Validation and Accreditation of Transient Stability Results

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PSERC Project S43

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  - Project was funded entirely at BPA
- Special thanks to Jamie Weber (PowerWorld) and Juan Sanchez (GE) for their help!

Project Overview

- Goal of project is to perform validation of the transient stability packages
  - Commonly thought that different transient stability packages give different results for the same system conditions
  - Software validation is (according to DOD), "The process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model."
  - This project is just focused on validating the packages against each other, as opposed to with real world data (which would be a natural follow-on)

Project Importance

- Transient stability looks at the time-domain response of a system following a disturbance (contingency) for several seconds to minutes
  - Integration timestep is usually ¼ or ½ cycle
  - Assessing angular and short-term voltage stability
- System stability is a growing concern, partially because of more wind integration
- PMUs providing more dynamic observability

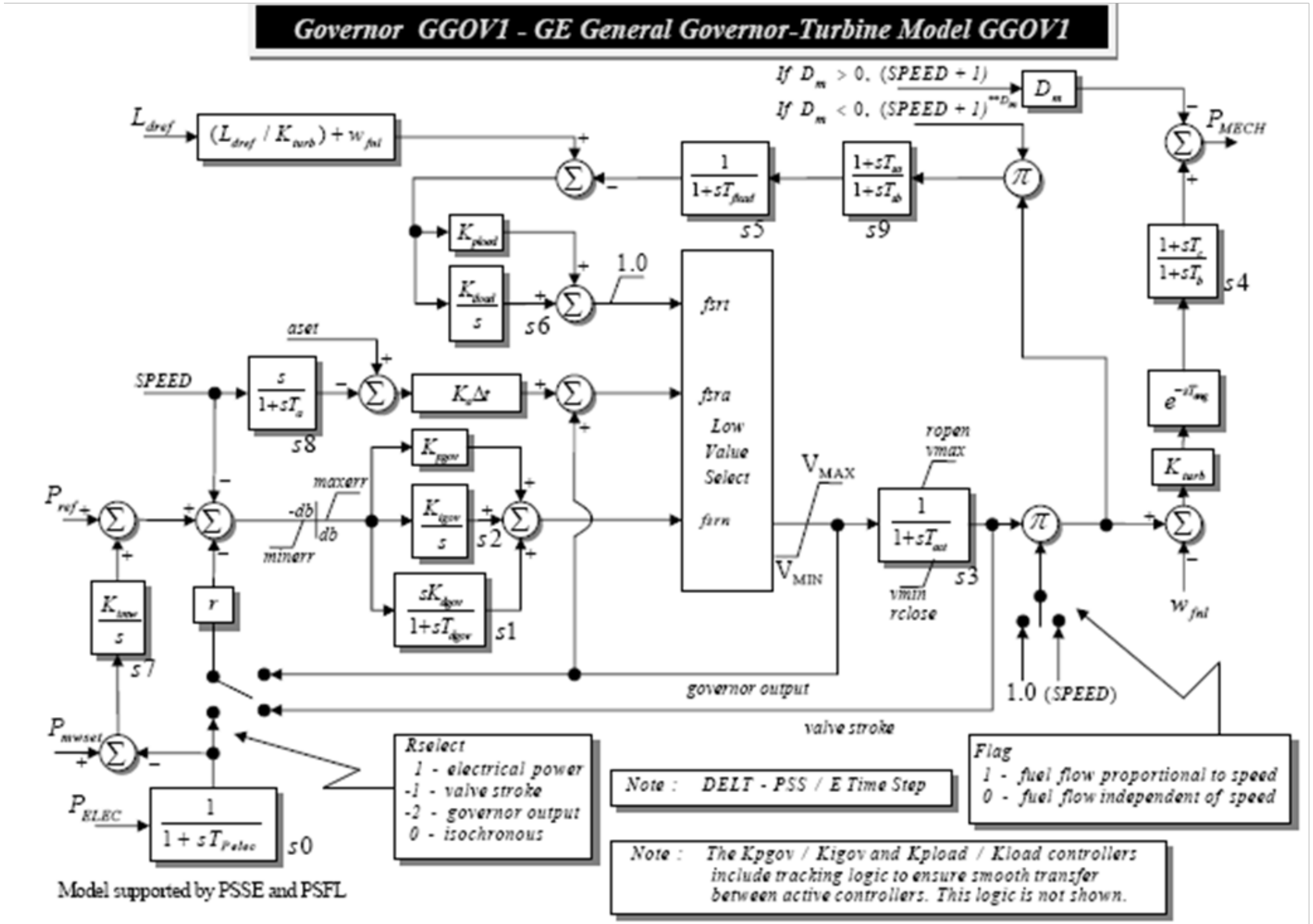
Background

- Transient stability packages being validated are PSLF, PSSE, TSAT, and PowerWorld Simulator
  - UIUC took the lead with PSSE and PowerWorld, WSU with PowerTech, and BPA with GE
- Ultimate project purpose is to enhance the utilization and reliability of the existing transmission system, and provide for more optimal system expansion. Large dollar values are at stake!
  - Providing a cross-checking of the different package results
  - Allowing for more competition in the transient stability market, hence helping to foster innovation

Project Challenges

- Key challenges include the sheer number of models that need to be validated.
  - WECC case has more than 3300 generators, 8200 loads, 77 different dynamic models (PSLF)
  - Individual dynamic models can have dozens of parameters that can substantially affect the behavior of the models
- The PSLF and PSSE packages often use different models to represent the same generators/loads
  - PowerWorld Simulator implements both sets
- Model parameters are sometimes incorrect, with values often automatically "corrected"

Model Example: GGOV1



Often some portions of the models are ignored. For example, only 51 out of 861 WECC GGOV1 governor models implement engine time delay.

Project Caveats

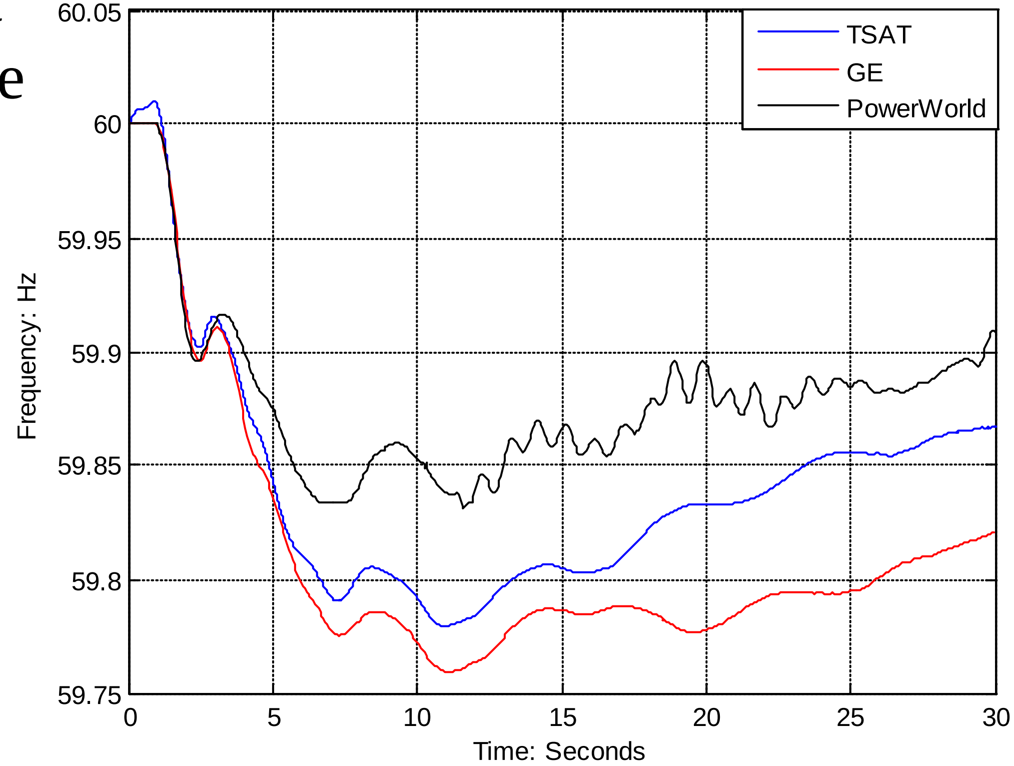
- Project required a deep knowledge of the transient stability solution process and the ability to solve large systems using the different transient stability packages
  - Net gain to industry when students graduate, but there is also a loss of university expertise
- Project focused primarily on PSLF and PowerWorld, and on the WECC system
  - Pointing out problems is not meant to imply they are “worse” than others, such as the Eastern Interconnect model; it just wasn’t studied

Data Confidentiality

- Many of the studies done for this project utilized confidential information that was provided to UIUC and WSU under NDAs
- These slides are the associated PSERC report are intended for eventual public release
- Therefore sometimes we need to be intentionally “vague” about the models

