk*
COMED: *Byron, Kincaid, Powerton, Quad Cities/Cordova*

Artificial Island Stability Comparison

A.I. Guide-TSA Stability Comparison for Hope Creek
(Hope Creek-New Freedom taken out of service)

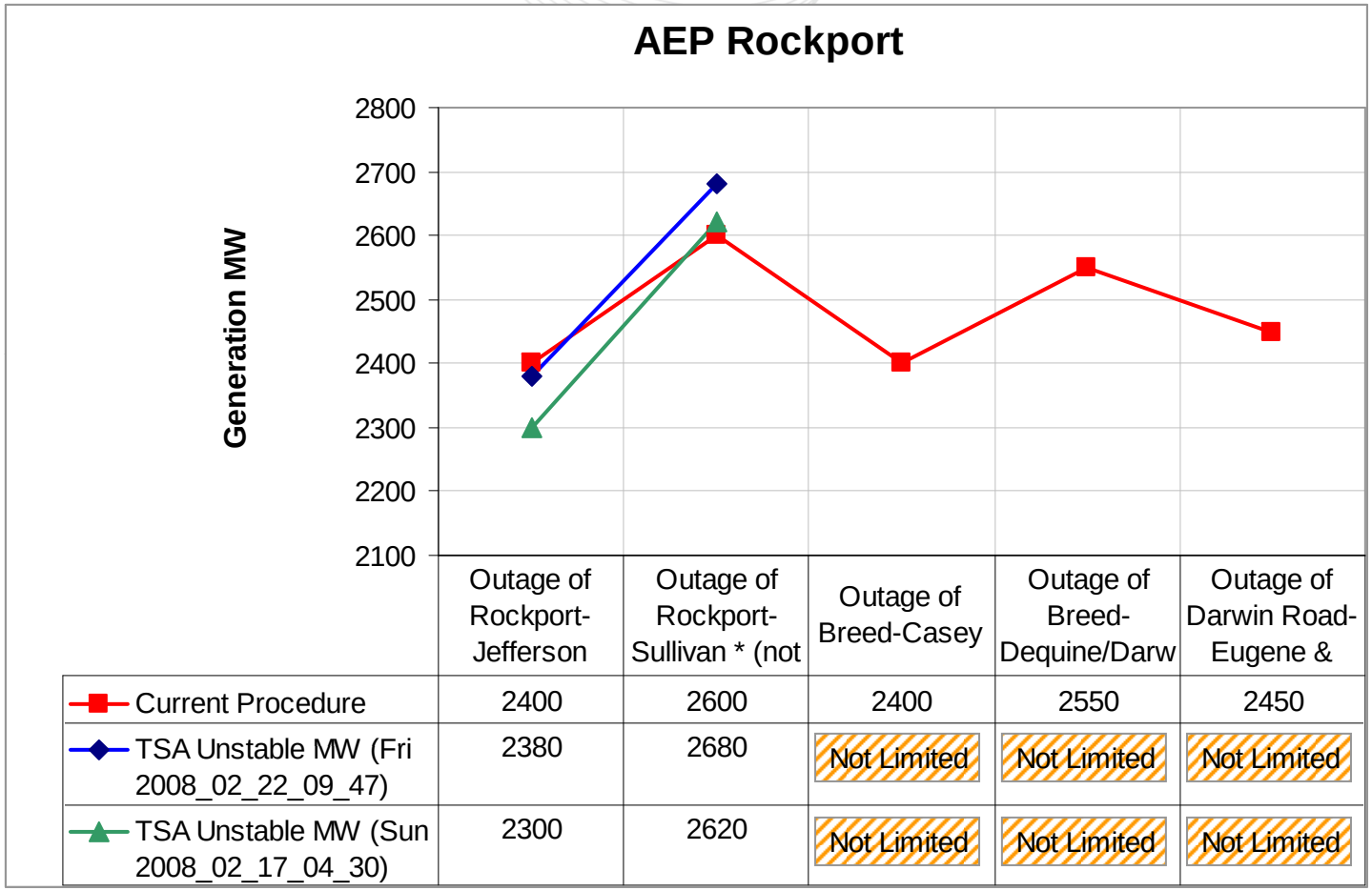


AEP CONESVILL Stability LIMITS Comparison



