Power System Stabilizer Applicability in the WECC System

Study Progress Report to WECC-0107 Drafting Team

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Introduction

Power System Stabilizers (PSS) are essential to the stability of the WECC interconnection. Their development and application were critical to the early interconnection, and their continued application on generators over the decades has provided a tangible benefit to the reliability of the WECC system. Therefore, there is a general interest in maintaining the practice of applying PSS in WECC generators, which is countered by a general interest in not requiring PSS on all generators. Balancing these two positions is less than straightforward and requirement thresholds have ultimately been determined without the benefit of technical data. Recently, a study report was provided by Dmitry Kosterev to support PSS standard drafting team discussion. This report is meant to augment that of Dr. Kosterev.

Background

Originally, stabilizers were applied to a handful of strategically located generators, but by the early 1970's, the recommendation was made to apply PSS to all generators 75 MVA and greater. Due to their location in the system, many units smaller than 75 MVA also included PSS at this time. Studies were performed in 1974 to establish a recommendation on minimal percentage of PSS equipped generators that should be online at any given time. The recommendation of applying PSS to units 75 MVA and larger was in place until the "Criteria to Determine Excitation System Suitability for PSS in WSCC System" report was released in 1992. This study recommended considering the application of PSS on all existing units of 75 MVA or larger, and all new machines with continuously acting voltage regulators. The WECC PSS Policy Statement, approved in 2002, required PSS on all existing units 75 MVA and greater, and all units of 30 MVA and larger, with new excitation systems considered suitable.

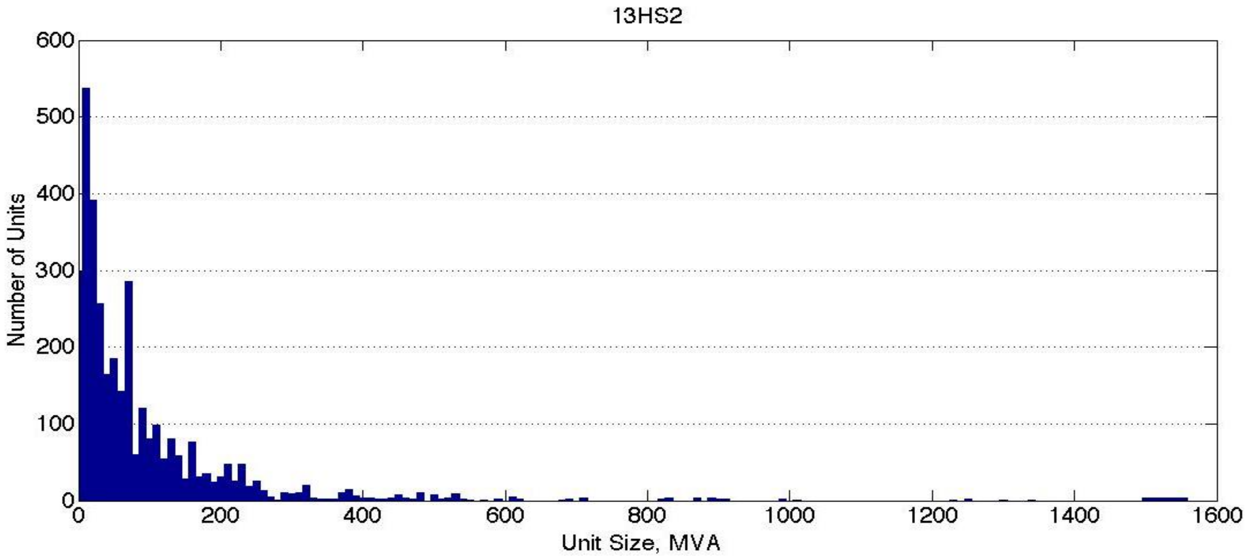
The PSS represented in the current WECC model database reflects the history of the recommendations and requirements of the last 40 years, that is, nearly all units greater than 75 MVA are equipped with PSS, nearly half the units sized between 30 MVA and 75 MVA are equipped with PSS, and less than 25 percent of units smaller than 30 MVA have PSS.