The Starting Point

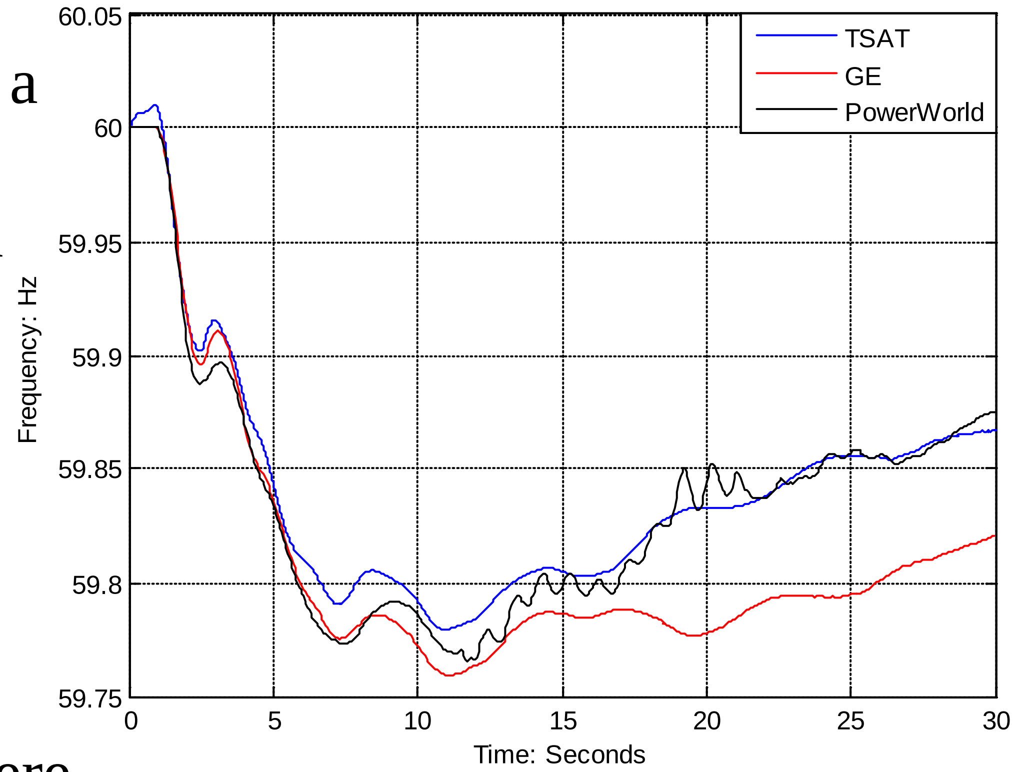
In May 2010, as the project was just beginning, we were able to do comparisons for a full WECC case (provided by BPA) between PSLF, TSAT and PowerWorld Simulator. The plot on the right shows the variation in a bus frequency following a large system disturbance for the three packages



We moved forward with both a top-down (full system) and bottom-up (individual model) approach

The Top-Down Approach

Within a week or two we were able to determine that a bug in how the frequency deviations for the induction motor loads were being handled by PowerWorld was causing some of the frequency variation. The new run is shown on the right. The oscillation in the PowerWorld frequencies were tracked down to a model error.

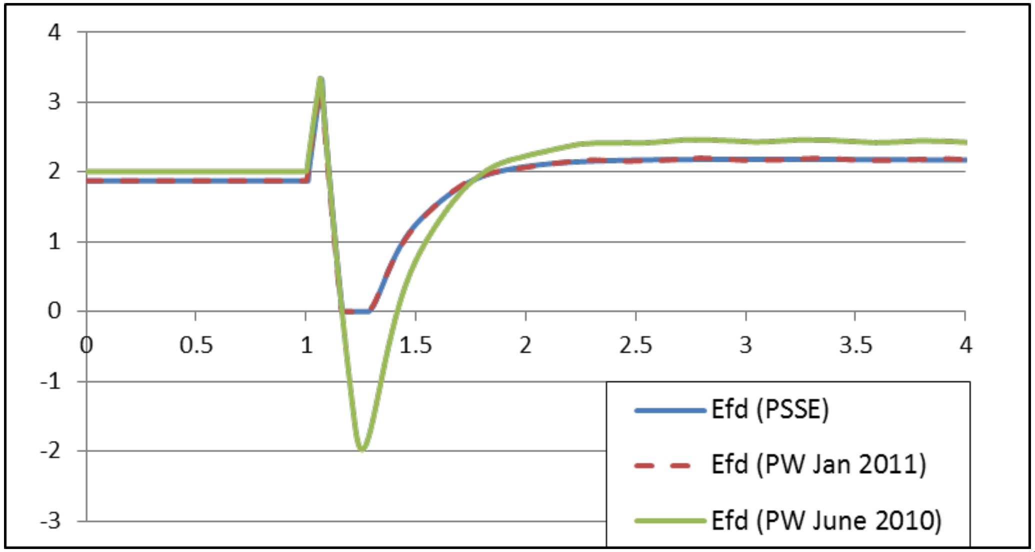


Model error was at the xxxxx generators associated with line drop compensation; fixed by auto-correction

Bottom Up Approach

- The bottom-up approach consists of creating two bus equivalents for the most common WECC generator models, and then running them in the different packages.
- This has resulted in several PowerWorld changes with the new code often giving quite close matches

Graph shows a comparison of the field voltage at generator for a fault on the two bus equivalent system between PSSE, and two versions of PowerWorld Simulator



The Bottom-Up Approach

- While there are lots of models, we have initially focused on the most widely used models.
- WECC case has a total of 17,709 models in 77 model types. But the 20 most common model types contain 15,949 (90%) of these models. These are the key focus areas for the bottom-up analysis.

	Model Class	Object Type	Active and Online Count	Active Count	Inactive Count	Fully Supporte
1	Load Characteristic	MOTORW	5093	5098	0	YES
2	Load Relay	LSDT9	1871	1878	0	YES
3	Machine Model	GENROU	867	1095	0	YES
4	Machine Model	GENSAL	796	1058	0	YES
5	Governor	GGOV1	727	867	0	YES
6	Exciter	EXST1_GE	647	860	0	YES
7	Stabilizer	PSS2A	694	833	0	YES
8	Machine Model	GENTPF	647	822	0	YES
9	Load Characteristic	WSCC	626	626	0	YES
0	Gen Other Model	OEL1	340	407	0	YES
1	Governor	IEEEG3_GE	275	356	0	YES
2	Exciter	EXST4B	291	355	0	YES
3	Exciter	EXDC1	241	313	0	YES
4	Governor	IEEEG1	221	287	0	YES
5	Exciter	REXS	175	225	0	YES
6	Governor	HYGOV	173	211	0	YES
7	Stabilizer	IEEEST	153	178	0	YES
8	Stabilizer	WSCCST	136	166	0	YES
9	Exciter	EXAC8B	136	158	0	YES
0	Exciter	EXAC1	137	156	0	YES
1	Load Relay	LSDT2	142	142	0	YES
2	Governor	GPWSCC	94	124	0	YES
3	Load Relay	LSDT1	105	105	0	YES
4	Stabilizer	PSSSB	66	83	0	YES
5	Machine Model	MOTOR1	31	78	0	YES
6	Gen Other Model	LCFB1	64	75	0	YES
7	Exciter	EXDC4	54	72	0	YES
8	Governor	HYG3	57	66	0	YES
9	Exciter	EXDC2A	55	63	0	YES

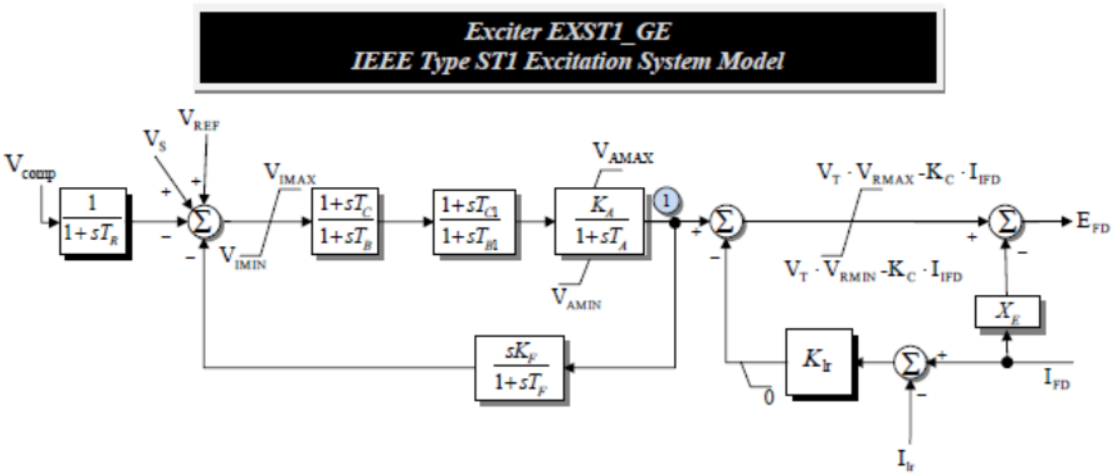
Practical Considerations

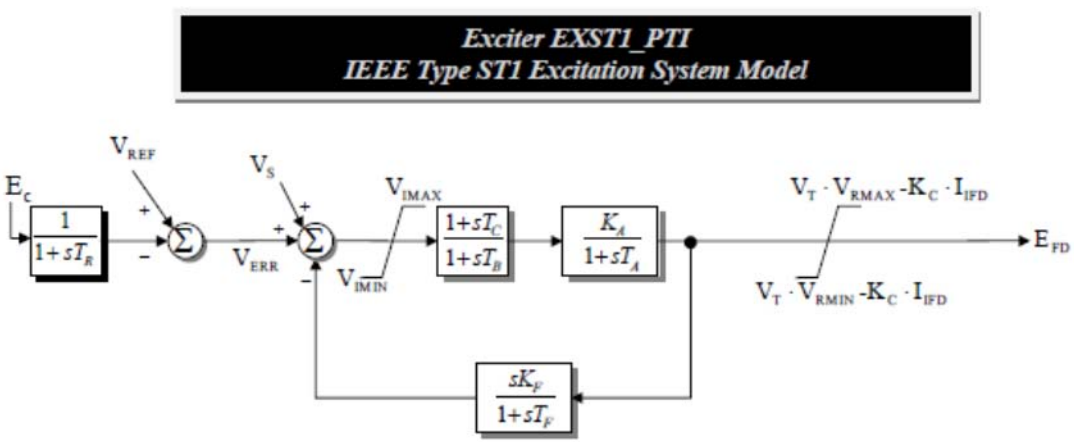
- The initial approach was to do comparisons with at least three of the four packages using the full WECC system
  - The PSLF model runs by BPA and WSU worked fine
  - The PowerWorld model runs by UIUC worked fine; UIUC did not have PSLF until late in the project (September 2011)
  - We could not get the PSSE or TSAT models of the WECC to solve flat (no initial variation)