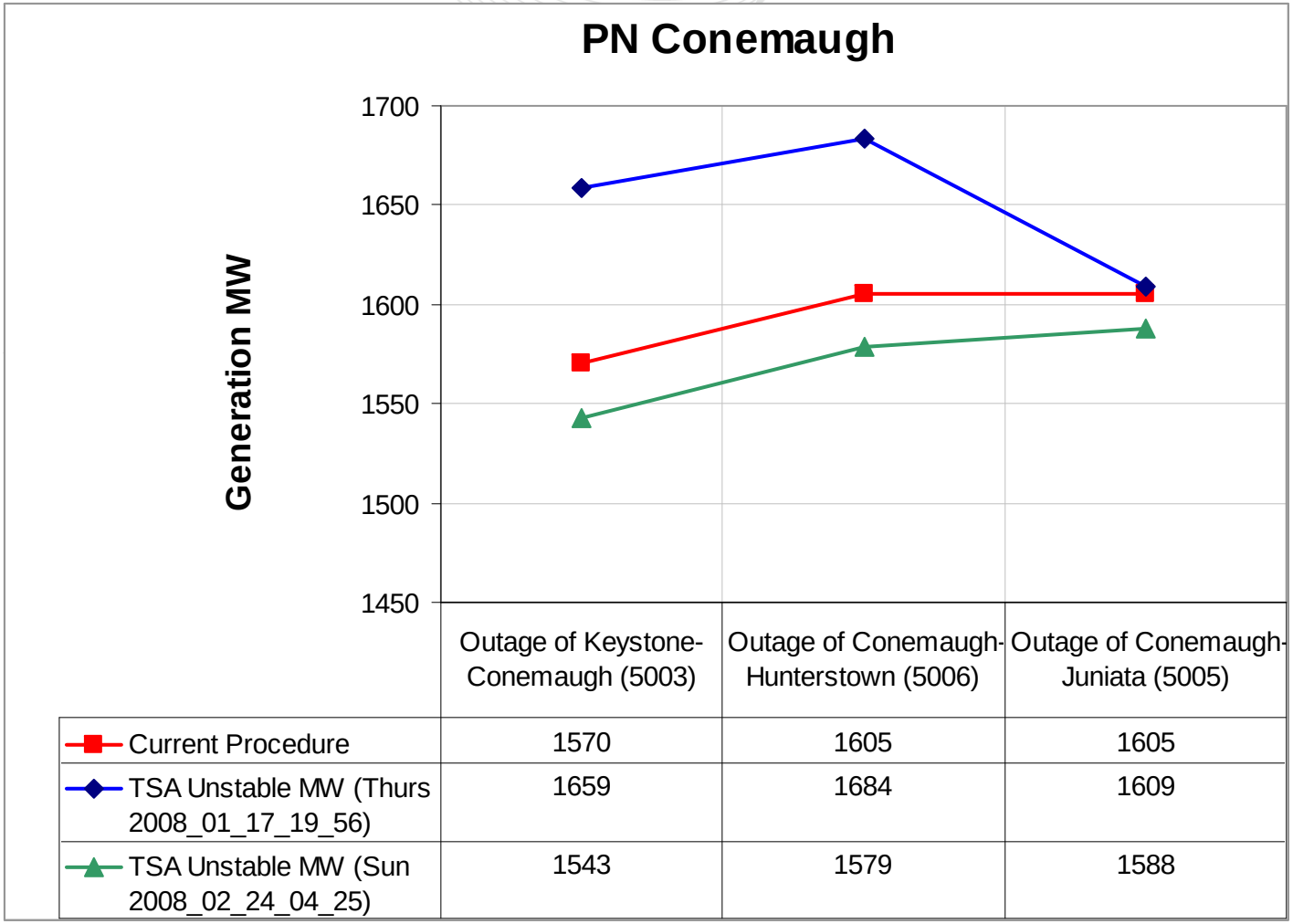
	Outage of Conesville-Corridor	Outage of Conesville-Bixby	Outage of Conesville-Hyatt
Current Procedure	1280	1280	1410
TSA Unstable MW (Sat 2008_02_16_04_45_48)	1429	1389	1414
TSA Unstable MW (Thurs 2008_02_21_14_27_59)	1468	1423	1458