Meaningful studies of PSS application, or for any generator equipment are difficult. With over 3,000 generators in the connected system, the impact of any single unit is nearly impossible to see. The effects of PSS are distributed throughout the system. Their influence depends largely on the varying system conditions. In some cases the response of a particular unit may be of great important to the overall system behavior, but in another case, have no impact. So the type of sensitivity study presented by Dr. Kosterev is a likely attempt to determine the wide scale effect of PSS throughout the system. However, conclusions based on such a study can be easily misinterpreted. Given the history of PSS application in the WECC, the results of such a study are predictable: Policy or recommendations have resulted in nearly uniform application of PSS on units greater than 75 MVA, therefore the results are sensitive to removing them from large numbers of these units. Removing PSS on units 30 to 75 MVA affects about half of them, so the results are sensitive, but not as much as the first case. Removing PSS on units less than 25 MVA affects almost no units, with the expected system impact.

Study Methodology

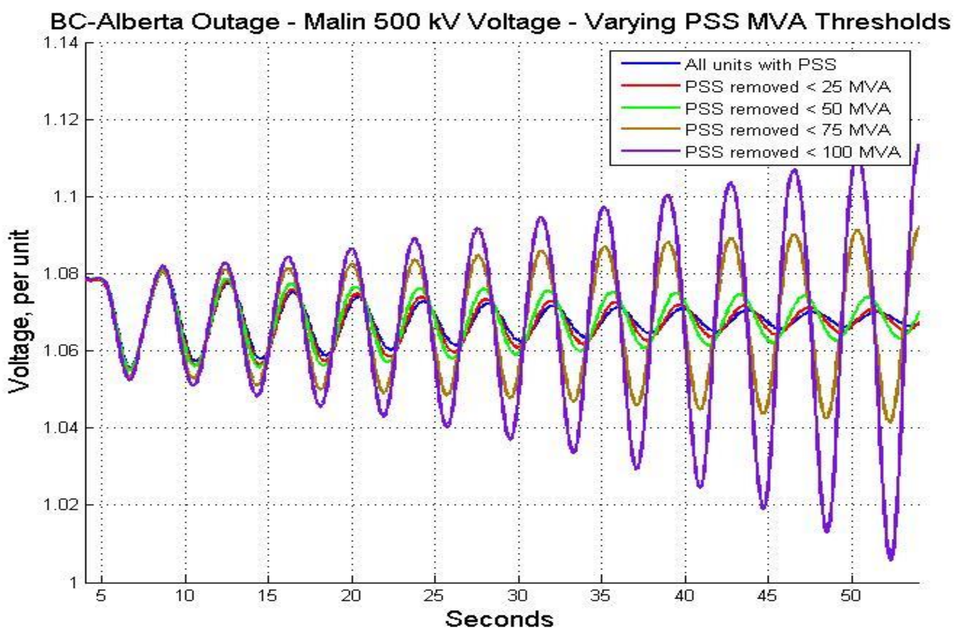
To examine the sensitivity of removing PSS from large groups of generators, then they all must at least have a PSS than can be removed. Therefore, Dr. Kosterev's study was performed, as similar as possible (same case, same disturbance) but with PSS installed on all possible units, i.e., units with excitation systems that allow a PSS input signal. This entailed the creation of about 1,200 PSS models to add to the existing 1,500 PSS models in the cases examined. As expected, most of these models were applied to units smaller than 75 MVA, but some were applied to much larger units that did not have PSS represented in the cases. There were 55 generators in the case, mostly smaller than 50 MVA, which have excitation system models that cannot accept a PSS signal.

An important factor to keep in mind when considering the WECC system is that more than half of the approximately 3,000 synchronous machines modeled are less than 75 MVA in size.



