Voltage Setpoint Tolerance in Power Flow Solutions

August 2019
Jamie Weber, Ph.D.
Director of Software Development
weber@powerworld.com
217 384 6330 ext 13

PowerWorld Corporation

2001 South First Street
Champaign, Illinois 61820
+1 (217) 384.6330

weber@powerworld.com
http://www.powerworld.com

The Big Idea

- Power flow cases need better generator Mvar output profiles
- Too many generators in power flow cases are at their Minimum or Maximum Mvar output limit

- This presentation shows a simple way to better condition the cases
  - It also better matches how voltage control works in the real world

Motivation for this Idea

- NERC/NATF Technical Conference on Power System Modeling
  – Held in June 20-21, 2017 at ComEd (Exelon) offices
- Shawn Patterson from Bureau of Reclamation gave a presentation on new IEEE 421.5 - 2016 Excitation system models (at least I think that was the topic?)
  – This includes more use of over/under excitation limit models
- One of his main points:
  The first step in improving this ***transient*** stability modeling is to improve the ***power flow*** initial conditions

What needs improvement in power flow models for Excitation Models?

- Most power flow cases have a large number of generators operating at their minimum or maximum Mvar output limits
  – Shawn's comment was that in his experience generators do NOT typically operate near those limits, but power flow cases seem to often be there!
- I took a look at a bucket of power flow cases and looked at the generators and Shawn is right
  – In a typical power flow case, 12 – 25% of generators are operating at a Mvar Limit

Why does Mvar output in power flow matter for transient stability?

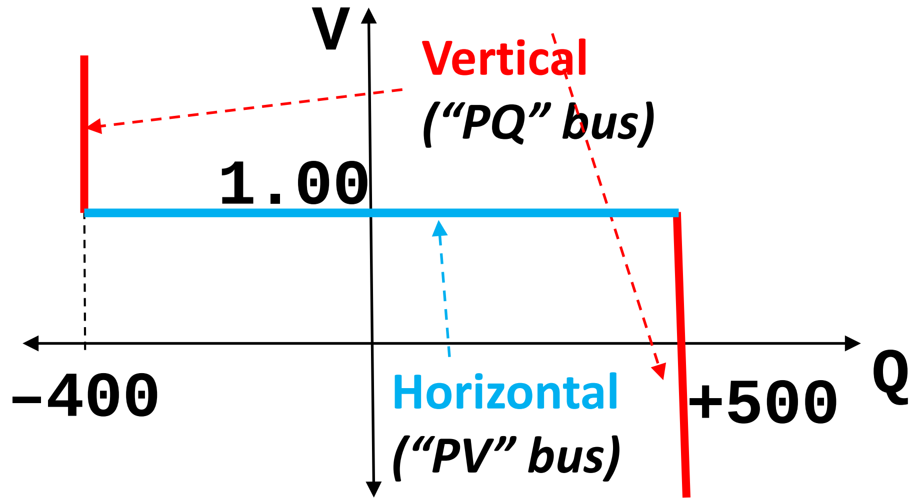
- What if over and under-excitation limiters are implemented throughout transient stability models?
  - If we start near the Mvar limit, then we will be hitting OEL/UEL limits in a transient simulation frequently.
  - If the initial generator Mvar outputs are not right, then hitting these limits is not right
  - Presently in most transient simulations the OEL/UEL models are not included, so there we don’t hit these limits
  - IEEE 421.5 – 2016 standard models suggest we move to modeling these

Go back to the Basic Power Flow

- Hitting MvarMax or MvarMin in a power flow is a function of how the voltage control works.
  - Traditional Power Flow Input data has a voltage setpoint for a generator
  - The generator will then vary its Mvar output to meet this voltage setpoint
  - But the generator Mvar output also is maintained within its MvarMax and MvarMin limits
- If a lot of generators are at limits, this means that the voltage setpoints are not quite right
  - This presentation discusses a modification to what we're doing that can help this.

Generator Voltage Control in Power Flow Solution

- How is generator voltage control modeled now
  - Voltage Setpoint and then Qmax and Qmin
  - Example
    - Vset = 1.00
    - Qmax = +500
    - Qmin = – 400



Revisit a Voltage Setpoint: What are instructions to operator

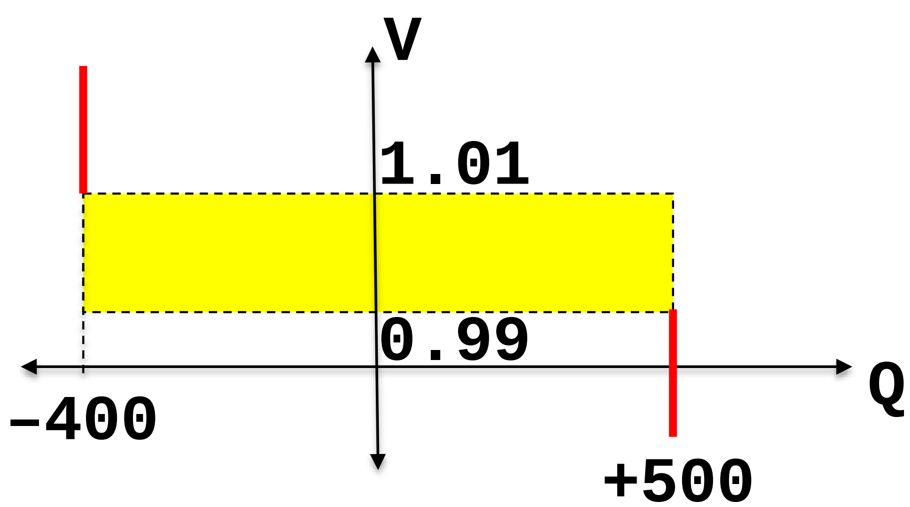
- Generators are given a setpoint (1.035 per unit)

  But they are also given a *tolerance*!