Practical Considerations

- Hence much of the project focused on comparing either PowerWorld with PSSE and/or TSAT two bus equivalents (bottom-up approach) or comparing PowerWorld with PSLF for the full WECC model (top-down)
- Our opinion is there are too many model differences between PSLF and PSSE for an in-depth comparison
- Ultimately we obtained a very good match between PSLF and PowerWorld

Example: EXST1 Exciter

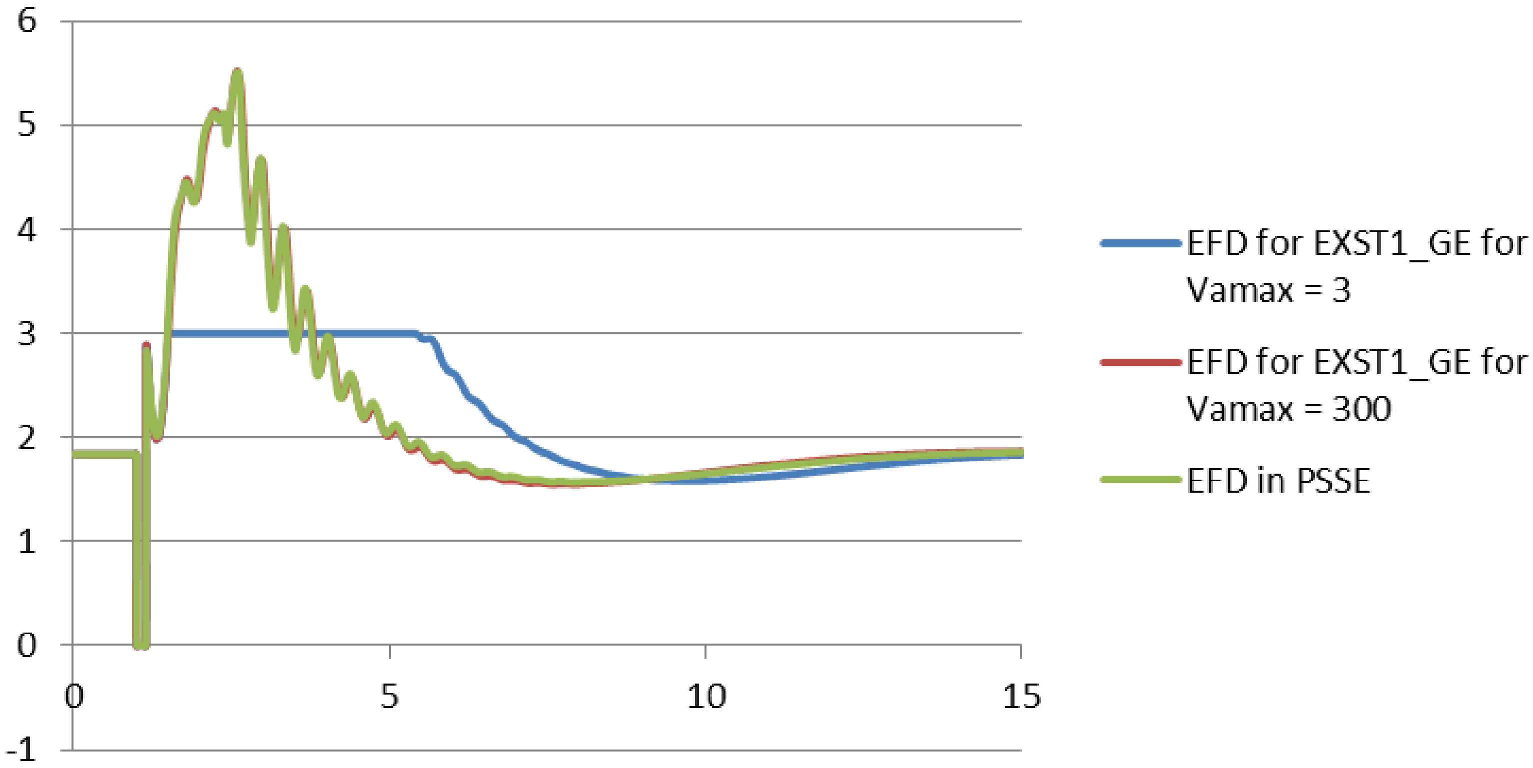




The EXST1 model is the most common exciter in the WECC. The two packages differ in whether they enforce a limit on Va. In the WECC model 230 out of 869 models have a realistic Va limit.

Example: EXST1 Exciter

- Below figure shows the two bus comparison of the response with and without the limit (red and green the same)

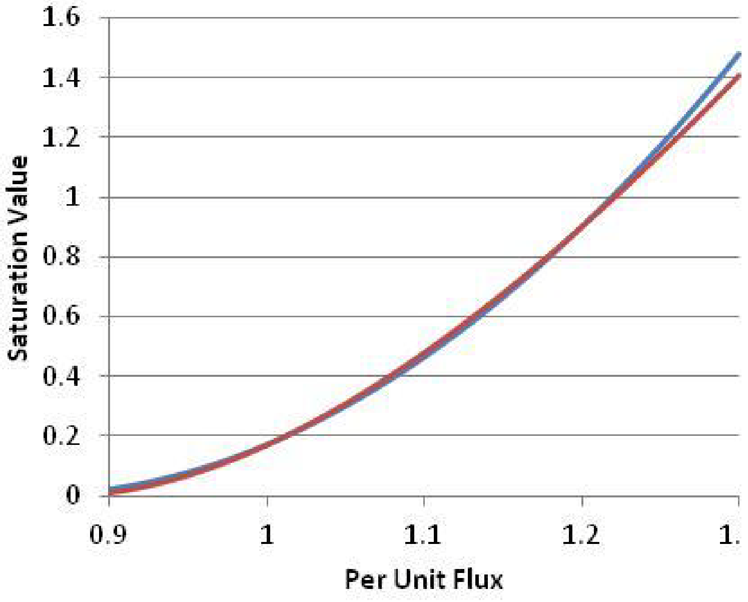


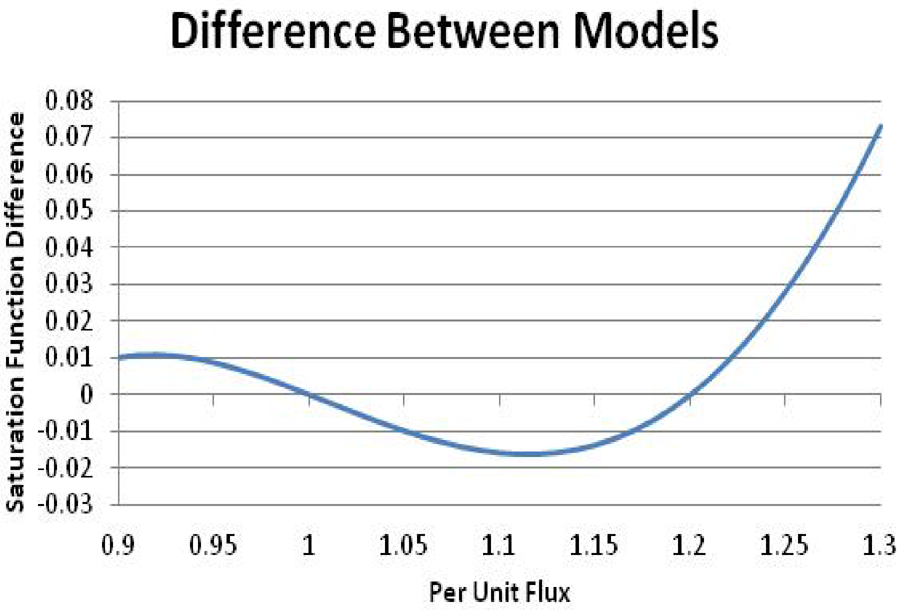
Example: Modeling Saturation

- Generator and exciter saturation is modeled using a quadratic function, but the nature of the quadratic curve varies slightly
  - Values specified at two points, which allows a unique function to be determined
    - Model A: S(input) = B1*(input-A1)^2/input
    - Model B: S(input) = B2*(input-A1)^2
  - Models match exactly at the two points, and fairly closely between the points, but can deviate for values outside of range
- PowerWorld allows both models

Modeling Saturation, cont.