AEP Rockport Stability Limits Comparison



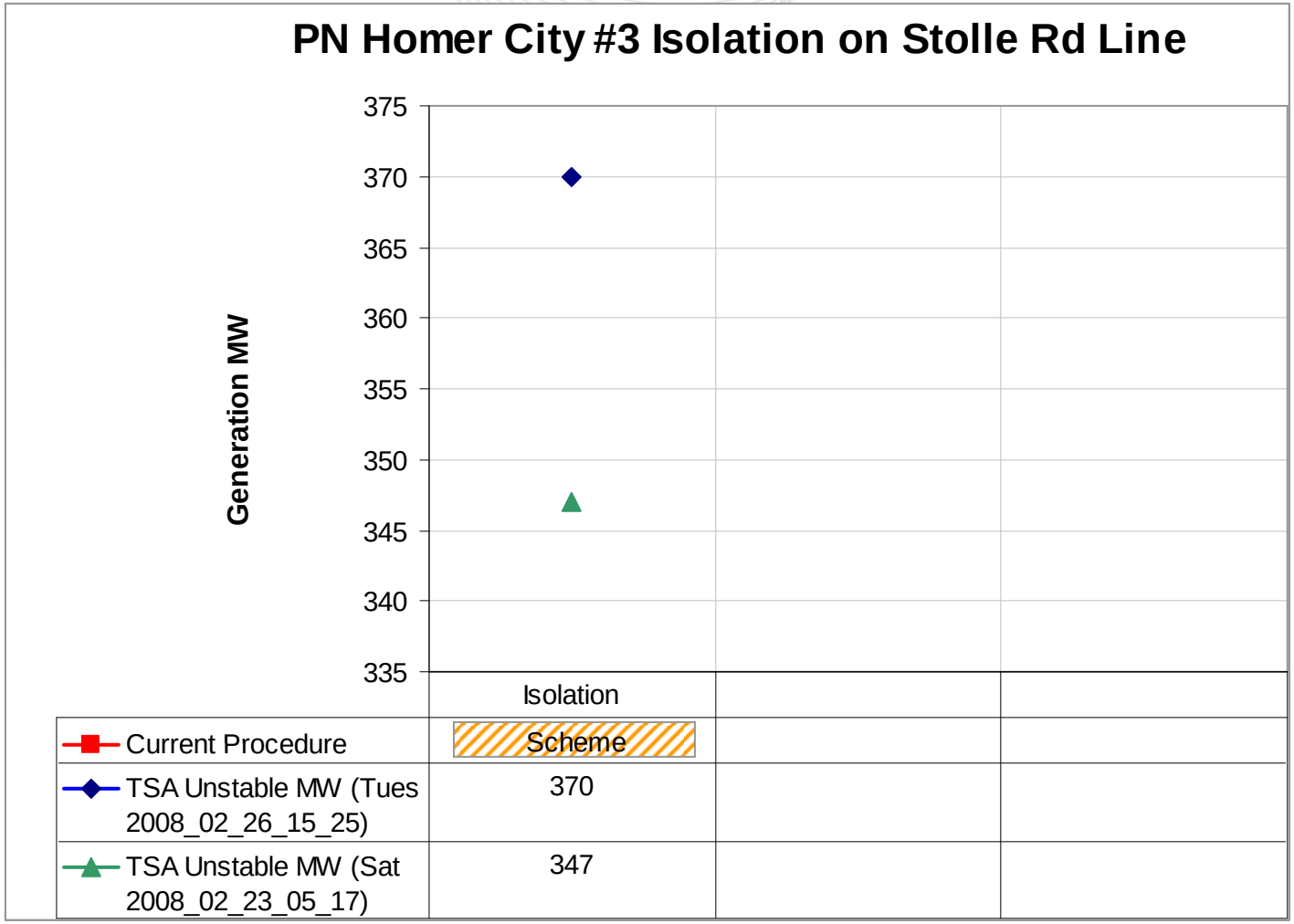
	Outage of Rockport-Jefferson	Outage of Rockport-Sullivan * (not	Outage of Breed-Casey	Outage of Breed-Dequine/Darw	Outage of Darwin Road-Eugene &
Current Procedure	2400	2600	2400	2550	2450
TSA Unstable MW (Fri 2008_02_22_09_47)	2380	2680	Not Limited	Not Limited	Not Limited
TSA Unstable MW (Sun 2008_02_17_04_30)	2300	2620	Not Limited	Not Limited	Not Limited

