based control [2] and to multiple FACTS devices that is significant to the coordination of various FACTS controllers and classical controllers in enhancing large scale power system transfer limits. The authors agree that the discusser-mentioned previous work has made important contributions to the topic.

2) In order to reduce the efforts in computer programming, the authors neglected the VSI losses of the UPFC in the paper. There is no serious difficulty to include it in the current model. The discussers recently revealed that it is important to include the VSI losses in the stability study through time simulation using detailed EMT model. The authors think the conclusion is reasonable. Usually the simplified math models are widely used in engineering study from synchronous machines to HVDC transmissions. As we all know the model simplification will cause some limitation in applications. The authors have that experiences in the past research work especially in the direct methods applications in transient stability study when incorporating the excitation system model [3] and the HVDC transmission model [4] into the direct methods. We think the discussers' work in this aspect is valuable.

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# Discussion of "The Application of Power System Stabilizers to a Multigenerator Plant"

M. J. Gibbard and D. J. Vowles

The author is to be congratulated on an interesting paper[1] in which some important issues are raised that are often overlooked in the tuning of Power System Stabilizers (PSSs).

Being interested in the problems posed in the paper,[1] we attempted to apply a somewhat different design procedure [1], [2] to the author's four-machine infinite-bus system. The procedure attempts to compensate for magnitude and phase of the transfer function ($PVr$) between the voltage reference input ($Vr$) and the electrical torque ($P$) on the generator rotor, the shaft dynamics of all generators being disabled. (A theoretical basis for this approach is established in [3].)

Manuscript received March 29, 1999.

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Publisher Item Identifier S 0885-8950(00)11322-7.

[1] G. J. Rogers, *IEEE Trans. Power Systems*, vol. 15, no. 1, pp. 350–355, February 2000.

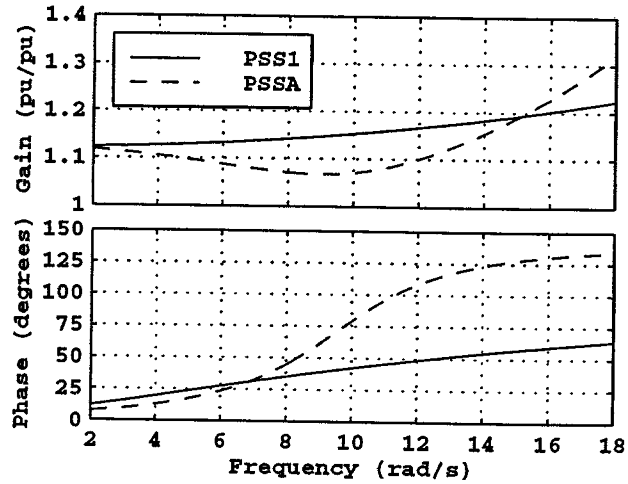


Fig. A. Comparison of the frequency responses of PSS1 and PSSA over the frequency range of interest.

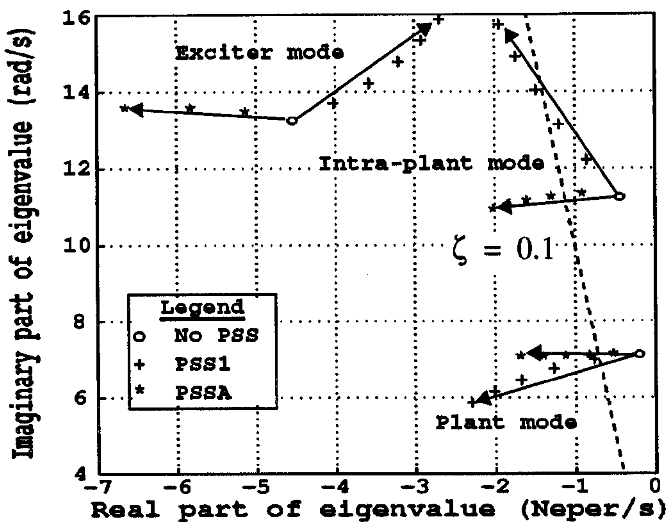


Fig. B. Root-loci of the plant, intra-plant and exciter modes for PSS1 and PSSA. The gains of both PSSs are incremented from zero to 10 in steps of 2.0 pu/pu.

An analysis of the $PVr$ transfer function for the generators reveals that considerably more phase lead is required at the intra-plant modal frequency than that provided by the author's PSS1. The speed-input PSS design based on the $PVr$ transfer function, PSSA, produces additional phase lead as shown in Fig. A. The root-loci plots of the plant, intra-plant and excites modes are shown in Fig. B for comparison with those of PSS1 given in Figs. 4 and 5. The transfer function of PSSA is the same as that for PSS1 except the compensator zeros are replaced by the complex pair $1 + 0.06s + 0.01s^2$.