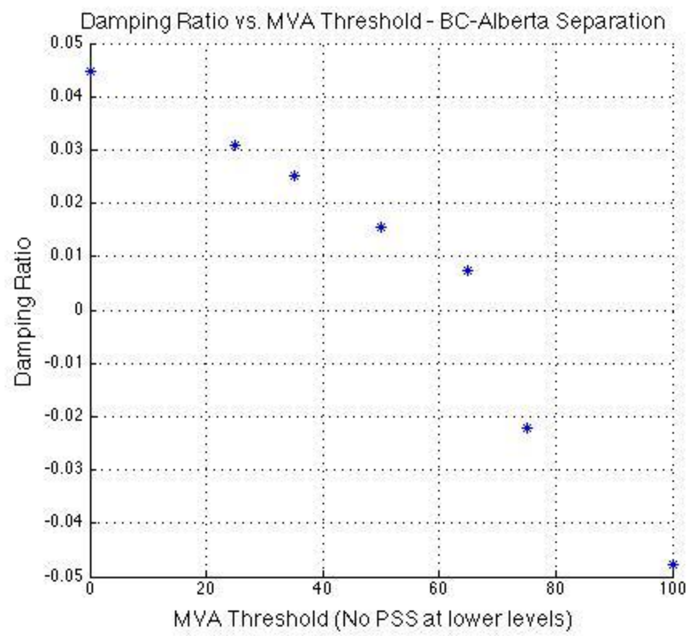
Results

Simulations of the BC-Alberta separation with the same 13HS case resulted in voltage swings at the Malin 500 kV bus to compare to the other report as follows:

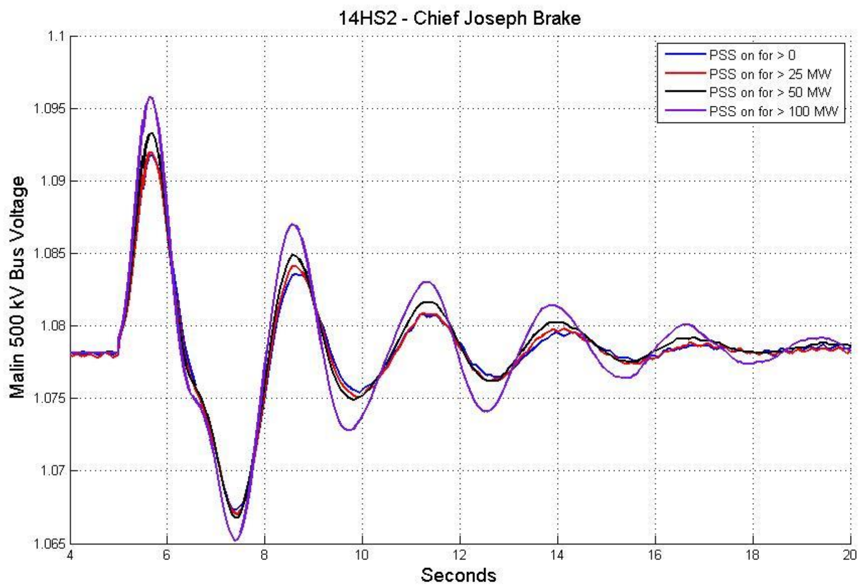


At first glance, comparison of the above figure to the original study appears largely the same. The differences are that in this case, there is an increased sensitivity to units less than 75 MVA, with noticeable impacts this time of units sized between 25 MVA to 50 MVA, and even those smaller than 25 MVA. The major difference between the studies is that unlike the previous one, there is no clear dividing line between 25 MVA and 50 MVA where the difference is negligible.