  - Typical values are 0.25% to 2.0%
  - Example: 0.5% = 0.005 per unit, so voltage is really instructed to be between 1.030 and 1.040
- This can be beneficial to consider in the context of a power flow solution!
  - Will give the power flow solution some more flexibility to self-coordinate setpoint

Generator Operating Space

- As an example, consider situation with
  - (Qmin, Qmax) = (– 400 Mvar , + 500 Mvar)
  - Vset = 1.000, Tolerance = 0.01 (1%)
- Thus the instruction for a generator is really
  - **Stay in the yellow box!**
  - Anywhere is fine



What is physically happening here?

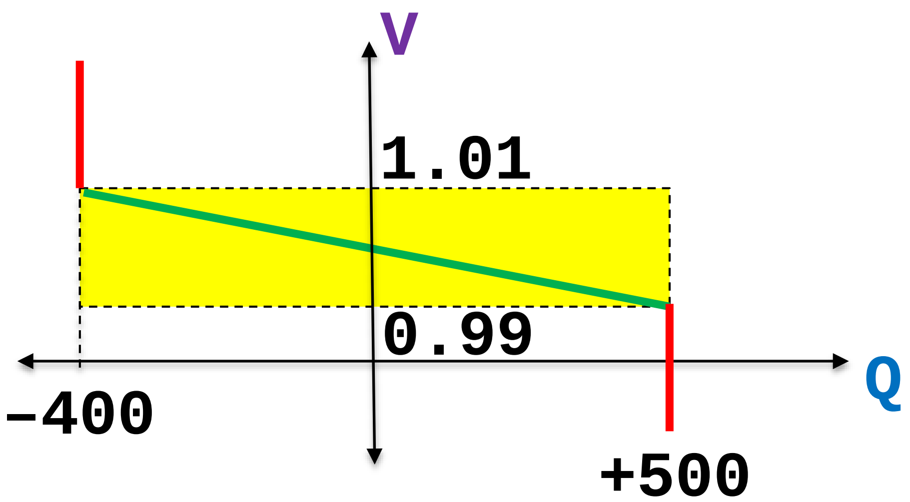
- This is typically *not automated* voltage control
- In practice a traditional large generator is simply told to operating within this tolerance
  - This means as the system moves the generator's local excitation system will cause the generator to respond
  - The operating point will move around in the yellow box
  - If the operating point gets near the edge of the yellow box, the operator (human), will change the voltage reference on the exciter.
- What are we discussing
  - Way to better coordinate generator setpoints
  - In manner that approximates this human behavior

Stay in the Yellow Box!

- In a Power Flow solution, need a more precise statement than just “stay in the yellow box”
  - Otherwise there is no unique solution to the power flow and the initial condition will effect the results
  - For the purposes of a power flow solution, we need
    - dQ/dV must be negative across entire range
      - We can discuss off-line why this is important
    - Must match at the upper left and lower right corners of our box (Q is a continuous function of V)

Use a Voltage Setpoint Tolerance

- Add a green line from (VoltSet – Tol, Qmax) to (VoltSet + Tol, Qmin)
  - Qmax = +500
  - Qmin = – 400
  - VoltSet = 1.00
  - VoltSetTol = 0.01



V = Voltage at the regulated bus.

Q = Summation of the Mvar output of all generators that are participating in the regulation of voltage at this bus.

This is NOT the reactive flow "arriving" at the regulating bus

Voltage Equation is Replaced

- Presently a PV bus enforces the following equation

$$V_{reg} - V_{set} = 0$$

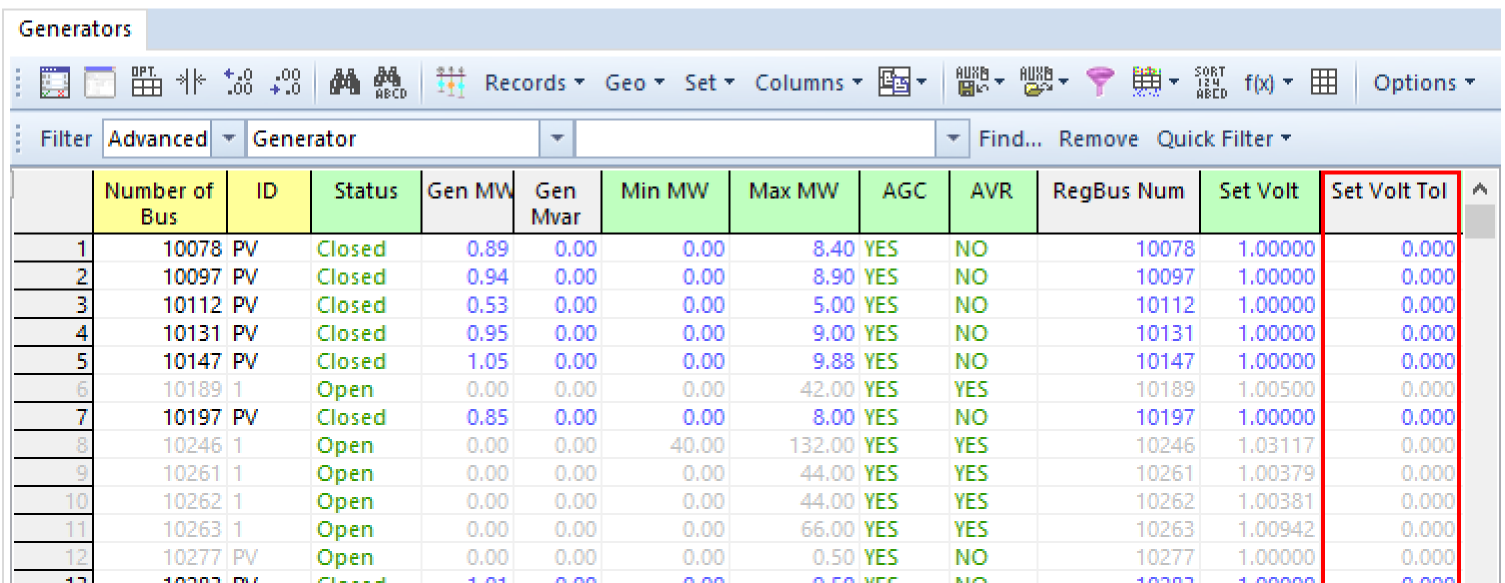
- To represent operation on the green line, this is replaced with the following line equation to create a "PVTol" bus instead of a PV bus.