PN Conemaugh Stability Limits Comparison

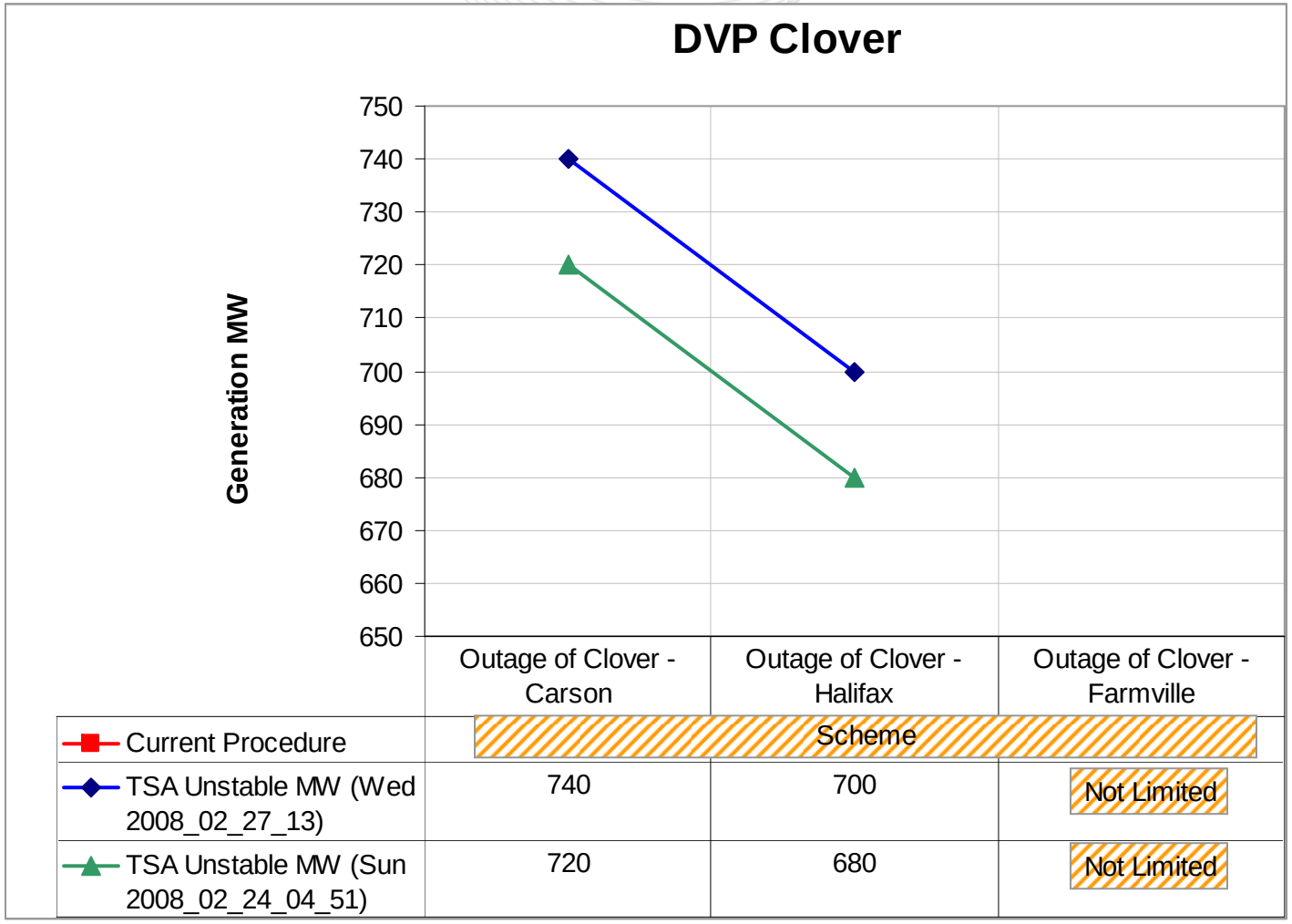


	Outage of Keystone-Conemaugh (5003)	Outage of Conemaugh-Hunterstown (5006)	Outage of Conemaugh-Juniata (5005)
Current Procedure	1570	1605	1605
TSA Unstable MW (Thurs 2008_01_17_19_56)	1659	1684	1609
TSA Unstable MW (Sun 2008_02_24_04_25)	1543	1579	1588