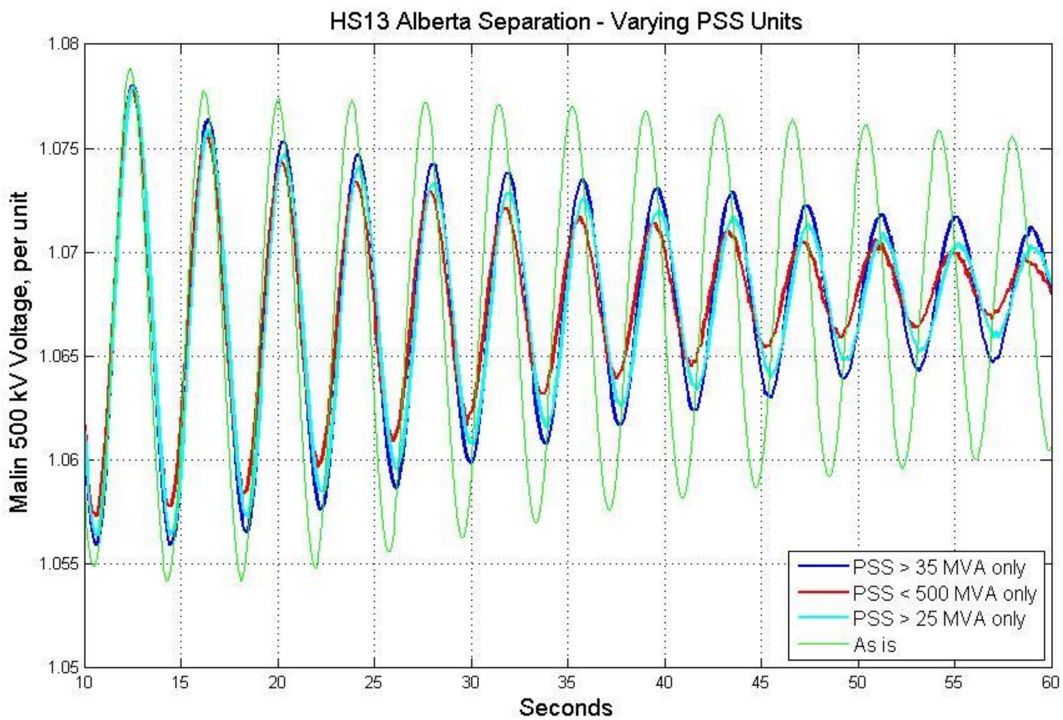
When considering figures like the one above, it is important to observe that the differences in damping, that is, the impact of each case, cannot be compared simply by the amplitude of the swings as the time progresses to the right of the graph. The comparison must be made between the calculated effective damping ratio of each signal. The graph below shows that the estimated damping from each of the above cases, with results from some additional simulations, when plotted against the threshold where all PSS are turned of is surprisingly somewhat linear, suggesting that the relationship between number of generators and MVA rating is roughly inversely proportional. (Note: the damping ratio calculation probably needs to be re-evaluated for the cases where it is negative. All damping estimates were made during the same simulation time frames, where the degree of nonlinearity may be different between positively damped cases and negatively damped cases.)



Similar results were obtained using a different base case and simulating a different disturbance, shown below:

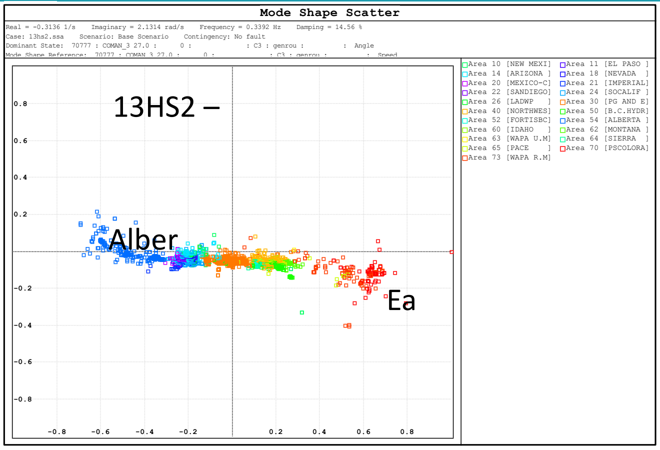


The figure below compares the Alberta separation case, this time including the reference base case, i.e., the existing model without additional PSS. Also shown is the simulation with PSS turned off on nearly all units greater than 500 MW, which affected a total capacity of more than 45,000 MW. Yet the results are better damped system than that where PSS was applied on all units greater than 25 MW, where only about 15,000 MW were left without PSS. The implication from this comparison is that for this case PSS application based on total unit capacity is not as effective as the number of units with PSS.

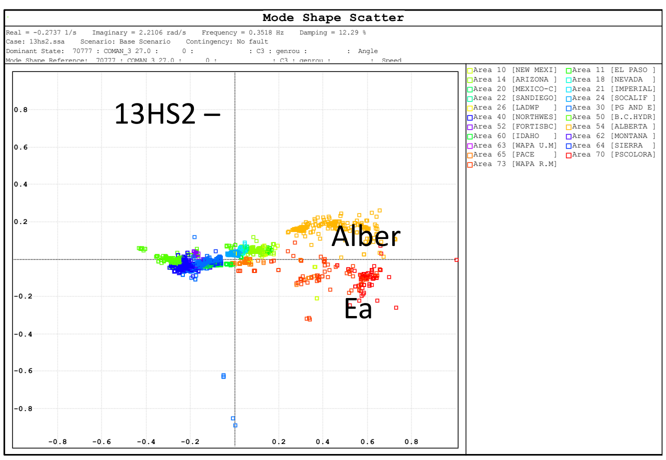


These results are neither surprising nor unique to this case. The effectiveness of a PSS and its contribution to damping inter-area oscillations depends on a great number of variables. As demonstrated in these examples, the relative size of the generator is not the most influential variable. It can further be demonstrated that the most important considerations in this example are generator location and how the PSS is tuned.