$$V_{reg} - V_{set} + V_{tol} + \left(\frac{2V_{tol}}{Q_{min} - Q_{max}}\right)(-Q_{gen} + Q_{max}) = 0$$

- The red variables are functions of terminal voltage variables
  - Q_{gen} is the summation of generator Mvar outputs

Software Implementation

- A new field has been added to a generator model to specify the tolerance (**VoltSetTol**)
- So now a generator has 2 parameters: **VoltSet** and **VoltSetTol**


Generators

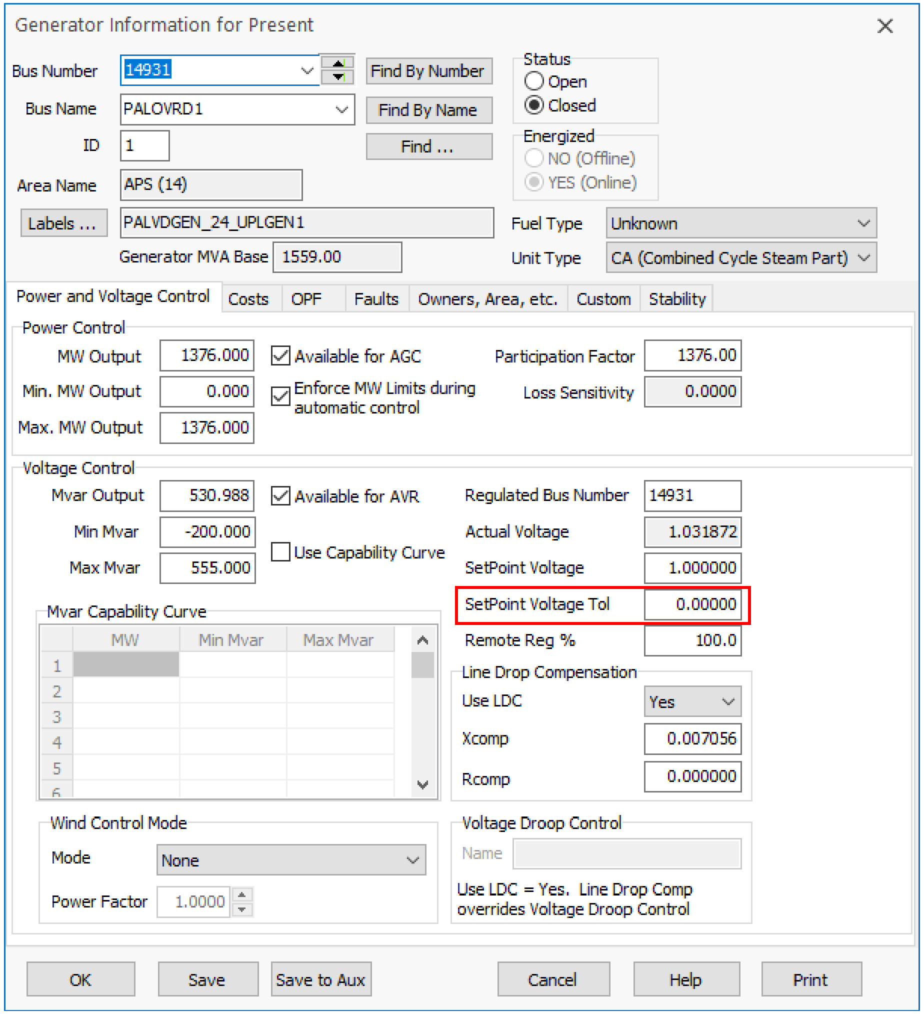
Records ▾ Geo ▾ Set ▾ Columns ▾ f(x) ▾ Options ▾

Filter Advanced ▾ Generator ▾ Find... Remove Quick Filter ▾

	Number of Bus	ID	Status	Gen MW	Gen Mvar	Min MW	Max MW	AGC	AVR	RegBus Num	Set Volt	Set Volt Tol
1	10078	PV	Closed	0.89	0.00	0.00	8.40	YES	NO	10078	1.00000	0.000
2	10097	PV	Closed	0.94	0.00	0.00	8.90	YES	NO	10097	1.00000	0.000
3	10112	PV	Closed	0.53	0.00	0.00	5.00	YES	NO	10112	1.00000	0.000
4	10131	PV	Closed	0.95	0.00	0.00	9.00	YES	NO	10131	1.00000	0.000
5	10147	PV	Closed	1.05	0.00	0.00	9.88	YES	NO	10147	1.00000	0.000
6	10189	1	Open	0.00	0.00	0.00	42.00	YES	YES	10189	1.00500	0.000
7	10197	PV	Closed	0.85	0.00	0.00	8.00	YES	NO	10197	1.00000	0.000
8	10246	1	Open	0.00	0.00	40.00	132.00	YES	YES	10246	1.03117	0.000
9	10261	1	Open	0.00	0.00	0.00	44.00	YES	YES	10261	1.00379	0.000
10	10262	1	Open	0.00	0.00	0.00	44.00	YES	YES	10262	1.00381	0.000
11	10263	1	Open	0.00	0.00	0.00	66.00	YES	YES	10263	1.00942	0.000
12	10277	PV	Open	0.00	0.00	0.00	0.50	YES	NO	10277	1.00000	0.000
13	10283	PV	Closed	1.01	0.00	0.00	9.50	YES	NO	10283	1.00000	0.000

New parameter on a Generator

- VoltSetTol:
  - SetPoint Voltage Tolerance



Software Mismatch Table

- New Bus Types appear called “PVTol”

Mismatches

Records Geo Set Columns

Filter Advanced Bus Find...

