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Comprehensive Studies on Controller Tuning for PSS2B and PSS4B: Challenges, and Straightforward Tuning Approach

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SUMMARY

Power System Stabilizers (PSSs) are key power system components that are employed in power systems to damp low-frequency power oscillations. Various PSS models have been developed, each having certain features and design challenges. PSS2B and PSS4B are two controllers with unique features and capabilities. PSS4B retains most of the good features of the PSS2B while improving the performance of the controller; however, this comes with increased challenges in the controller design. This paper investigates and studies controller tuning of these two PSS types, based on real data from a transmission power system of a Hatch client (Confidential), and proposes a straightforward approach for the tuning of PSS4B. The parameters of PSS4B have been tuned to mimic the response of the PSS2B. The results are compared using the two-area power system test cases to show the performance of the designed controller. The parameters are then implemented in the PSS/E software into the real power system model, which show a very close performance and consistency for both controllers.

KEYWORDS

Power System Stabilizer, Transient Stability, Controller design PSS2B, PSS4B, MATLAB, PSS/E

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I. INTRODUCTION

Power systems are subject to low-frequency oscillations due to large and small disturbances. The most common method to enhance the stability of a power system during the disturbances in a power system is achieved through proper deployment of well-tuned PSS. The large and small disturbances affect the transient rotor signal stability and small signal rotor stability, respectively [1]. The instability is associated to the inability of the power system's angular swings to remain synchronous after a disturbance [1]. According to [2], when a PSS is implemented into the power system, it maintains the operating equilibrium by providing damping to the low-frequency oscillations by modulating the electrical torque in phase with the rotor speed deviations [2]. Additionally, as stated in [2], power system stabilizers are tuned to address low frequency oscillation modes between 0.1 to 2.0 Hz modes of oscillation [2]. PSSs utilize input signals, commonly the input signals are speed, terminal frequency, and/or power [2].

A. Types of Power System Stabilizers

The types of PSSs include several models including but not limited to; single-input power system stabilizers, such as PSS1A, dual-input power system stabilizers, such as PSS2B and PSS3B, and multi-input power system stabilizers, such as PSS4B [3]. This study focuses on the implementation of PSS2B and PSS4B; these are digital stabilizers. PSS2B was introduced in the Nineties. PSS4B was later introduced in the year 2000, which retains most of the good features of PSS2B and provides an improved and more effective signature of lower-frequency inter-area modes [4].

B. The Challenges of PSS4B

The challenge of tuning PSS4B is that it has multiple inputs, including speed and electric power and various controller path including low, medium and high frequency range. To effectively design a controller path, obtaining the open-loop response of the controller is necessary.

Due to the multiple input of the PSS4B controller, an open loop bode plot cannot be produced in a straightforward manner. As stated in [4], it is "impossible to measure a frequency response from a single-output, multiple-input system". Consequently, an alternative or more complex method of tuning must be implemented to assess the frequency response.

The challenge of tuning the multiple-band PSS4B has been addressed by [5] based on a pole placement method and lead/lag filters. Reference [5] examines the technique of tuning each band individually. This method uses a simplified structure of each band and some variables (required for the PSSE model tuning are missing).

Another method, presented in [6], also implements a tuning approach that states tuning the PSS4B. While the approach tunes each band independently from the others, the interaction between the controller paths were not considered. This method uses a simplified PSS4B structure that requires symmetrical filters and only tunes six parameters; thus, diminishing the feasible performance flexibility and ability of the PSS4B.

C. The motivation of this paper

- In the design stage of this project, the PSS were tuned with the assumption of that the stabilizer on site will use the PSS2B model.
- Based on the advantages of PSS4B, the PSS4B has been selected for to be installed on the generator.
- To redesign the PSS4B, it would require additional effort that has already been applied for the PSS2B development and to change the PSS4B to PSS2B the process would be very expensive and time taking.
- The best way moving forward was to mimic the well designed PSS2B behaviour in PSS4B.