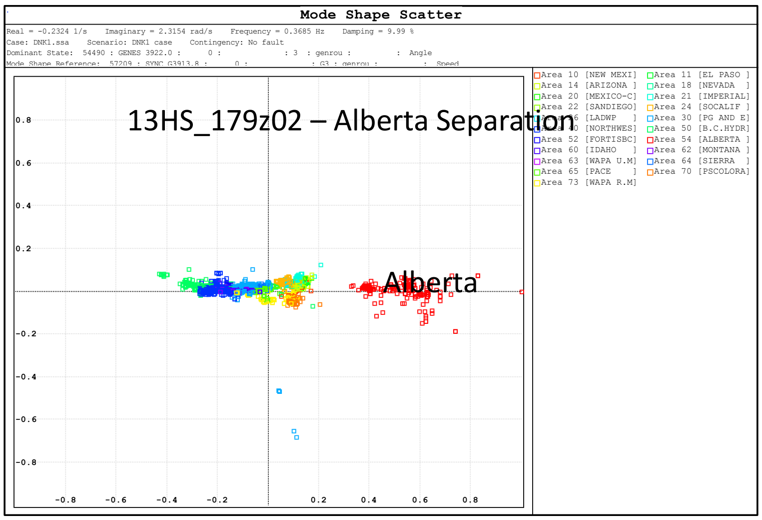
The following figure illustrates how one of the major modes of oscillation in this case appears throughout the WECC system. Each point represents one generator, and the graph shows that the mode of oscillation consists primarily of the generators in blue oscillating against the generators in red. PSS will be more effective for this mode on these units, whereas PSS on units in the center of the plot will not be as important.



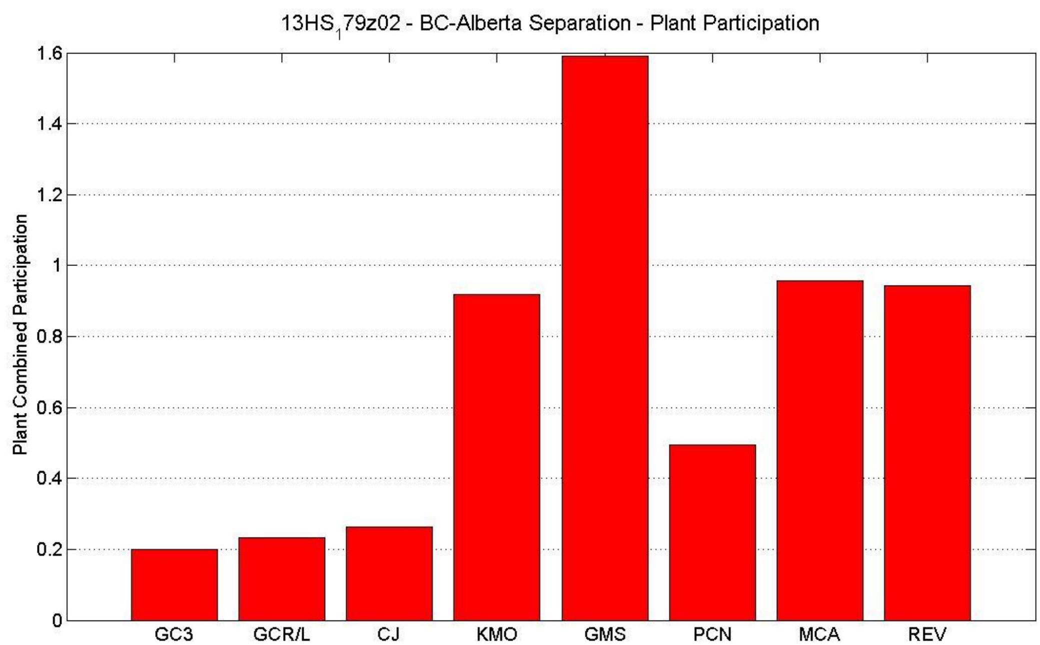
The other major mode of oscillation in this case is shown in the next figure, where the oscillation consists of a different combination of generators.



When the net load flow of this case is increased, the first oscillation mode is altered, becoming dependent on a new combination of generators, shown below.