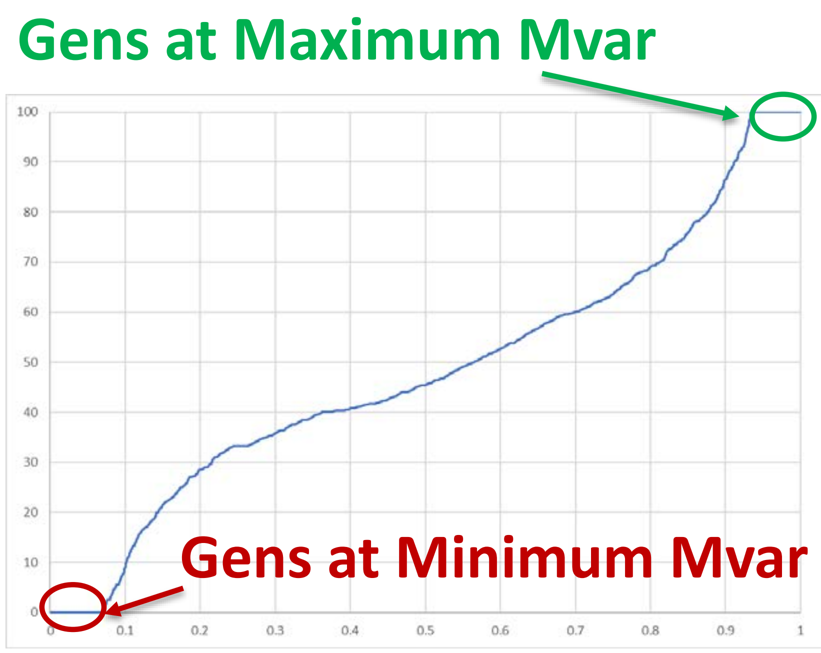
	Number	Type	Mismatch MW	Mismatch Mvar	Mismatch M
2	26011	PQ	0.00	-0.00	0.00
3	26012	PQ	0.00	-0.00	0.00
4	14915	PVtol	-0.00	0.00	0.00
5	14914	PVtol	-0.00	0.00	0.00
6	44212	PQ (Remote Reg Secondary)	-0.00	0.00	0.00
7	79152	PVtol	-0.00	0.00	0.00
8	79151	PVtol	0.00	0.00	0.00
9	44211	PVtol (Remote Reg Primary)	0.00	0.00	0.00
10	37124	PQ (Remotely Regulated at Var Limit)	0.00	0.00	0.00
11	26097	PQ	0.00	0.00	0.00
12	14933	PQ (Remote Reg Secondary)	0.00	0.00	0.00
13	14932	PQ (Remote Reg Secondary)	0.00	0.00	0.00
14	33151	PVtol	-0.00	0.00	0.00
15	66280	PQ (Remotely Regulated at Var Limit)	0.00	0.00	0.00
16	54485	PQ	0.00	-0.00	0.00

Example Cases Used

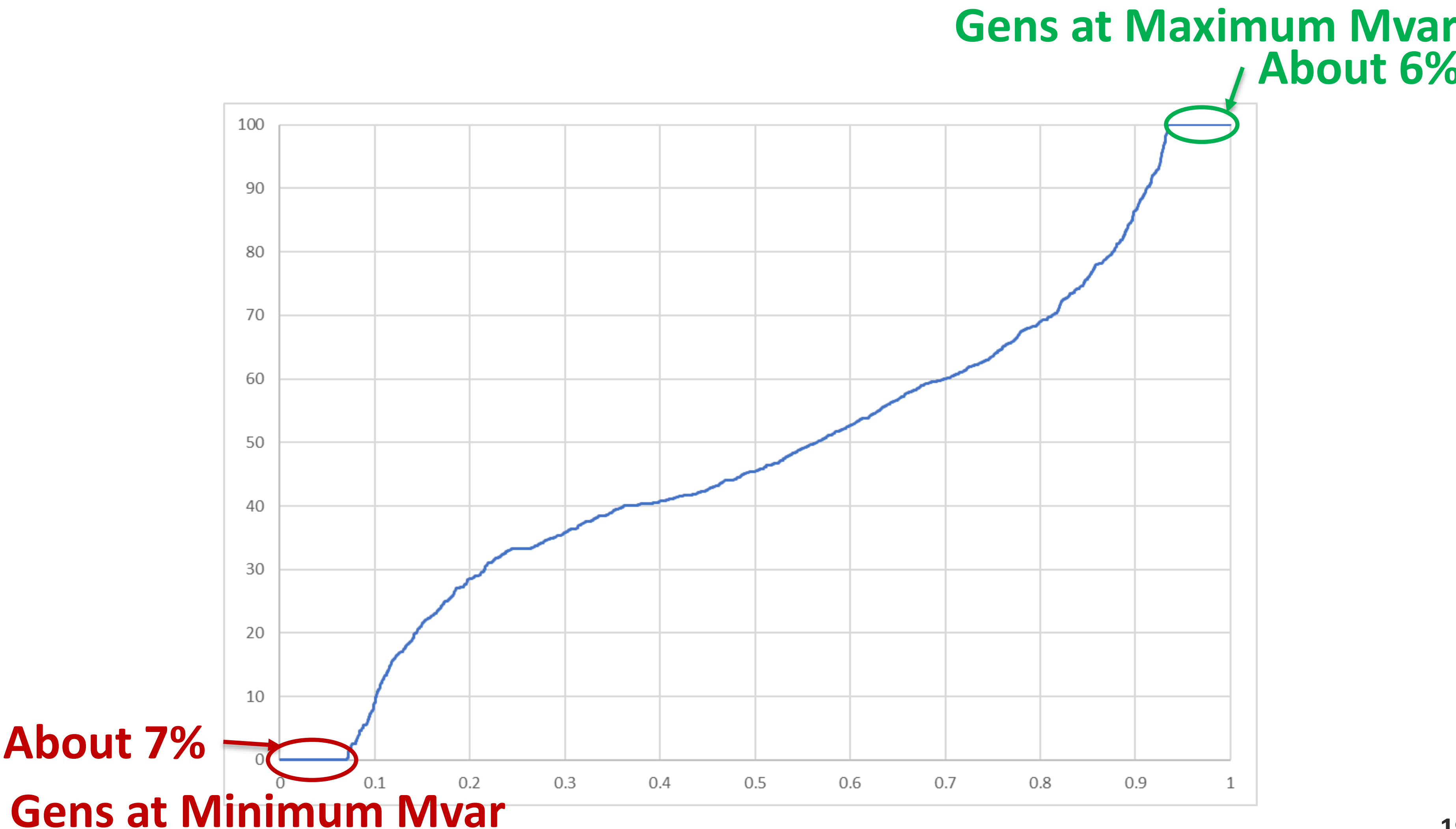
- Took 3 sample cases
  - Western System (WECC)
  - Eastern ERAG MMWG
  - ERCOT Case
- Following plots only show generators with (MaxVar – MinVar > 0.1 Mvar) AND (On AVR)
  - WECC case had 3309 generators
  - ERAG MMWG case had 5087 generators
  - ERCOT case had 711 generators