During this project, it is noticed that there is not sufficient publication on PSS4B tuning and also the tuning methods are not complete and may not be practical and/or time effective to be used in industrial projects, therefore; without a standardized benchmark, designing the PSS4B is more challenging. This paper tries to address all the required procedure for the PSS4B tuning and assist the reader in the procedure of the controller design.

The study presented in this paper follows a straightforward approach in how to tune the PSS4B in MATLAB/Simulink considering a practical test procedure in PSSE as a well-known and industrial acceptable software for transmission utilities.

II. POWER SYSTEM STUDIES

Hatch was retained to perform studies to design a power system stabilizer for a 1200 MW power plant using PSS4B stabilizers. The original PSS design was performed in PSS2B and later the physical stabilizer was selected as a PSS4B. The aim was to achieve the same performance with PSS4B as achieved by PSS2B in the simulation studies. This approach resulted in project cost and time saving throughout the project.

For this study, Hatch received the power system in the PSSE format. The PSS2B can be tuned as a speed-based PSS. The model for this power system study is created based on the parameters provided to Hatch by the client. The model is shown in Figure 1.

Alternatively, the PSS4B structure modeled as shown in Figure 2, has separate controller bands to provide phase lead/lag at low (0.01-0.1 Hz), intermediate (0.1-1 Hz) and high-frequency (1-4 Hz) bands. The input for PSS4B high-frequency band can be selected as power, generator speed deviation, and voltage. However, PSS/E software only accepts electrical power as input for high-frequency band. The electrical power then will be converted to speed for the high frequency band as shown in Figure 3.

As discussed with the client, it is confirmed that the onsite PSS4B also uses speed (ω) and electric power (P_e) as the inputs.

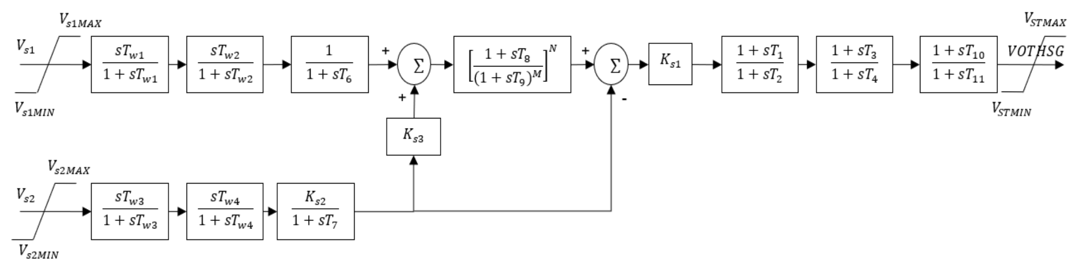

Figure 1 PSS2B Block Diagram [4].

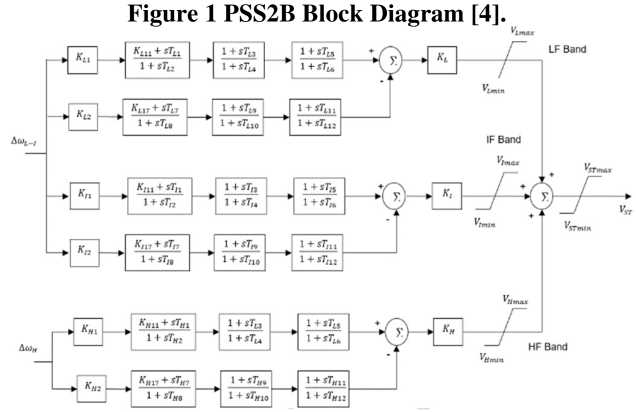

Figure 2 PSS4B Block Diagram [2].

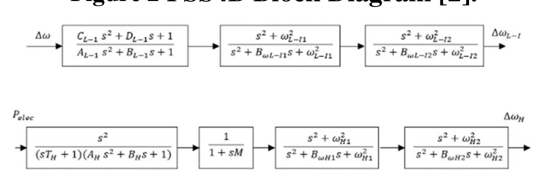

Figure 3 The Transducer for PSS4B

In pursuance of this study, a tuning approach had to be developed for the multiple-input, multiple-band, and single-output PSS4B power system stabilizer. The remainder of the paper discusses the method that was developed to resolve the challenges of PSS4B tuning.