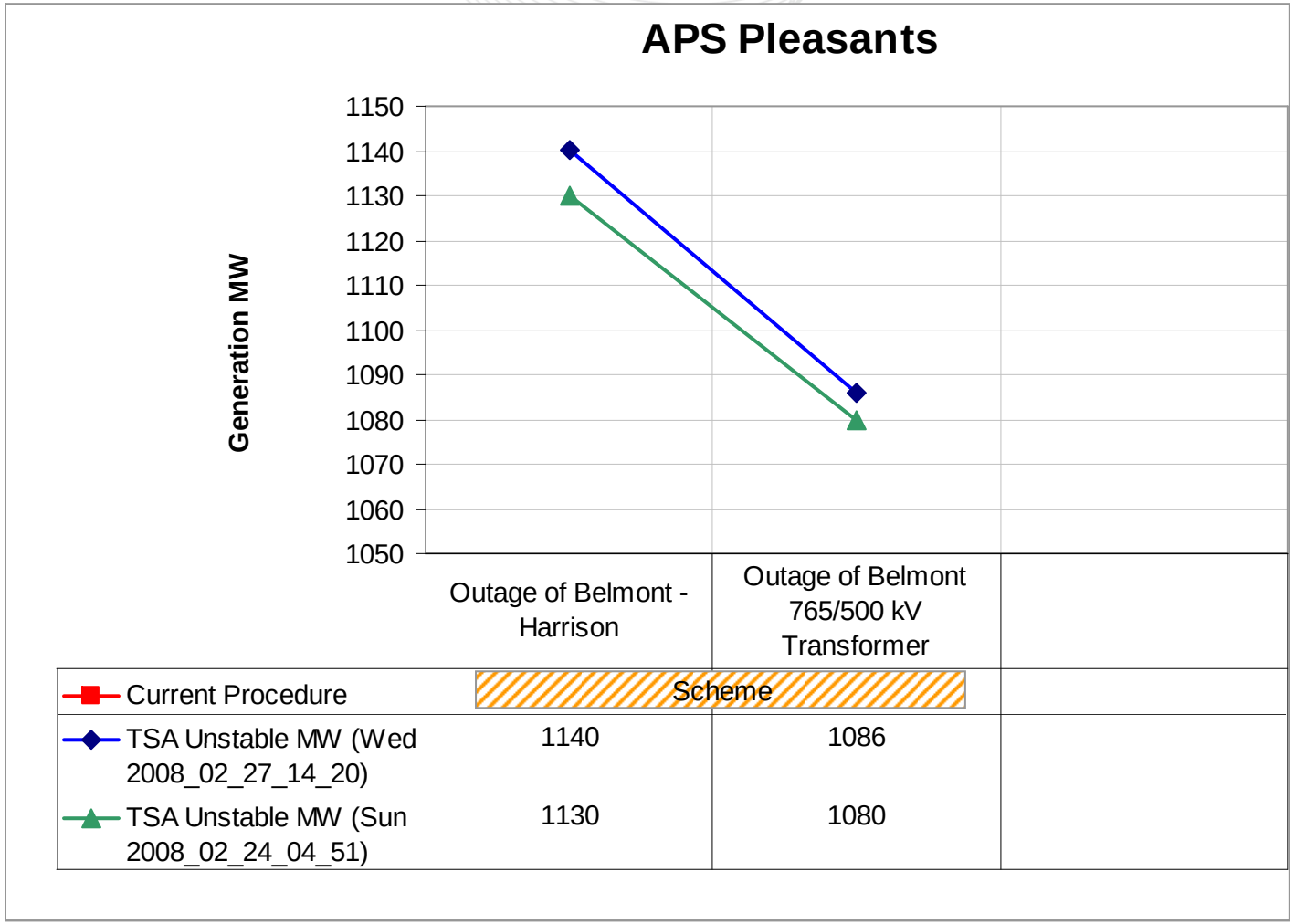
PN Homer City Stability Limits Comparison