- Not a major source of error, except when value are way outside of their range





Dealing with Model Errors

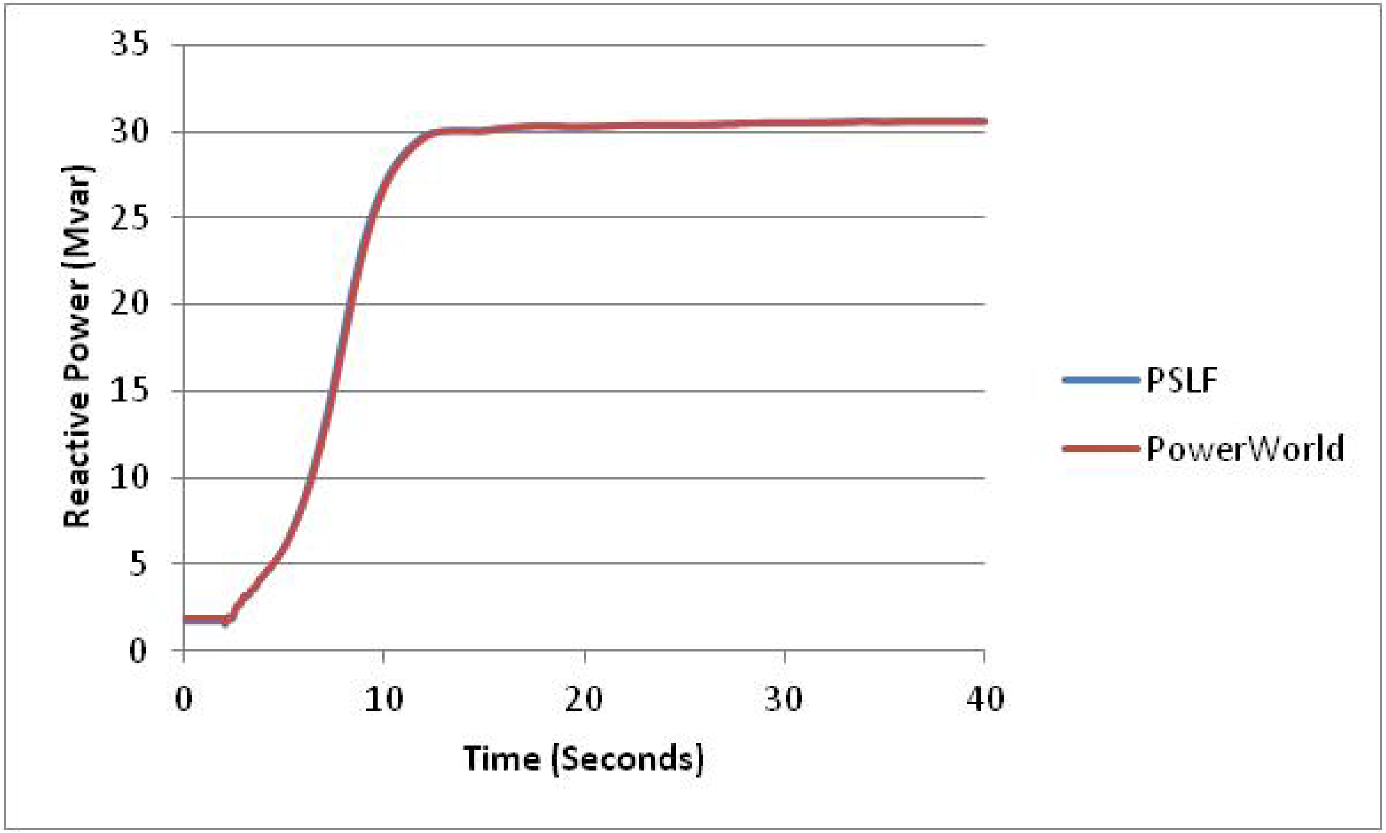
- One of the project challenges has been dealing with "errors" in the model
  - The "known" errors are "auto-corrected", but how this occurs in package specific
    - Examples are generator Xl > Xd'' and a non-increasing piecewise linear governor gate function (PowerWorld treats as error, others do not)
  - The "unknown" errors can stress the system in unusual ways, exacerbating model differences

Example: Incorrect Xcomp Value

- An example is a generator in which the Xcomp is set too high
  - Compensation is used to change the effective voltage regulation point; in this case looking out into the system for improved voltage stability
  - In this example the generator is attempting to regulate a voltage well beyond its step-up transformer

GE and PowerWorld Match

- Plot shows the Q output of a 20.5 MVA generator. PW and PSLF match, but because of incorrect Xcomp both are wrong



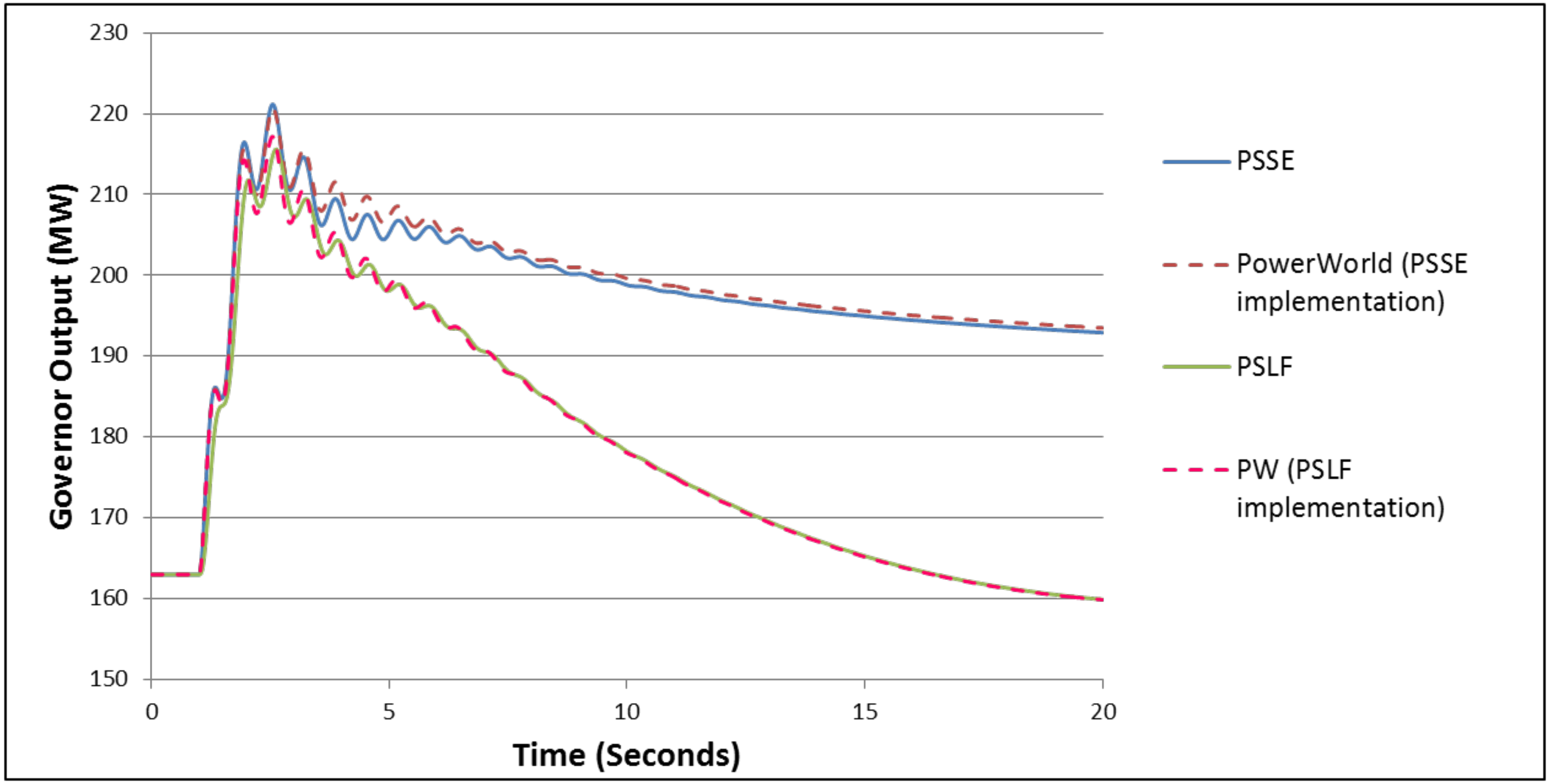
Q output is finally limited by the gen's exciter (EXAC8B) hitting a limit on Vr

LCFB1 Model

- The LCFB1 models a supervisory turbine load controller that changes the governor setpoint; intended to model “reset” action.
- Output is a PI control. In 10/2011 we learned for certain governors (e.g., IEEEG1) the PI output is scaled by a factor of 25 in PSLF. This greatly increases the action of the device, changing the system frequency recovery.
- We do not believe PSSE includes this term