III. Small Signal Studies

A. Two-Area Power System

The initial PSS/E model given to Hatch was too large to be converted to MATLAB/Simulink. Therefore, to compare the behaviour of both stabilizers, the approach was to test the controllers on a smaller-scale power system and to compare the overall behaviour of the units.

Although the controllers response may not represent the controllers behaviour on the actual system, in this approach, the benchmarking of the overall behaviour of the controllers for this system can provide a confidence of the design in the open loop and also can be tested on a smaller scale power system. For this study, Hatch used the Two-Area power system model as developed in [2] and shown in Fig. 4. This power system is designed to be a simplified yet, nearly accurate representation of the actual operation of the power system with the purpose of simulating low frequency oscillations [2]. The Simulink model of the system is presented in Fig. 5. This model can be found in the Matlab Simulink examples.

B. Challenges in PSS4B Tuning

In this study, Hatch used the available controller tuning applications in MATLAB/Simulink using Linearization Blocks to match the frequency response of the PSS2B with PSS4B. From the Two-Area power system model, bode plots can be generated with the intention of plotting the open-loop controller response in relation to the changes influenced by tuning the parameters of the PSSs. The bode plots are an essential tool in tuning the PSS2B and, likewise, the PSS4B, by showing at what frequency the controller should comprise of lead or lag phase. However, this is where the tuning of the PSS4B becomes a challenge.

As mentioned earlier, to compare the open-loop bode plot of both controllers, a test can only be done for a single-input and single-output block. The challenge here is that the bode plots can not be benchmarked since the PSS4B is a multiple-input and single-output system. Theoretically, according to the design of the PSS4B model, the inputs for the PSS4B controller could be only speed for all the frequency ranges (low, intermediate, and high) or, alternatively, the inputs could be speed and electric power. The latter is the case for the model implemented in the PSS/E software and for the actual PSS on site.

C. Overcoming the Challenges

To overcome the challenge of plotting the response of the PSS4B controller, the input for the high-frequency band in PSS4B has been changed from electric power to speed to have a single-input and single-output controller. Once the controller parameters are tuned in MATLAB/Simulink for PSS4B, the input for the high-frequency band was reverted to electric power (as required by PSS/E and the actual PSS4B model on site). To do this, a transducer was implemented in the PSS/E model to convert the electric power to speed. Please note that the transducer will not change the controller response in the frequency range of interest (0.1 to 10 Hz) and the controller parameters remained the same as designed in MATLAB. Hence the same behavior as actual PSS4B in PSSE model with two inputs can be achieved with this approach.

D. MATLAB/Simulink Results

1) Open-loop response: Once the PSS4B model was properly adjusted to be implemented as a single-input model, the bode plots could be generated to be compared to the PSS2B plot. Figure 4 shows the Bode plot of the PSS2B, the proposed PSS4B (provided by the Client), and Hatch adjusted PSS4B controllers. It is shown that the phase shift and the magnitude of the PSS4B is tuned to closely match with the PSS2B controller. For parameters tuning, Hatch used matlab contoller desing available in Matlab simulink. The bode plot shows the controller response in open-loop. The open loop response should stay the same for the frequency range of (0.1 to 2 Hz). To ensure the higher accuracy of the results, Hatch has closely matched the frequency response of both stabilizers for the range of 0.1 Hz to 10 Hz.