Visualization of Generator Mvar Solutions

- Example solutions showing where generators are at within their Mvar Range
- Y-Axis of Plots
  - 100 = Gen at MvarMax
  - 0 = Gen at MvarMin
- X-Axis of Plots
  - Portion of generators operating at or below this point in range

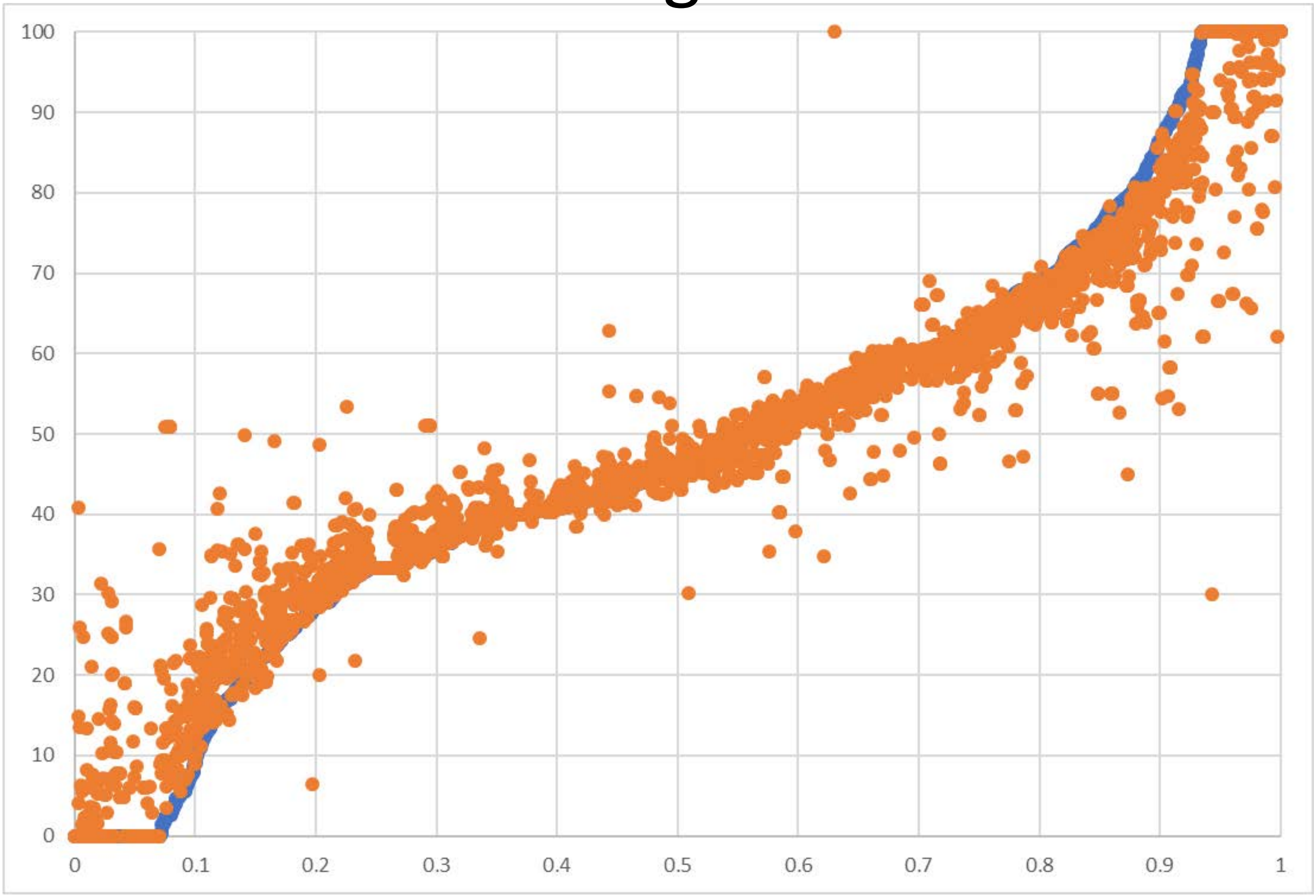


WECC Initial Case



WECC Solution with VoltSetTol = 0.01

- Notice that overall generators move toward the middle of their Mvar range

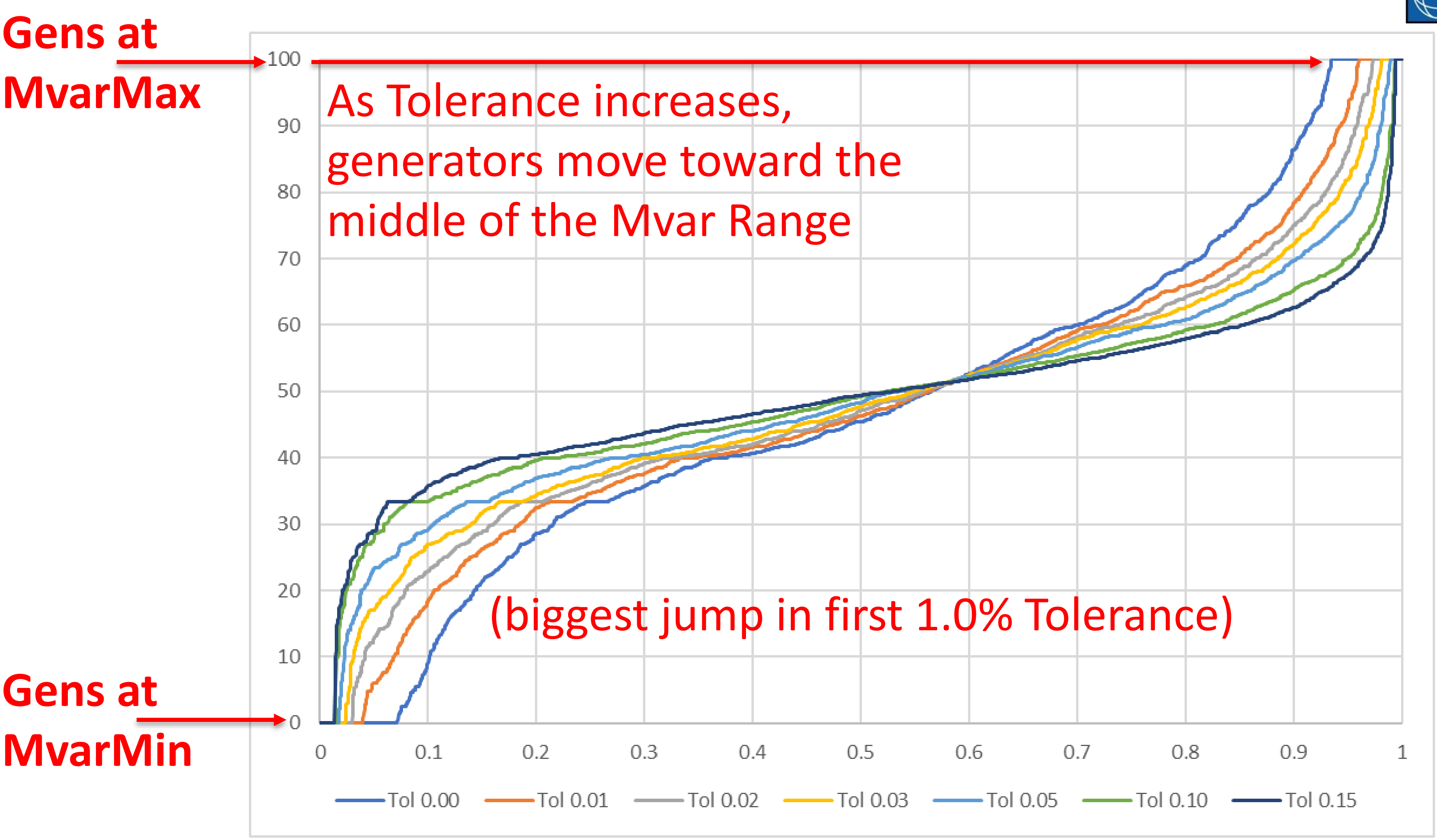