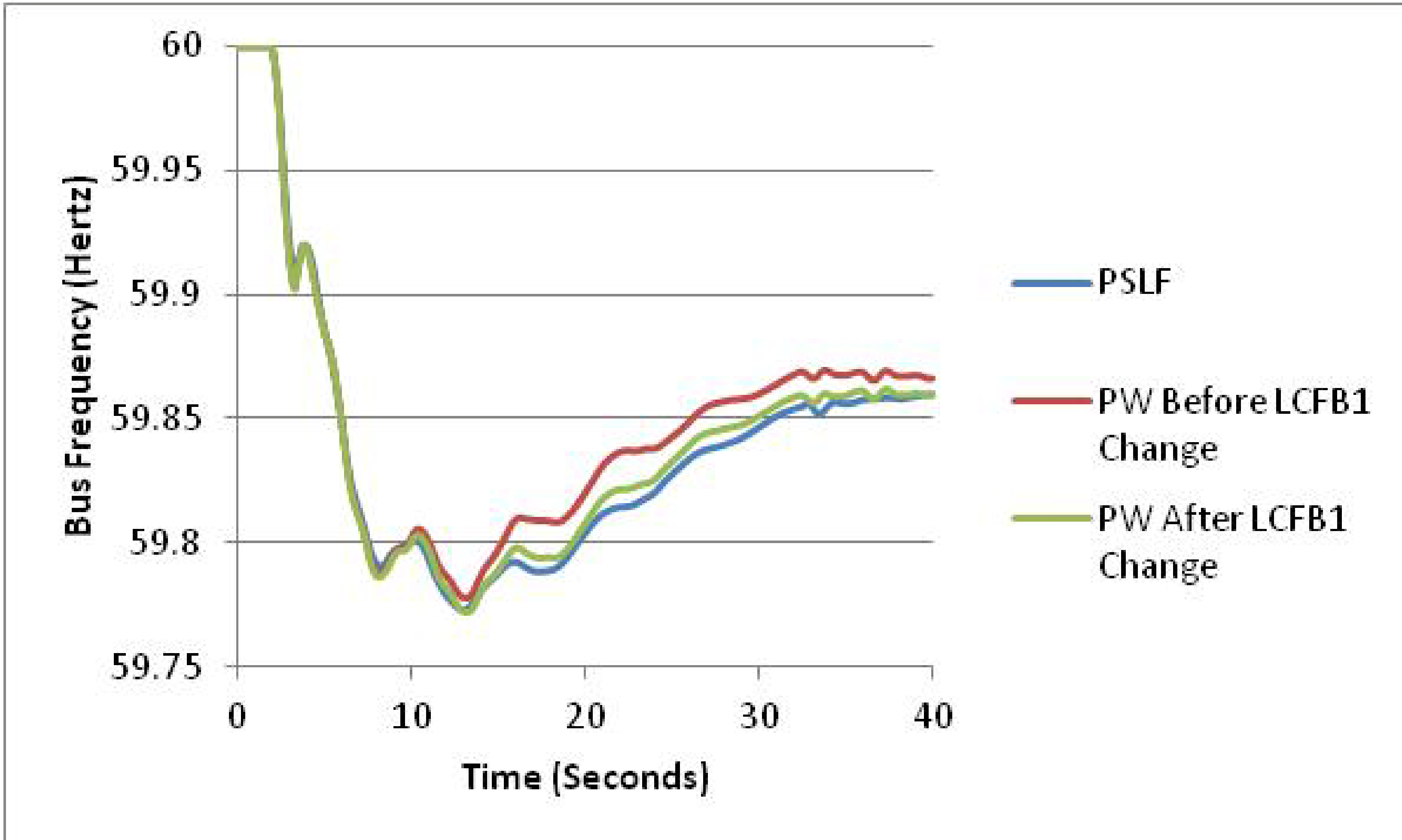
LCFB1 Model

- Below figure shows the difference in the governor output in different packages. We see that the PSLF output has a scaling factor while PSSE does not implement this. Powerworld models both these implementations.



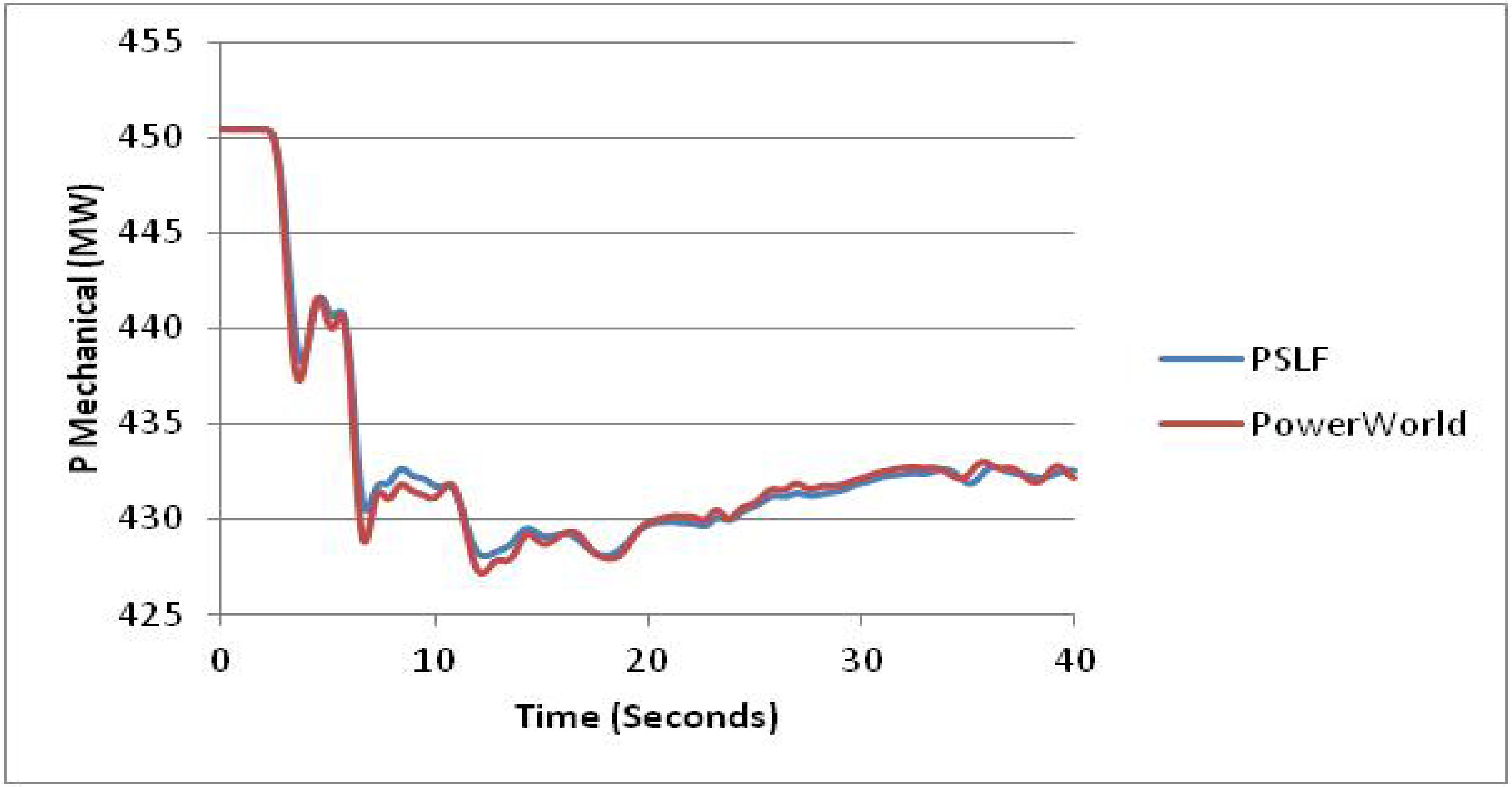
Present PowerWorld/PSLF Match

Graph shows frequency comparison at a representative bus before and after the recent PowerWorld modification to the LCFB1 model



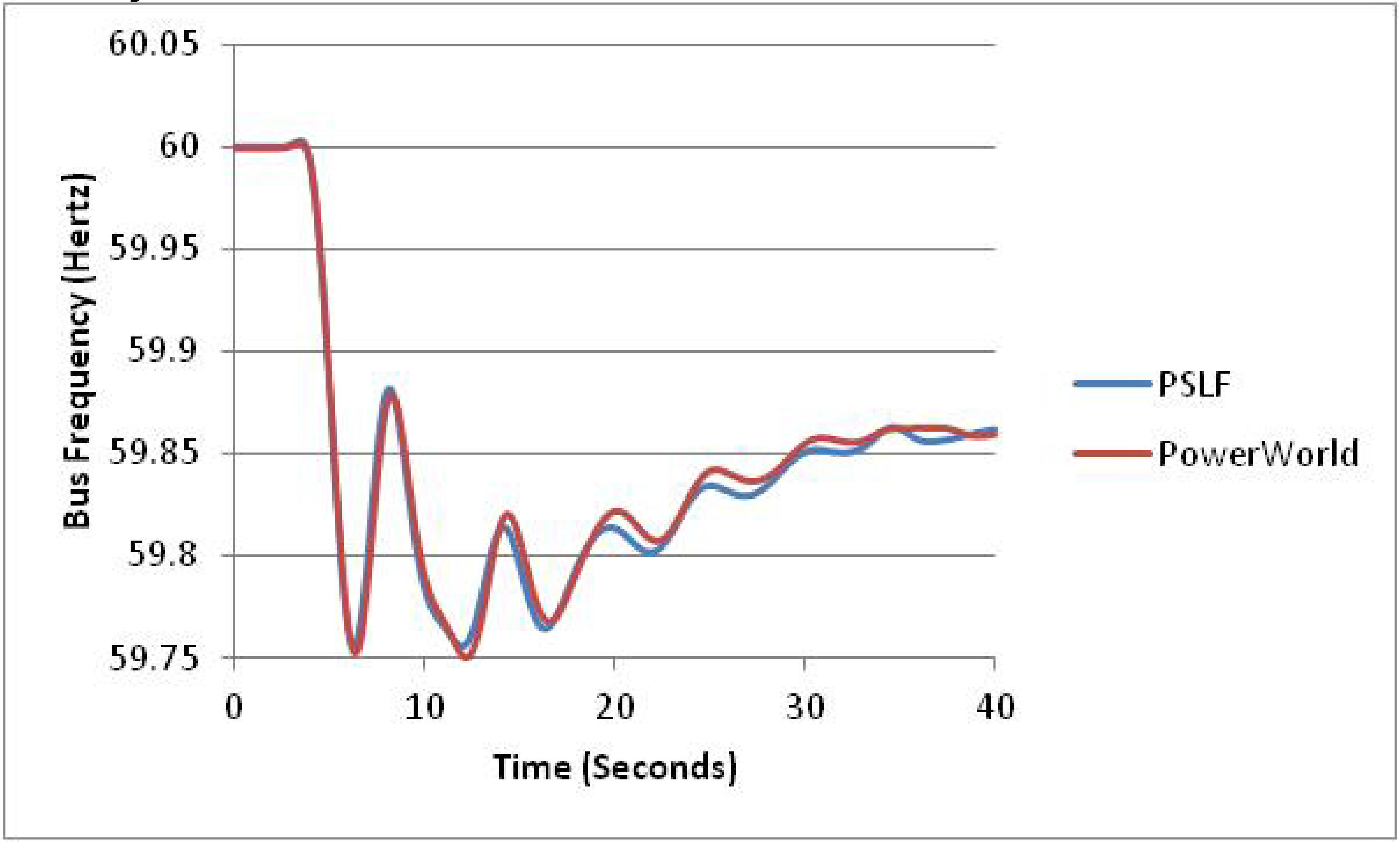
But is this the "Desired" Result?