As an example for comparison, the following figure depicts the relative amount of importance of eight different plants in the northwest part of the system in the oscillation mode in the case above. What is significant to the point is that the relative importance to this oscillation does not correlate with unit size.



PSS Applicability Based on Generator Size

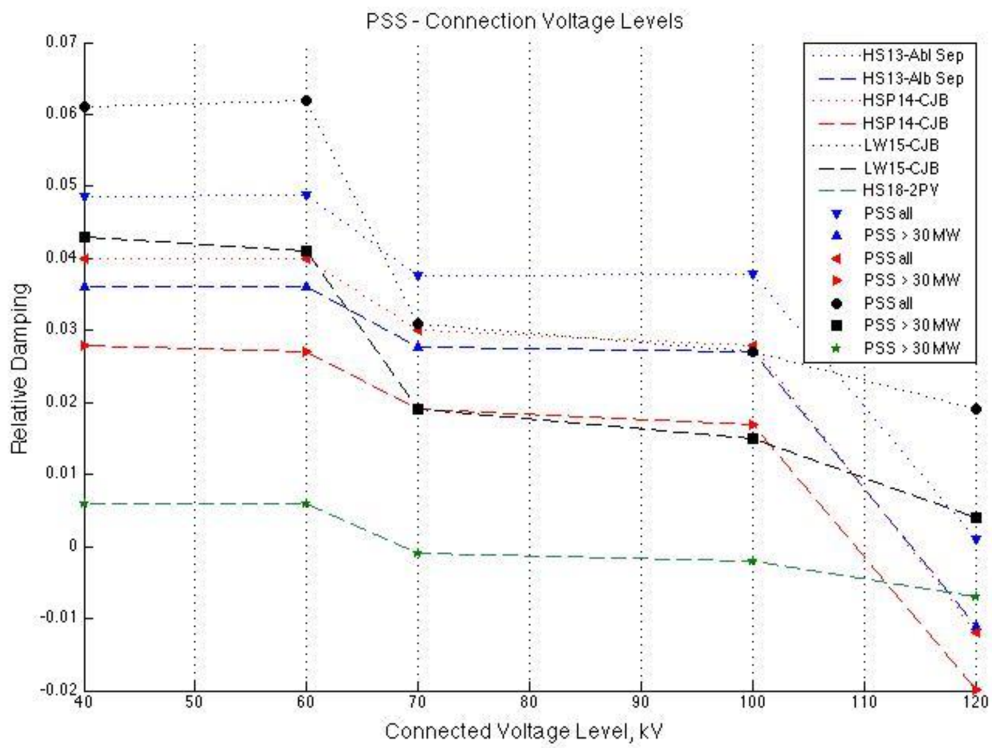
The results of this study suggest there is no clear generator size threshold below which the application of PSS does not provide a significant benefit. However, conclusions regarding units below 10 MVA based on the WECC database cannot be given full consideration due to the known lack of and quality of representation of many of these generators.

The nearly universal application of automatic voltage regulators (AVR) greatly enhances steady state stability as well as transient stability margins in a power system. However, they also introduce a destabilizing effect in the WECC system at natural system resonances at frequencies below 1.0 Hz. The PSS was developed to correct the destabilizing effect of the AVRs, and therefore improve the damping of these low frequency oscillations. The original application required retrofitting existing units, and equipping new excitation systems with first generation PSS, which required a substantial cost. This is unquestionably the reason a cutoff point in generator size was set.

The 1992 WECC study and resulting criteria recommendations, recognizing that there is no technical justification for excluding generators with new excitation systems, included considering PSS for all new systems regardless of unit size. At that time, this seemed more reasonable as the cost of PSS was declining. Since then, the cost of adding PSS to a new excitation system has become significantly less as all new systems are digitally implemented. Now it is not unusual to apply PSS at no additional cost.