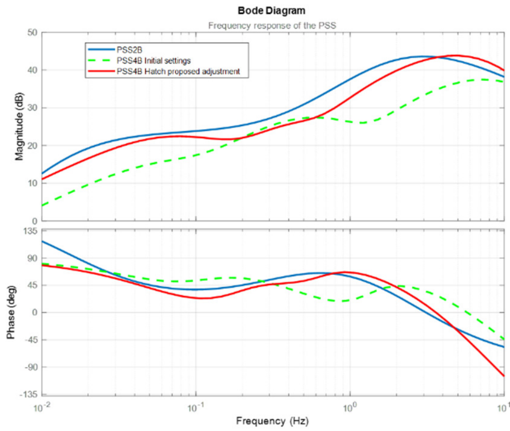

Figure 4 Frequency Response of the Power System Stabilizers

I. Transient Study Results

A. PSS/E Test

The proposed PSS4B and the provided PSS2B were tested in the provided PSS/E case by the Client. Several contingencies were tested and results for the generators angle and power output are shown in Figure 5 and Figure 6. Due to confidentiality, the PSSE case cannot be shown here. There are 4 generator units that uses this PSS4B and the test cases shows the results for the generator A of the plant.
The contingency case studies include, line *X* trip and line *Y* trip (due to confidentiality the name of the lines cannot be disclosed in this paper).

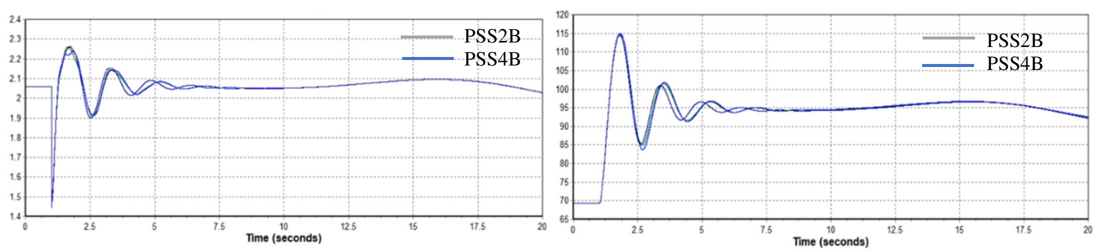

Figure 5 a. Generator A Power Output for Line *X* trip b. Generator A Rotor Angle for Line *X* Trip

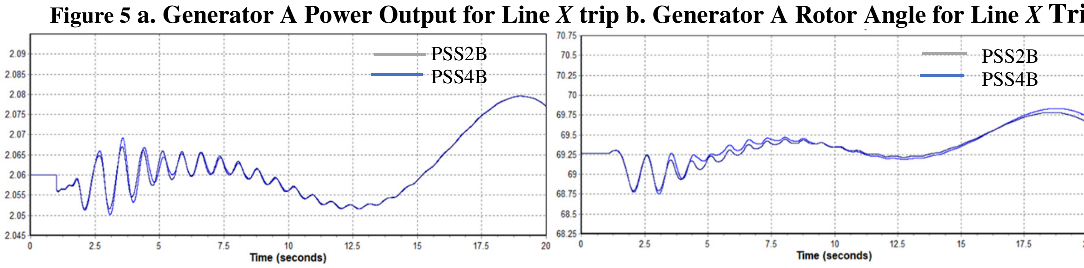

Figure 6 a. Generator A Power Output for Line *Y* trip b. Generator A Rotor Angle for Line Y Trip

As shown in the PSSE test cases, results show a very close matching for all the contingency cases.

II. Conclusion

Power system stabilizers are essential for the stable operation of power systems as power systems are subject to small and large disturbances. Meanwhile, the tuning of the PSS4B is challenging due to the multiple-input specification of the model. Hatch noticed that not enough publications are available for tuning of PSS4B and/or the proposed methods may not be practical for industrial applications. In this paper a straightforward approach for designing a PSS4B stabilizer is presented which reduces the complexity of the control design.

Multiple input was converted to only one input, speed, and then the transducer is added to be aligned with the PSS/E model. By developing small-signal studies and transient studies with the Two-Area power system model, Hatch was able to compare the open-loop and the close-loop response of PSS4B and the PSS2B and design the controller in a smaller and more realizable power system. The PSS4B controller parameters were tuned to provide the same performance as PSS2B in MATLAB. To ensure the accuracy of the results, the controllers were tested in the full-scale power system in PSS/E. Several contingencies were considered, and results show a very close match between PSS2B and PSS4B as expected; thus, confirming the straightforward approach is effective.

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