Below graph shows a coal power plant generator output. It is unusual that the Pmech goes down when the frequency is below 60 Hz. The cause is 1) the governor response is "blocked" to not increase, and then 2) the LCFB1 model "resets" the reference value.



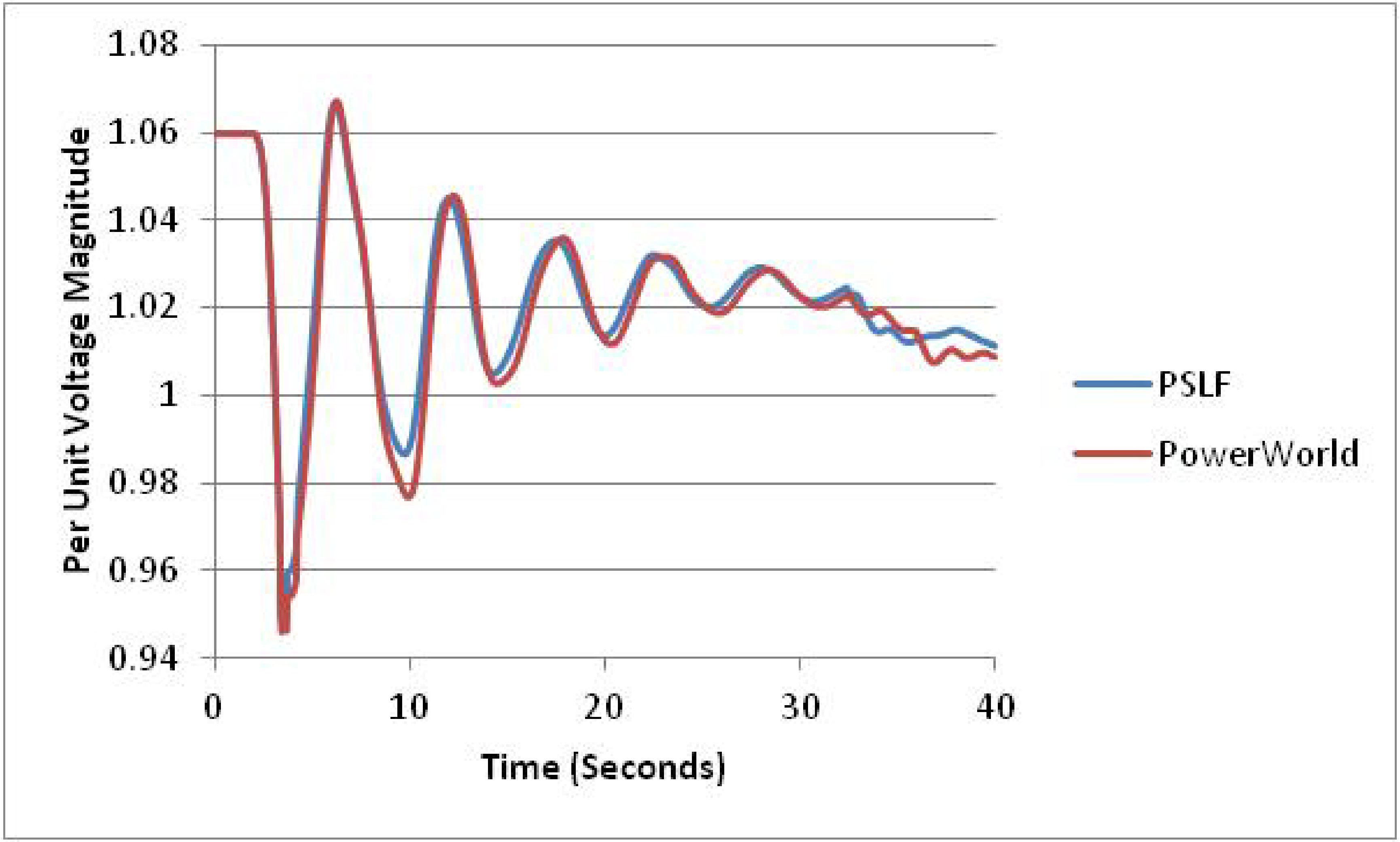
Another Bus Frequency

Plot compares bus frequency at a location on the other side of the system



Key Voltage Magnitude Comparison

Plot compares bus voltage magnitude at a key system location

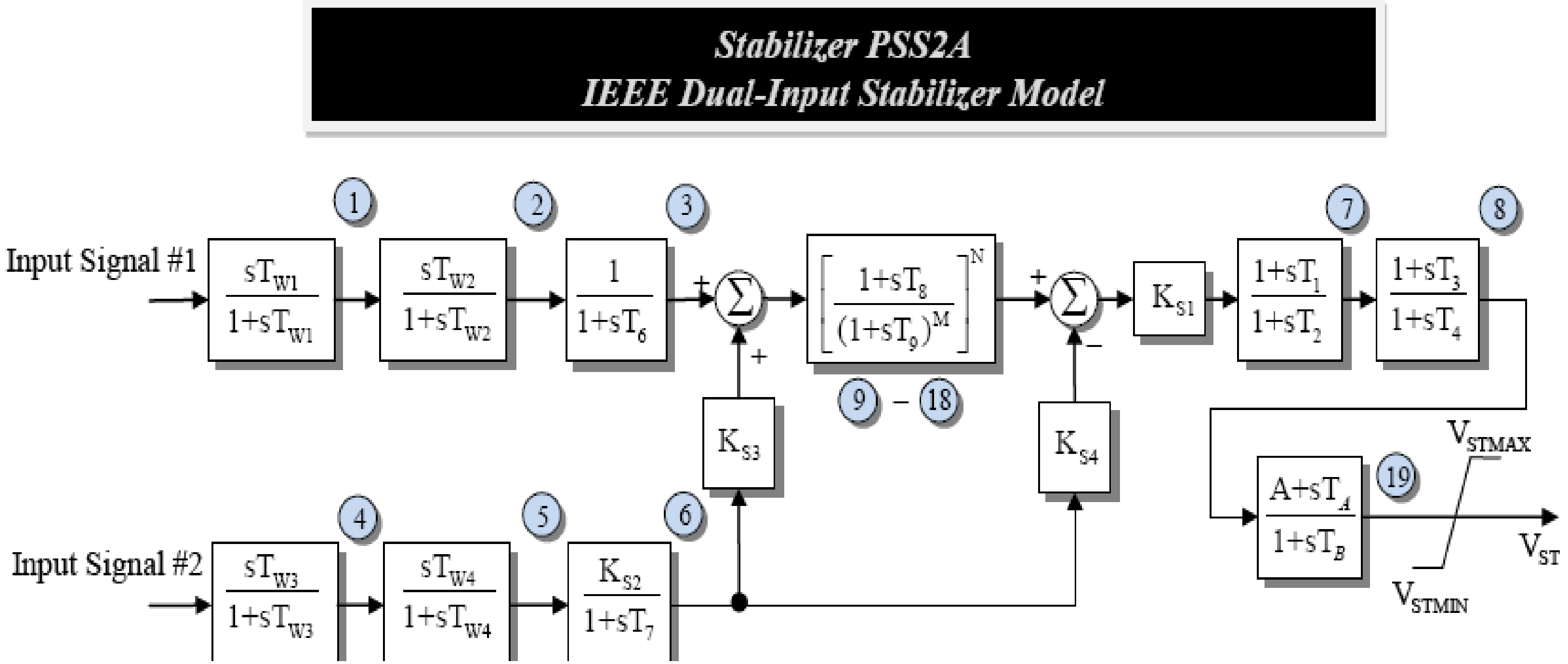


A Few Specific Bugs

- All tested packages have suspected bugs or documentation issues. PowerWorld and GE have addressed or are addressing all issues found.
- Example: In GE the PIDGOV model did not use the Trate model for calculations; rather it used the Gen MVA base. Two exciters had documentation issues on how limits are enforced. Neither issue resulted in substantially different solutions.

PSS2A Stabilizer

- The PSS2A is the very common IEEE Dual Input Stabilizer Model (903 models in the WECC case and 704 in the MMWG [2006 series]; most common in both cases).