WECC Example

- Performed solutions with a range of tolerances
  - From 0.01 (1%) up to 0.15 (15%)
  - Big Drop in units at Max and Min even for a 1% tolerance

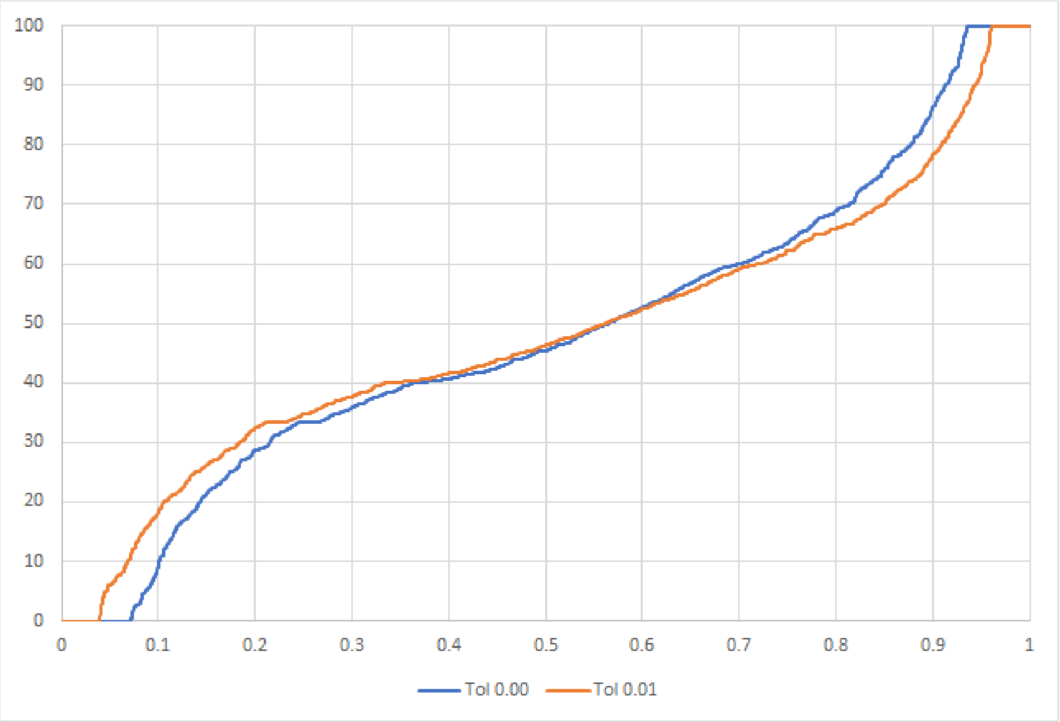
	At Min	At Max	At Min or Max
Initial Case	7.04%	6.32%	13.36%
Tolerance 0.01	3.90%	3.90%	7.80%
Tolerance 0.02	2.99%	2.69%	5.68%
Tolerance 0.03	2.36%	1.90%	4.26%
Tolerance 0.05	1.75%	1.06%	2.81%
Tolerance 0.10	1.39%	0.63%	2.02%
Tolerance 0.15	1.36%	0.54%	1.90%