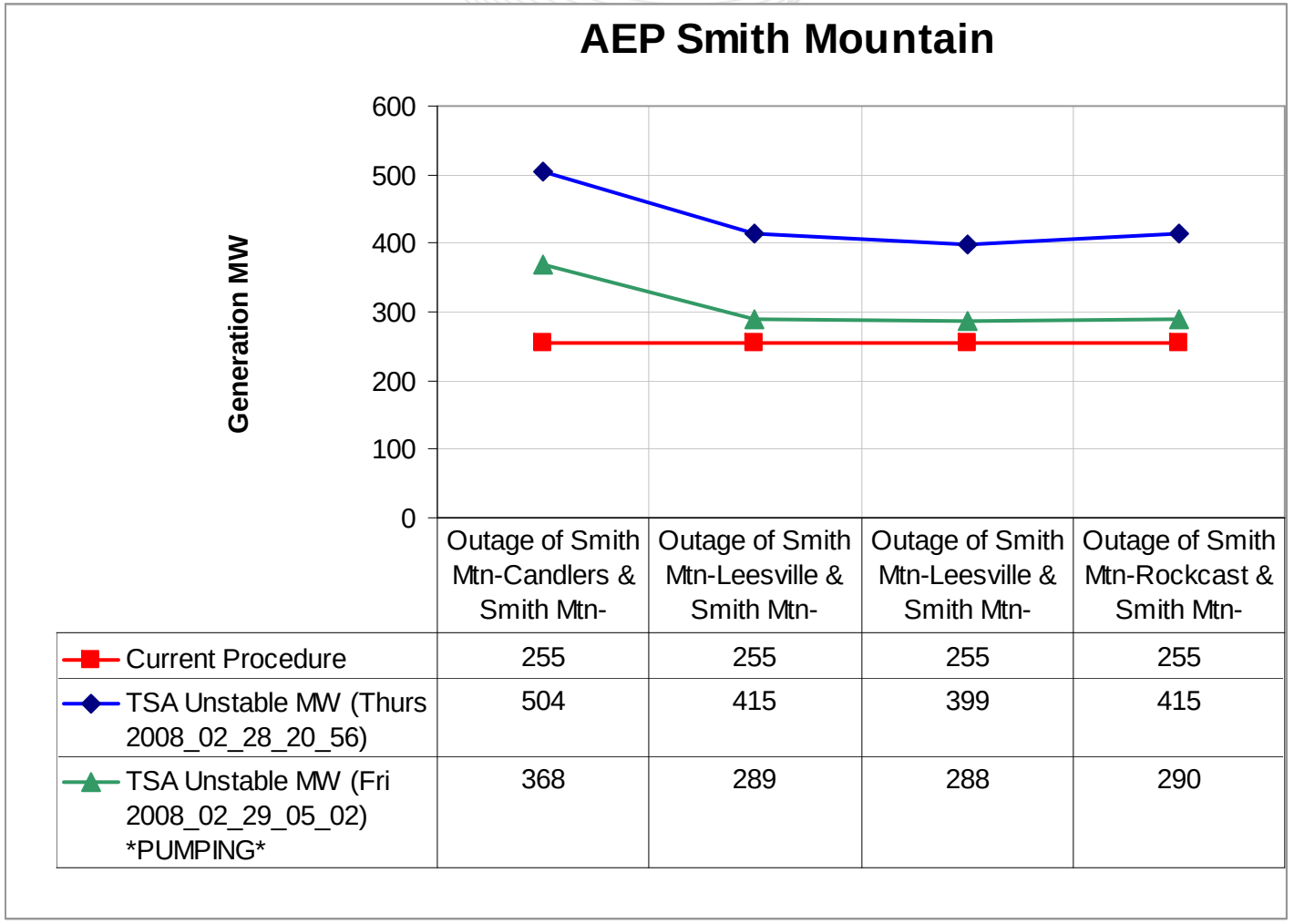
DVP Clover Stability Limits Comparison



APS Pleasants Stability Limits Comparison

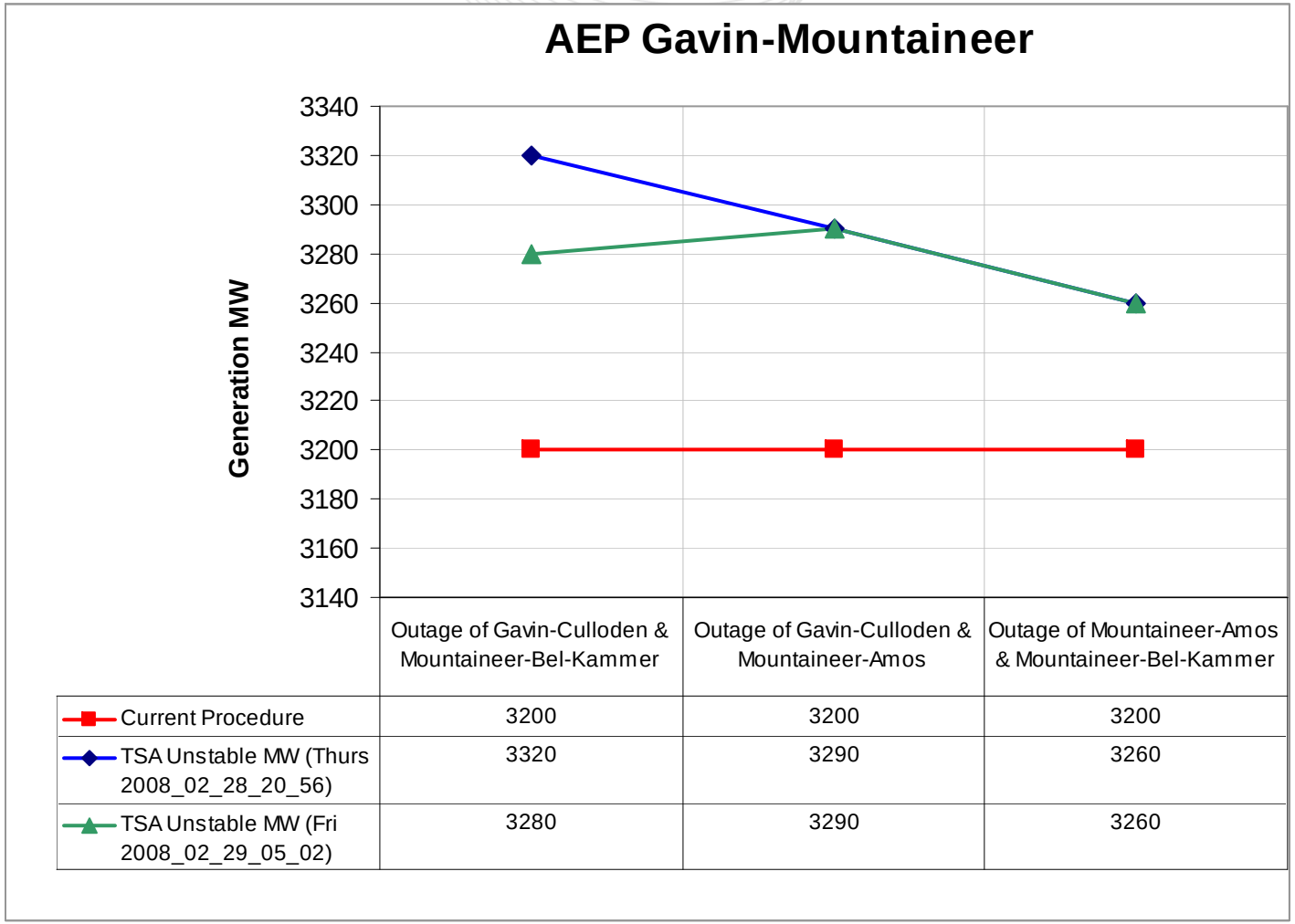


AEP Smith Mountain Stability Limits Comparison



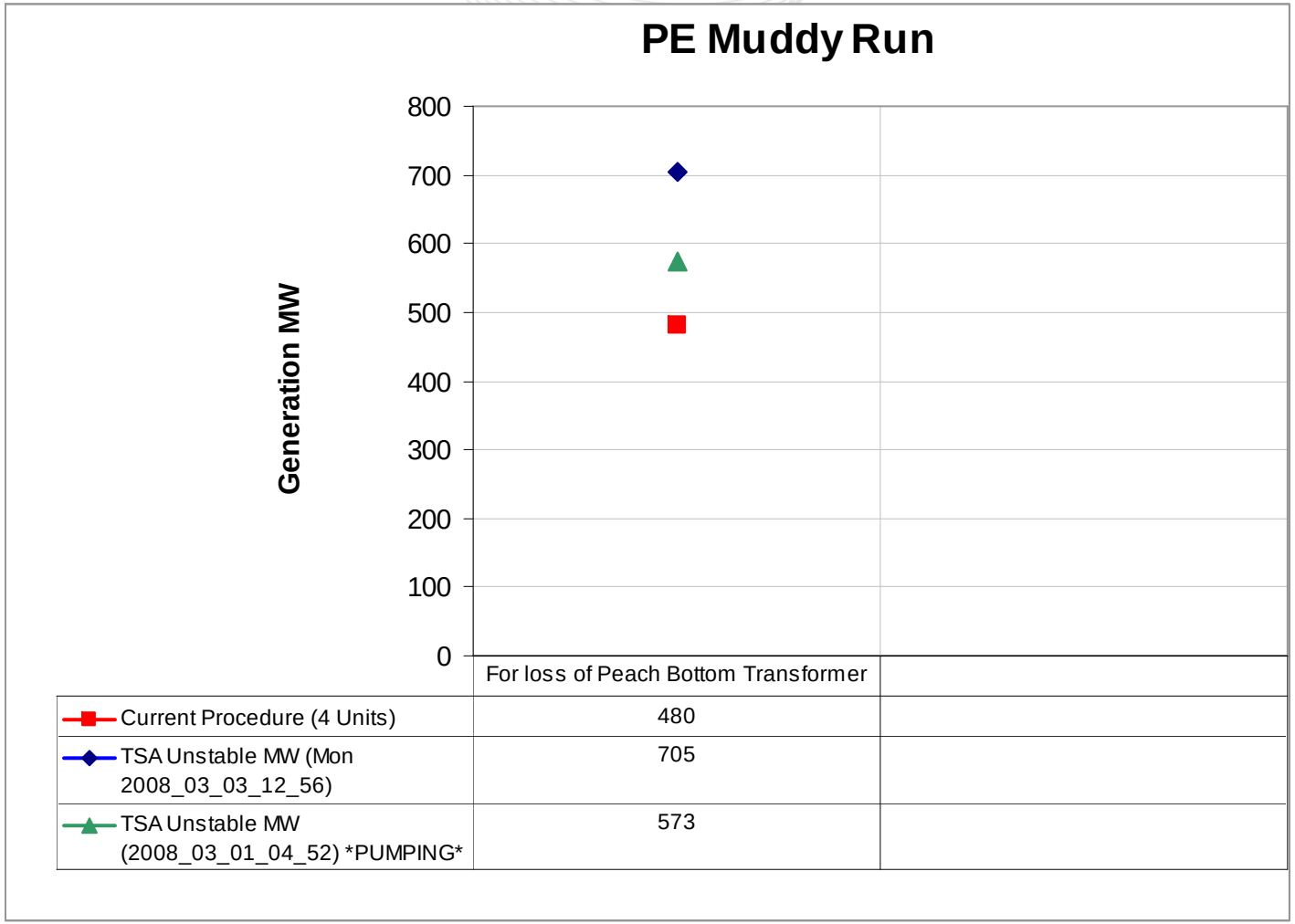
	Outage of Smith Mtn-Candlers & Smith Mtn-	Outage of Smith Mtn-Leesville & Smith Mtn-	Outage of Smith Mtn-Leesville & Smith Mtn-	Outage of Smith Mtn-Rockcast & Smith Mtn-
Current Procedure	255	255	255	255
TSA Unstable MW (Thurs 2008_02_28_20_56)	504	415	399	415
TSA Unstable MW (Fri 2008_02_29_05_02) *PUMPING*	368	289	288	290

AEP Gavin-Mountaineer Stability Limits Comparison



	Outage of Gavin-Culloden & Mountaineer-Bel-Kammer	Outage of Gavin-Culloden & Mountaineer-Amos	Outage of Mountaineer-Amos & Mountaineer-Bel-Kammer
Current Procedure	3200	3200	3200
TSA Unstable MW (Thurs 2008_02_28_20_56)	3320	3290	3260
TSA Unstable MW (Fri 2008_02_29_05_02)	3280	3290	3260

PE Muddy Run Stability Limits Comparison



Remarks of Initial Validation

- The test results produced by TSA software and by PSSE software are same with same input cases
- The test results by TSA operation models and Planning models are consistent. Some of test results showed the differences.
- Review of differences of TSA models and Planning models