Studies Comparing Connection Voltage and Minimum Unit MVA

Simulations conducted using 4 different base cases and 3 different disturbances are summarized in the following:



Cases/Disturbances used/simulated/Oscillation Frequency:

2013 Heavy Summer/Alberta Separation/0.26 Hz

2014 Heavy Spring/Chief Joseph Brake/0.36 Hz

2015 Light Winter/Chief Joseph Brake/0.41 Hz

2018 Heavy Summer/Double Palo Verde Unit Trip/0.21 Hz

For each case/scenario, PSS application was varied as follows:

PSS only on all units connected > 40 kV

PSS only on all units connected > 60 kV

PSS only on all units connected > 70 kV

PSS only on all units connected > 100 kV

PSS only on all units connected > 120 kV

PSS only on all units connected > 40 kV, Units > 30 MVA

PSS only on all units connected > 60 kV, Units > 30 MVA

PSS only on all units connected > 70 kV, Units > 30 MVA

PSS only on all units connected > 100 kV, Units > 30 MVA

PSS only on all units connected > 120 kV, Units > 30 MVA

All cases and disturbances show basically the same sensitivity to varying connection voltage and unit size.

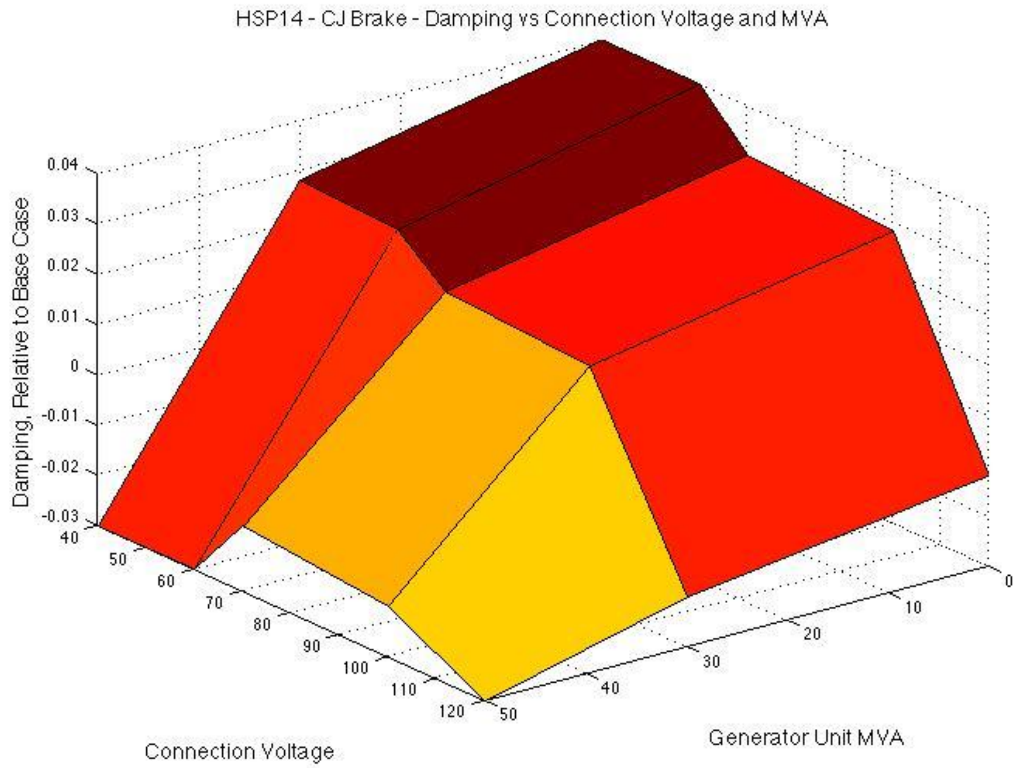
There is very little difference between a minimum connection voltage of 60 kV and 40 KV (not many units connected below 60 KV).

The lowest noticeable change in minimum connection voltage occurs at 70 kV.

There is very little difference between a minimum connection voltage of 70 kV and 100 KV (not many connection voltages in the range).

Removing PSS on units connected at 120 kV and below has a significant impact on the results.

Additional variation of unit size, units 50 MVA and less, was conducted for the HSP 14 Chief Joseph Brake scenario, and is summarized in the following figure:



Conclusions

Generating unit MVA rating is, in general, not directly proportional to its impact on damping of particular modes of oscillation.

Generally speaking, in the WECC system model, generator size is inversely proportional to the number of generating units.

The nature of system wide modes of oscillation and the effectiveness of individual generating units on these modes varies with the system topology and the instantaneous operating point conditions.

There is no technical justification to exclude application of PSS on a generating unit based on size alone.

Raising the threshold for PSS applicability from the current 30 MVA will reduce the number of generators with PSS, which will decrease system damping proportionally to the number of units affected.