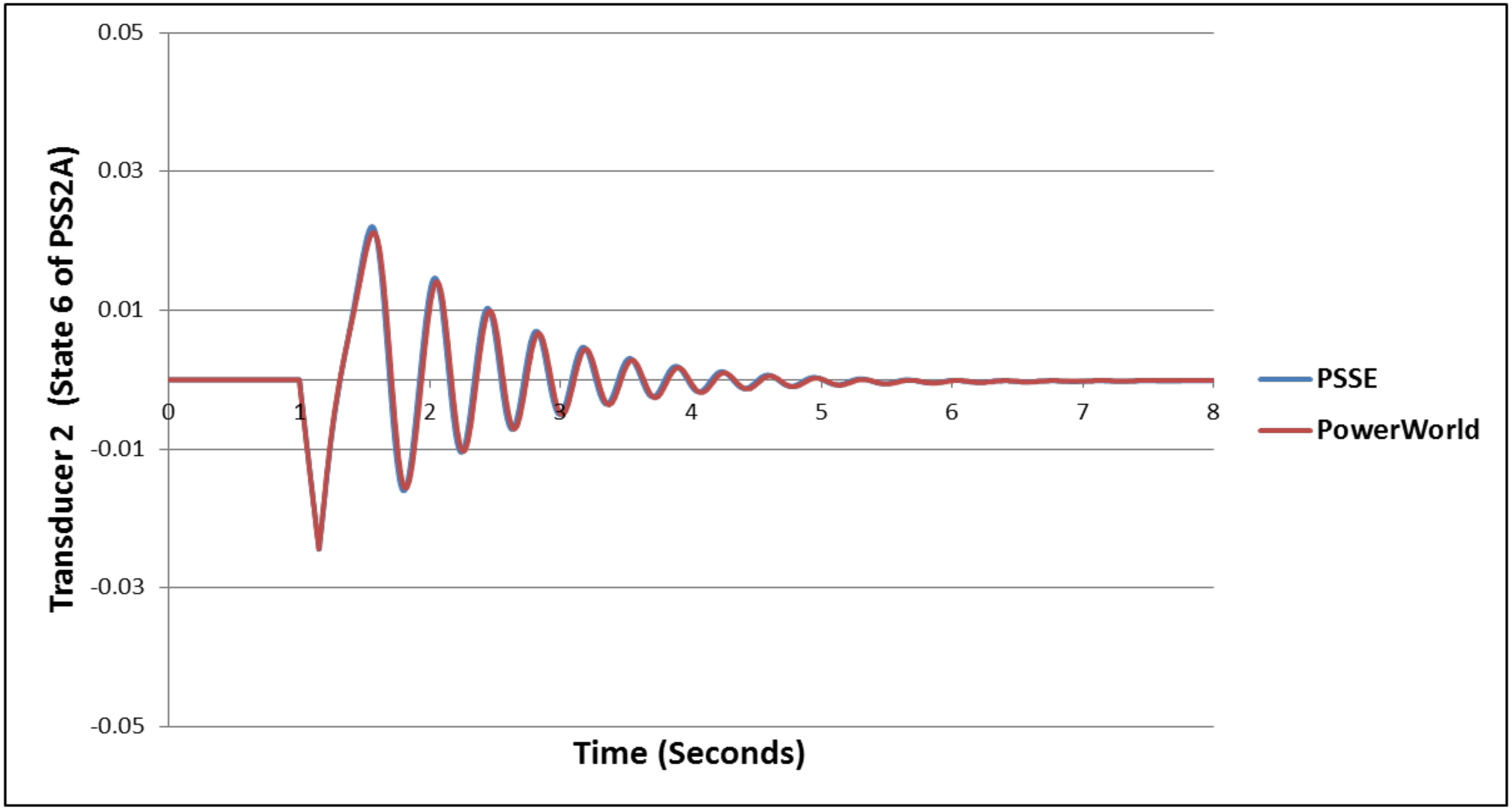


Something to "Try at Home"

- In running validation of the PSS2A stabilizer model between PowerWorld and PSSE (version 32) we would only get a match with Ks2=1 in PSSE. Hence our hypothesis is that this is a constant value in PSSE (actual value of Ks2 is being ignored).
  - This can be tested with an case that includes a PSS2A stabilizer

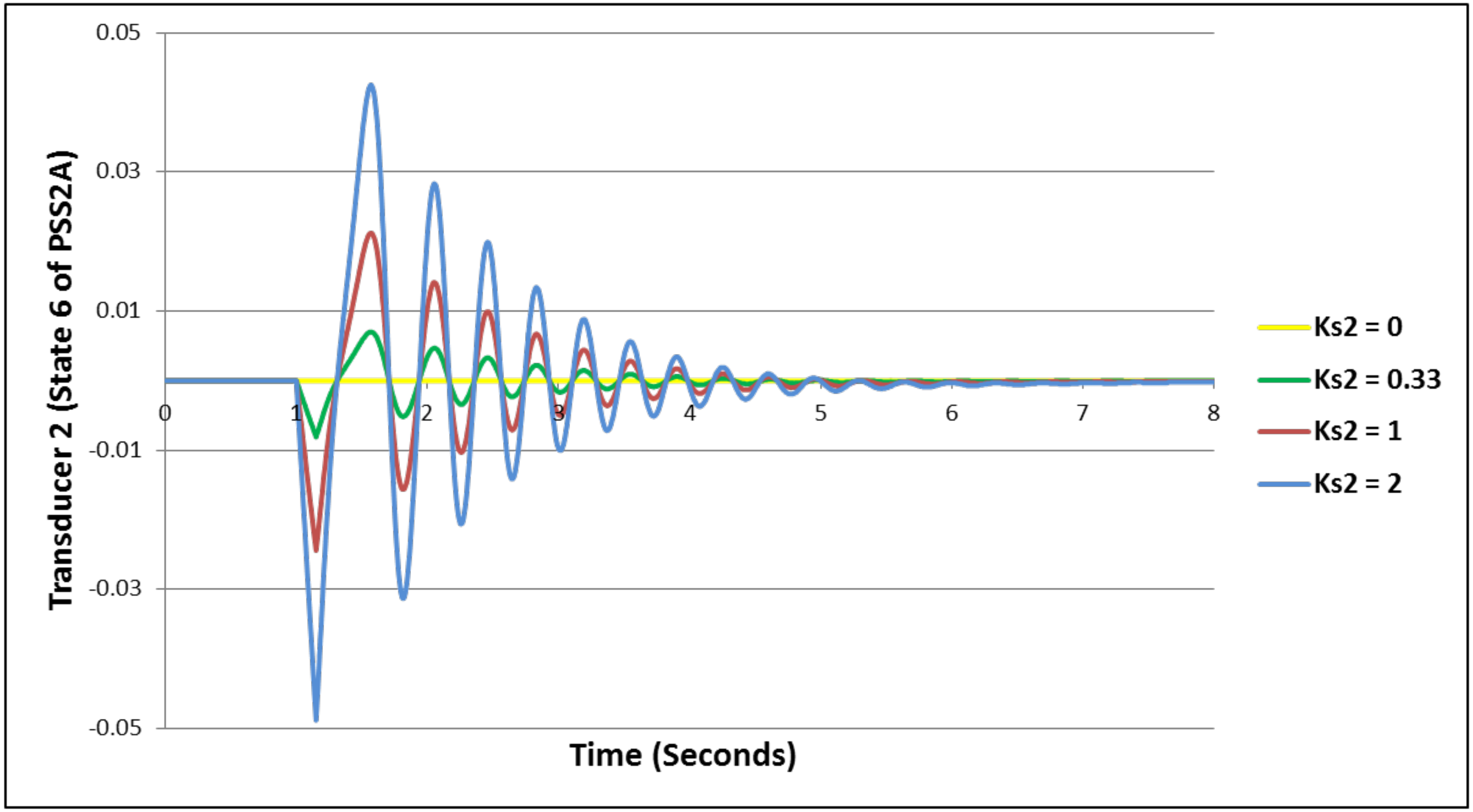
PSS2A PowerWorld and PSSE

- Below figure shows the two bus comparison of the transducer 2 (state 6 in block diagram) for Ks2=1. We see that they match very closely.