Some slight modifications to PSSA further improve its performance. While the form of the root-loci for the plant and intra-plant modes in Fig. B can be explained, an explanation for those of the excites mode requires further work.

This four-machine infinite-bus system appears to have a number of anomalous features.

- In performing an analysis of interactions between stabilizers for this system, it was found that significant interactions occur. When positive, such interactions enhance the damping of the particular rotor mode, when negative the effect is deleterious to damping

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[4]. The discussers have performed similar studies on Australian power systems in which all machines in a power station, together with their PSSs, have been fully represented. Interactions between stabilizers in these cases have proved to be relatively small and consequently the effects on damping of local- and inter-area modes are minor.

- The generator transformer reactance is 8.64% on machine rating. Such transformers typically have a value twice this amount. This reduces the amount of phase lead required from the PSS.

Though the author includes a study on a simple interconnected system, it would be of interest to carry out a similar study when such a 4-machine group is a component of a practical, multimachine power system in which a number of local- and inter-area modes come into play and interactions between stabilizers in different stations may occur. For a given generator group or station, an investigation of the robustness of the stabilizer design, particularly with respect to intra-plant and excites mode behavior, different generator loadings in the station and the outage of one or more PSSs or generators would be of practical value.

A further question raised by the paper[1] is the implications for the intra-plant, exciter and other modes of i) tuning PSSs of generators, electrically close to other machines, using on-site measurements and ii) conditions under which such measurements are performed.

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## Closure to Discussion of "The Application of Power System Stabilizers to a Multigenerator Plant"

Graham J. Rogers

Drs. Gibbard and Vowles make some interesting points about power system stabilizer design. The use of complex zeros in the power system stabilizer's transfer function certainly allows more freedom to match the ideal phase. The power system stabilizers with real zeros used in the paper[1] conform to the range of settings available in many production power system stabilizers. Of course, with the introduction of digital power system stabilizers, such restrictions may be removed. The additional phase lead that the complex zeros provide reduces the synchronizing torque at the intra-plant mode frequency, this is very obvious in Figure B of the discussion. A study of the residues associated with the transfer function between Vr and speed should explain the beneficial effect of PSSA on the exciter mode.

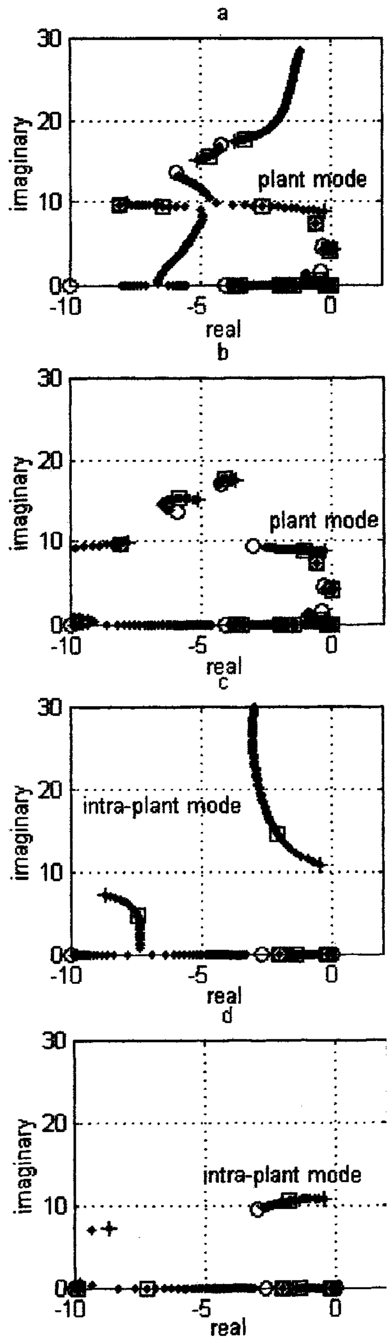


Fig. C. Root loci with power system stabilizer gain (a) Aggregate system—pss1 (b) Aggregate system—pssa (c) Intra-plant system—pss1 (d) Intra-plant system—pssa square—gain = 10.

I agree with the discussers comments on the four generator infinite bus system. I also agree that the intra-plant modes in multiple generator plant are frequently satisfactory. However, this is not always the case, particularly if the power system stabilizers are tuned to damp only the local mode. Since the analysis is relatively straightforward, it should not be left to be discovered on commissioning.