WECC Tests with several tolerances



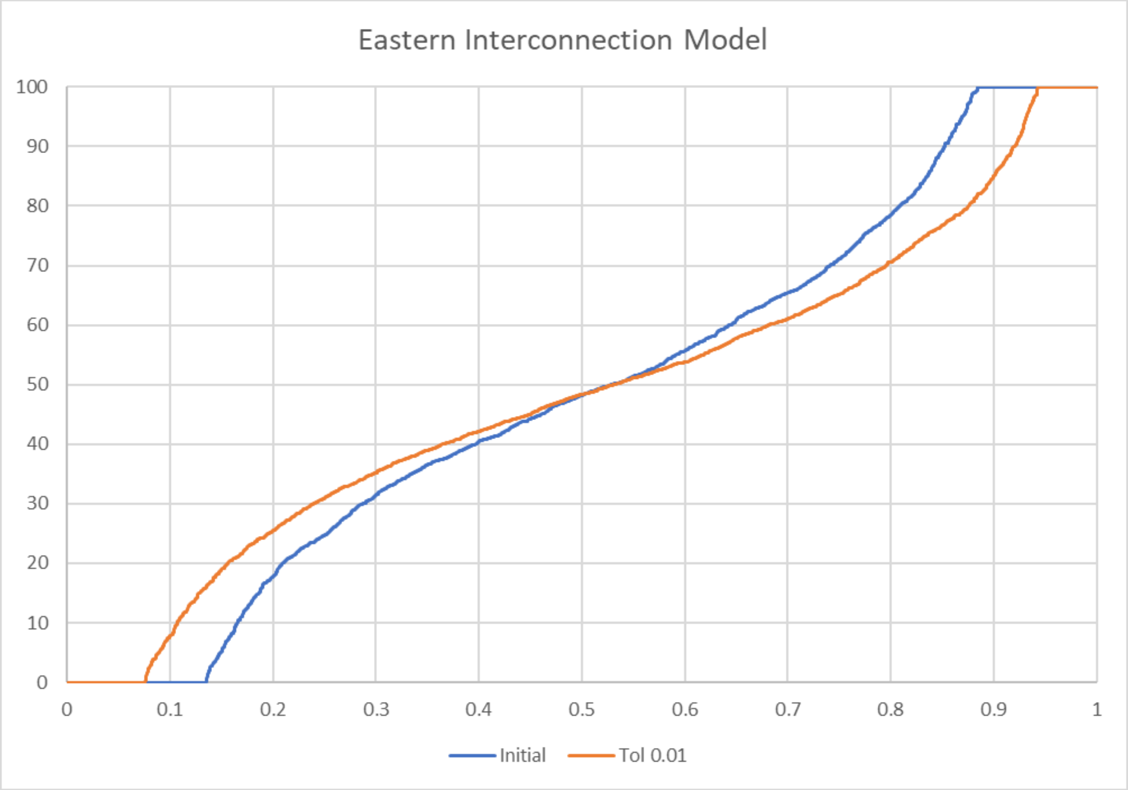
WECC Example
Adding 1% Tolerance

	At Min	At Max	At Min or Max
Initial Case	7.04%	6.32%	13.36%
Tolerance 0.01	3.90%	3.90%	7.80%



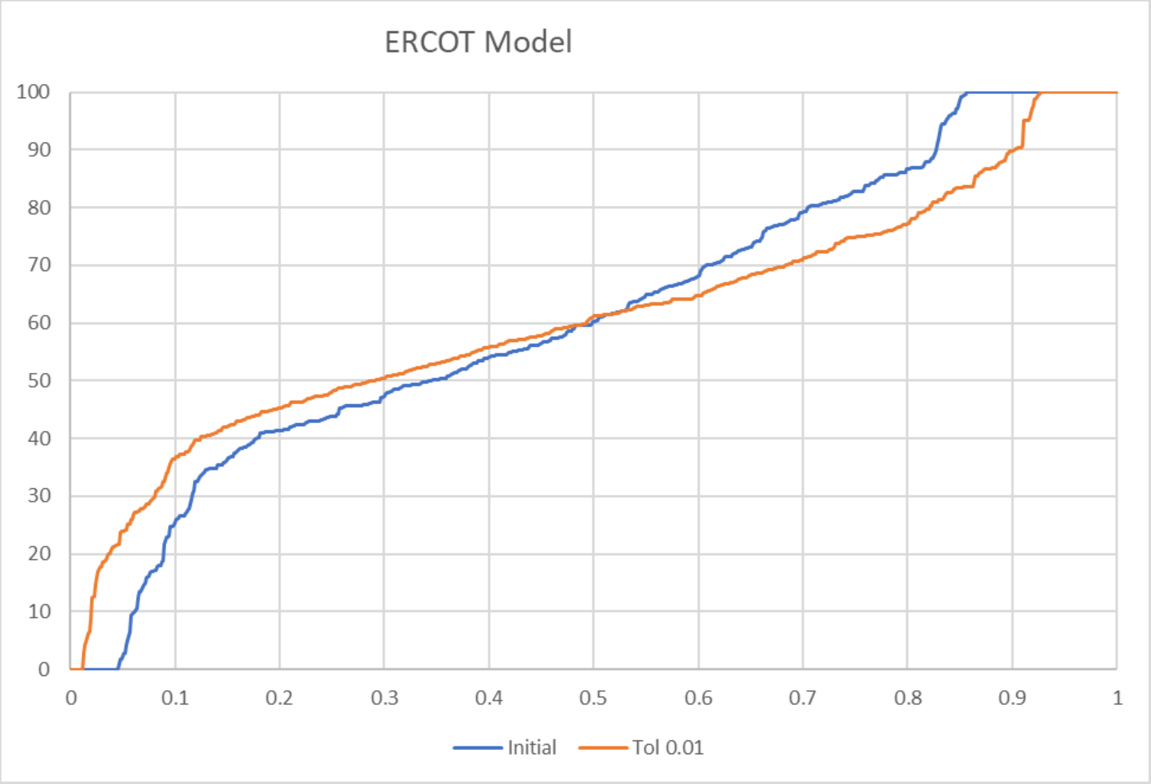
Eastern Interconnect Example
Adding 1% Tolerance