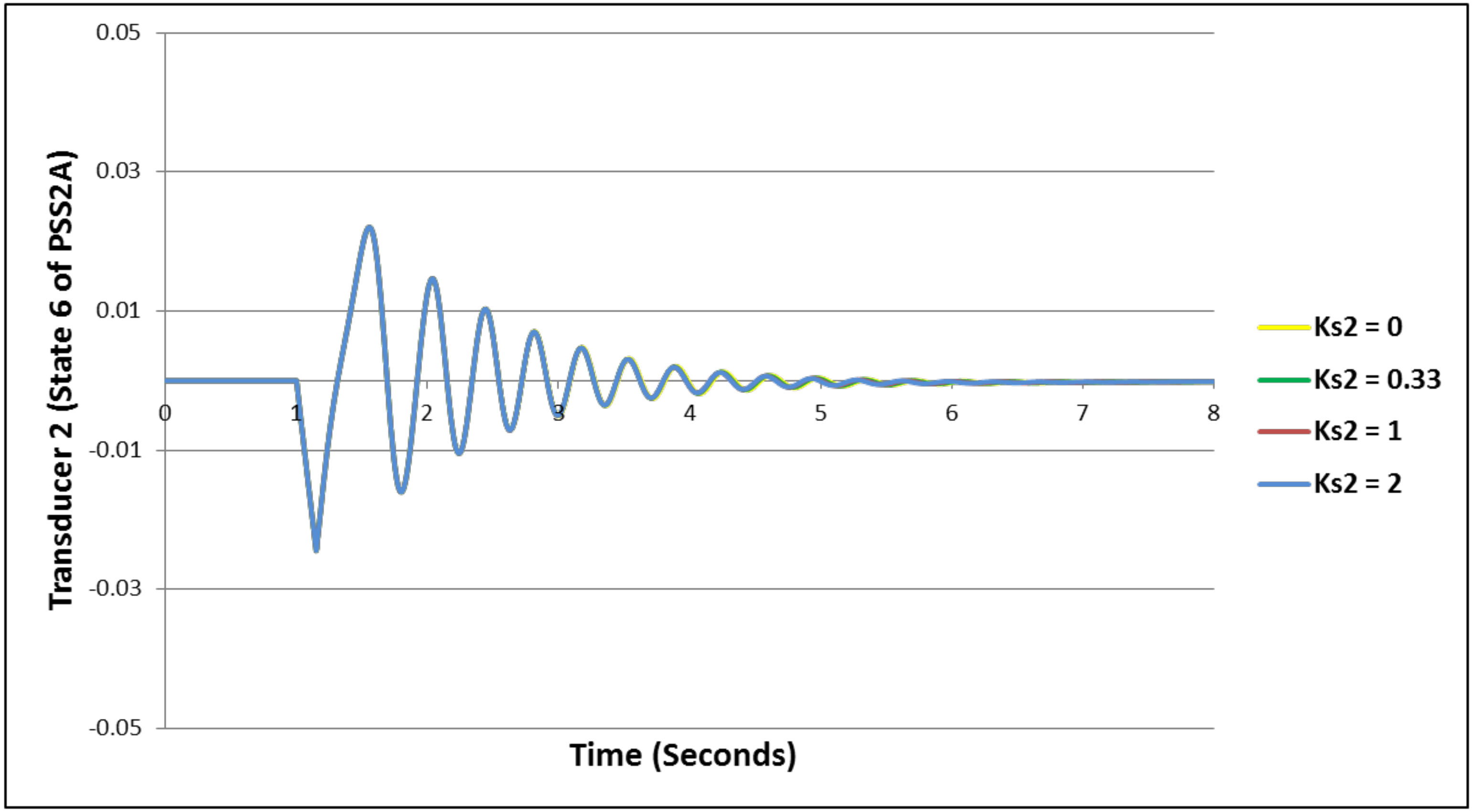
PowerWorld Variation for Ks2 Changes

- Below figure shows the variation in response of the transducer 2 state in PowerWorld for different values of Ks2.



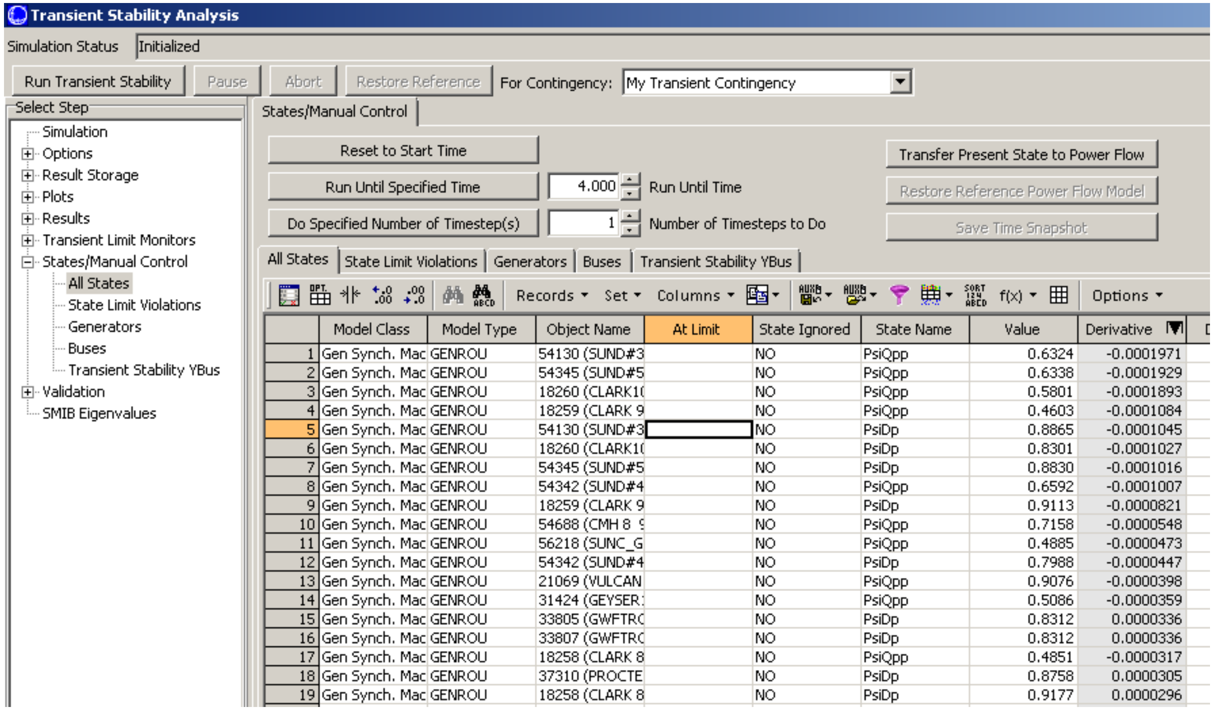
PSSE Variation for Ks2 Changes

- Below figure shows the response of transducer 2 in PSSE for different values of Ks2. The response does not vary with Ks2 (all plots are the same)



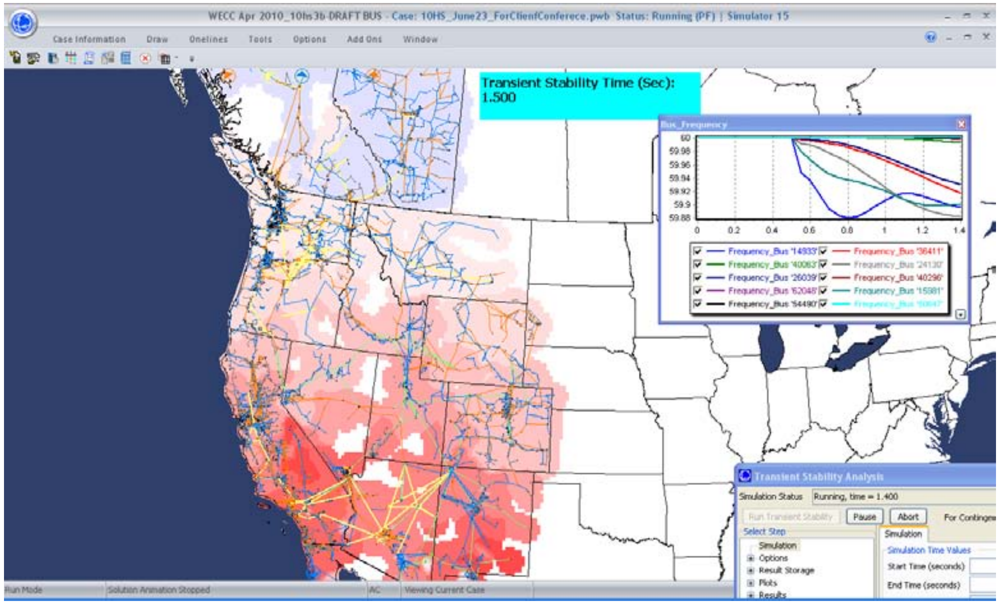
Visualization

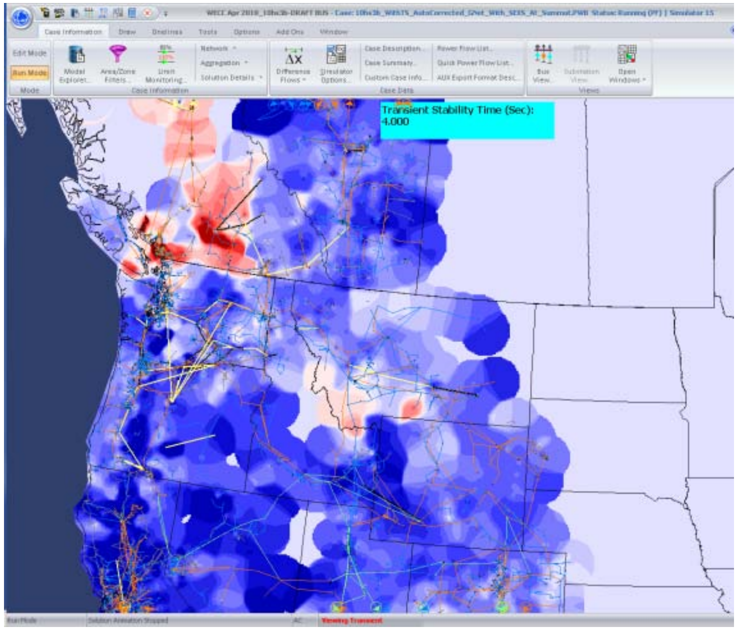
- PowerWorld Simulator provides extensive capability for interactive display/visualization of the transient stability results, allowing for quick identification of potential system bugs.



One important capability for the determining initial limit violations is the ability to see/sort all the system state variables and their derivatives

Visualization, cont.





The visualization on the left shows how an animated frequency contour can be coupled with a standard frequency plot to show the geospatial variation in system frequency. The voltage magnitude contour on the right is one way to track the variation in bus voltage magnitude during a transient stability simulation

A Few General Observations

- Having near identical power flow solutions is extremely important (e.g., different generator Mvar outputs change field voltages)
- Providing easy access to initial state derivatives helps with getting a flat solution
- Looking a min/max state variable values provides a “necessary” condition for a match
- SMIB analysis helpful for determining errors
- Determining the reason for differences still requires lots of engineering insight

Moving Forward

- The PSERC project has concluded, but this work is too important to stop.
- We are continuing to move forward with funding provided by the Illinois Center for a Smarter Electric Grid (ICSEG)
- Industrial participants are invited to join us
  - BPA has already expressed an interest to continue participating in this effort
  - Email overbye@illinois.edu if interested

Questions?