Manuscript received August 13, 1999.

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Publisher Item Identifier S 0885-8950(00)11321-5.

[1]G. J. Rogers, *IEEE Trans. Power Systems*, vol. 15, no. 1, pp. 350–355, February 2000.

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While the two-area system has only a single inter-area mode, it does illustrate quite successfully the performance of power system stabilizers in a practical system. As far as intra-plant modes are concerned, they are largely independent of the rest of the system, and testing their control characteristics in larger models will not add any new information. This of course is not true of the plant and inter-area modes.

In Fig. C, the PSS1 from the paper[1] and PSSA from the discussion are compared when placed at the multiple plant generators in the two area system. The plant modes for the two power system stabilizers are shown in (a) and (b), and the intra-plant modes in (c) and (d). The complex zero has a profound effect on the plant exciter modes. The two higher frequency modes are hardly altered by the power system stabilizer, and the lower frequency exciter mode is made even more stable. It would be interesting to examine its effect with frequency input. The plant mode is satisfactorily stabilized, but the amount of damping available is limited by the complex zeros. The inter-area mode is stabilized similarly with both power system stabilizers. The effect of PSSA on the intra-plant mode is to reduce the frequency slightly while adding damping. Since the complex zero effects only the local modes, I would expect its performance to be robust to changes in system operating conditions. However, this would have to be thoroughly checked.

## Discussion of "Marginal Pricing of Transmission Services: A Comparative Analysis of Network Cost Allocation Methods"

Hugh Rudnick

The authors are to be congratulated for their paper,[1] which contributes to the crucial discussions taking place worldwide on transmission allocation methods in open access schemes. Their numerical and qualitative evaluation of three different methods contributes to the understanding of their differences and similarities. We would appreciate your comments on the following issues.

The Stanford Energy Modeling Forum has developed a set of principles to assess the performance of transmission pricing schemes [1], which read as follow:

1) Promote the efficient day-to-day operation of the bulk power market
2) Signal locational advantages for investment in generation and demand
3) Signal the need for investment in transmission system
4) Compensate the owners of existing transmission system
5) Be simple and transparent
6) Be politically implementable

Although you partially employ these principles, we would appreciate your full rating of the three proposed methods under the Stanford framework.

The need to develop benchmarking methods for transmission pricing remains an open issue. There are no analytical technical or economic demonstrations that support one approach over the other, and discussions often arise on how much of the transmission payments must be transferred directly to consumers and how much to generators. How do the tree methods compare in relation to the allocation to these agents?

Participation factors to measure system usage can be formulated based on incremental use or on "total" use. Total use can be electrically determined through generalized distribution factors [9], unlike the mean factors given in the paper that are based on a crude principle of proportionality. Do the authors have a position on the advantages of using an incremental concept or a total one for allocation of payments?

Transmission networks can be understood as providing two different services. One is the transmission of energy and the other is the provision of capacity for peak transfers. Depending on which service is understood to condition transmission expansion and cost, different allocation schemes can be formulated. Chile has a scheme where use of system at peak demand determines allocation of payments to generators. Bolivia has a different scheme, where usage of system along a load duration curve conditions allocations to generators and consumers. Based on your studies, would you favor one or the other?

Transmission networks in South America are often of a radial nature [2], many times with radial single circuit branches. The application of the benefit factors would become difficult in those situations, as an exercise in power system planning would have to be developed to define alternatives without transmission corridors. Based on the experience of the authors in other countries, how would you approach this difficulty?

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Publisher Item Identifier S 0885-8950(00)11324-0.

[1]F. J. Rubio-Odériz and I. J. Pérez-Arriaga, *IEEE Trans. Power Systems*, vol. 15, no. 1, pp. 448–454, February 2000.

## Closure to Discussion of "Marginal Pricing of Transmission Services: A Comparative Analysis of Network Cost Allocation Methods"

Fco. Javier Rubio-Odériz and Ignacio J. Pérez-Arriaga

We thank Prof. Rudnick for his comprehensive comments and questions.

We respond to them following the same order as in his discussion.

a) Rating of the three proposed methods following the Stanford Energy Forum Principles:

1) "Promote efficient day-to-day operation." Since all three methods assume the previous application of nodal pricing (they assign the complementary charge), short term efficiency is guaranteed.

2 & 3) "Investment signals." Only the method of allocation to beneficiaries may guarantee that long term signals (for location of demand, generation and also transmission reinforcements) are correct, as compared to an ideal centrally planned process.

4) "Owners' compensation." By definition, all three methods cover the complete transmission costs.

Manuscript received March 9, 1998.
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