	At Min	At Max	At Min or Max
Initial Case	13.51%	11.54%	25.04%
Tolerance 0.01	7.55%	5.72%	13.27%



ERCOT Example
Adding 1% Tolerance

	At Min	At Max	At Min or Max
Initial Case	4.50%	14.49%	18.99%
Tolerance 0.01	1.27%	7.31%	8.58%

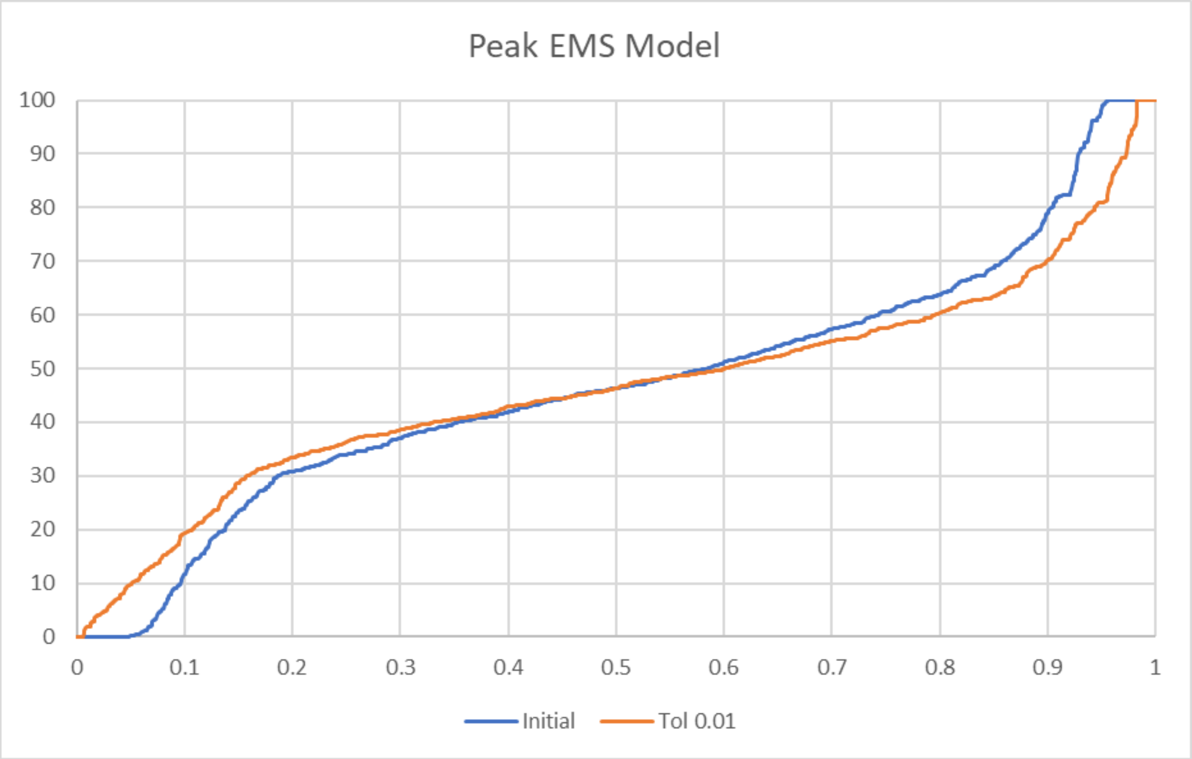


An aside: I took a look at a Real-Time EMS snapshot for Peak Realiability

- Did same analysis which largely confirms our assumption
  - Case had many fewer generators at Mvar limits
  - Also, for those generators at Mvar limits they were much closer to backing off the limit (i.e. the regulated voltage wasn't that far away from the setpoint)
  - Introducing the voltage tolerance in the EMS case reduced the generators at limits even more

Peak EMS (West-Wide System Model) Adding 1% Tolerance

	At Min	At Max	At Min or Max
Initial Case	4.45%	4.26%	8.71%
Tolerance 0.01	0.65%	1.77%	2.42%



Conclusion

- Adding in a small Voltage Setpoint Tolerance does move generators away from their Mvar limits as expected
  - Voltage setpoint tolerance should become part of our input parameters in power flow cases
  - This is how generator control is done as well
- Initial testing shows
  - Implement this does NOT cause numerical troubles in the power flow solution, but make solution more stable
  - Tolerance helps with badly coordinated setpoints
- PowerWorld Help Documentation Link
  - https://www.powerworld.com/WebHelp/#MainDocumentation_HTML/PowerFlow%20Voltage%20Setpoint%20Tolerance.htm