

### Discussion

**H. Rudnick** (Universidad Católica de Chile, Santiago, Chile): The authors are to be complimented on their paper and their assessment of the practical value of simplified power system models for the study of damping devices.

It would be interesting to learn about the simplified-full model comparison made by the authors and what do they mean by "encouraging", as indicated in their conclusions. Similar sustained low frequency electromechanical oscillations occurred on the United Kingdom interconnected 400/275 kV system at the beginning of 1979 [21]. Reference [13] reports simplified studies of that power grid which were in close relation with results obtained with more detailed models [22]. This was confirmed by actual stabilizer sitings made in that system [23]. Was that the case in the NORDEL system?

The graphical presentation of results proposed is interesting. It is similar to the three dimensional graphical approach proposed by [13], which helped in understanding the geographical characteristics of the British problem. How do the authors see their graphical presentation replace standard eigenvalue/eigenvector listings? Is this presentation being used by NORDEL engineers?

### References

- [21] W. Fairney, A. Miles, T. M. Whitelegg and N. S. Murray, "Low frequency oscillations on the 275 kV interconnectors between Scotland and England", CIGRE 1982 Session, paper 31-08, September 1982.
- [22] H. Rudnick, "Steady state stability of multimachine power systems", Ph.D. Thesis, The Victoria University of Manchester, UK, January 1982.
- [23] K. M. Trantor, "Installation of power system stabilisers and the evaluation of settings", *IEE Proceedings*, Vol. 135, Pt. C, No. 3, pp. 244-250, May 1988.

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**G. Andersson and T. Smed**, (Royal Institute of Technology, Stockholm, Sweden): The authors are congratulated to an interesting and illuminating paper on damping problems in electric power systems: The simplicity of the model makes it possible to gain useful insights into this problem and to draw important general conclusions that can be of great value for the system engineer. We have made the following observations.

- a) The mass-scaled right eigenvector component squared corresponding to mode  $i$  and generator  $j$ , i.e.  $M_j u_i(j)^2$  in equation (3.24), is identical with the participation factor  $a_{ij}$  of ref. [A], which can be seen as follows.

Assume  $u_i$  is a right eigenvector with eigenvalues  $\lambda_i^2$ , i.e.

$$\lambda_i^2 u_i = M^{-1} K_1 u_i \quad (i)$$

Transposing (i) and multiplying by  $M$  from the right gives

$$\lambda_i^2 (M u_i)^T = u_i^T K_1^T \quad (ii)$$

where the fact that  $M$  is symmetric has been utilized. The following matrix manipulations of the right hand side of (ii) are straightforward

$$u_i^T K_1^T = u_i^T I K_1^T = u_i^T M M^{-1} K_1^T = (M u_i)^T M^{-1} K_1^T$$

and (ii) can be written as

$$\lambda_i^2 (M u_i)^T = - (M u_i)^T M^{-1} K_1^T \quad (iii)$$

and  $M u_i$  is obviously a left eigenvector of  $M^{-1} K_1^T$ :

$$v_i = M u_i \quad (iv)$$

The vector  $v_i$  is also a left eigenvector to the matrix  $M^{-1} K_1$  if  $K_1$  is symmetric.

The participation factor  $a_{ij}$  is defined as

$$a_{ij} = \frac{v_i(j) u_i(j)}{u_i^T v_i} \quad (v)$$

With an appropriate scaling the participation factor of the system dealt with becomes

$$a_{ij} = v_i(j) u_i(j) = M_j u_i(j)^2 \quad (vi)$$

which is equal to the mass-scaled eigenvector component referred to above.

The equivalency depends obviously on the symmetry property of the matrix  $K_1$ . It is easily shown that for a lossless transmission network, i.e.,  $r_{kl} = 0$ ,  $K_1$  is symmetric, and for realistic transmission systems it is reasonable to assume that  $K_1$  is close to symmetric.

- b) The left eigenvector component of mode  $i$  corresponding to generator  $j$ ,  $v_i(j)$ , is a measure of how much a change in the row of matrix  $a$  corresponding to the  $d\omega/dt$ -equation will influence the eigenvalue as seen from equation (3.26). This can also be expressed as that the controllability of mode  $i$  from generator  $j$  is reflected in  $v_i(j)$ . Furthermore, since

$$v_i(j) = M_j u_i(j) \quad (vii)$$

as shown above, a right eigenvector component is small when the corresponding left eigenvector component is small. (This applies for the uncontrolled case, i.e. no damping, and  $K_1$  symmetric.) As the observability of mode  $i$  at generator  $j$  is reflected in  $u_i(j)$ , the above reasoning implies that if observability is small, so is also controllability. The benefits of remote signals for power system damping should thus be marginal. An exception would possibly be for a large generator.

- c) The above comments illustrate one application how the method in the paper can be used to gain physical insight into the problem and how it can be used to obtain qualitative results easily. The application to the NORDEL system reported in the paper is an interesting demonstration of how the model can be used for a realistic power system. Could the authors comment on how their model and method compares with other eigenvalue based methodologies, such as those in ref. [20] of the paper and ref. [A].

We would appreciate the authors comments on the above observations and question.

### Reference

- [A] I. J. Pérez-Arriaga, C. G. Verghese and F. C. Schwepe; Selective Modal Analysis with Application to Electric Power Systems, Part I: Heuristic Introduction. *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-101, No. 9, (1982), pp. 3117-3125.

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**BO ELIASSON, DAVID HILL:** We thank the discussors for their interesting comments and questions.

Professor Andersson and Dr Smed point out a useful connection between the modal kinetic energy and participation factors. Their comments about observability and remote signals are thought provoking. While hinting at a simple procedure to select stabiliser signals, we do not see that the degree of benefit from remote signals can be ascertained so simply. Our studies show that the use of a remote frequency measurement in damping a system mode can significantly improve damping. The methodologies in our paper and references [20], [A] are quite complementary. Our aim is to give a simplified physical view of damping coordination across the whole large system. The simplification is obtained at the device level by using simplified component models. In reference [A], emphasis is on a flexible procedure to reduce a system model to preserve selected modes; the simplification is at the system level and there is no particular emphasis on damping structure. Reference [20] gives a comprehensive analysis with complete models. We see our tools serving in preliminary studies before the more accurate comprehensive analysis.

Dr Rudnick refers to our comments about use of simplified models. We were a bit surprised by how accurately the simplified models captured the essential modal behaviour. As indicated above, this was adequate to get useful information on stabilizer placement. Much more detail is available in reports [5-7] and the thesis [16]. However, confirmation by actual stabilizer settings has not yet occurred in the NORDEL system. Certainly our

graphical presentation is somewhat similar to the graphical approach in [13], but we have oriented the information to be superimposed on system representations not matrices. This graphical presentation is used by Sydkraft AB, Sweden and it is anticipated that it will be used more widely in NORDEL.

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