Power Engineering Letters

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Original and significant contributions in applications, case studies, and research in all fields of power engineering are invited. Of specific interest are contributions defining emerging problems and special needs in specific areas. Brief notes may also comment on published areas of established power topics.

This issue includes the following Power Engineering Letters:

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- The Energy Market in Norway and Sweden: Congestion Management, by Richard D. Christie and Ivar Wangersten
- An Efficiency-Optimization Controller for Induction Motor Drives, by M.E.H. Benbouzid and N.S. Nait Said.

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Effect of Nonuniformity on the Continuous Representation of Electromechanical Dynamics in Large Power Systems

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Abstract: The purpose of this note is twofold. First, it brings to the attention of the readers reference [1] with essentially the same subject matter as the recent reference [2], namely the representation of a large power system — from the point of view of its electromechanical dynamic behavior — as a distributed continuum. Reference [1] predates reference [2] by a quarter of a century. Second, it points to a detail in [2] needed to render it truly nonisotropic as opposed to the homogeneous and isotropic modeling used in the approach adopted in [1].

Keywords: Distributed modeling, electromechanical dynamics, modeling of large systems.

Introduction: The recent paper of reference [2] by J.S. Thorp, C.E. Seyler, M. Parashar, and A.G. Phadke is the first and only report on the topic of continuous power system representation for electromechanical dynamics that came to my attention since the publication of my study on the same topic a quarter of a century ago [1]. The motivation for that study was primarily to gain insights into the nature of phenomena (such as propagation of disturbances, reflection and amplification of electromechanical waves, etc.) that can be expected in a very large power system — extending over many thousands of miles, (in some cases) “sea to sea”. The study assumed complete uniformity of the system, i.e., the distributed parameters were considered to be the same all over the system in terms of location and direction: the continuous model was thus both homogeneous and isotropic. It was analogous to existing and extensively studied models of field problems that constitute the object of numerous texts on the (partial differential) “equations of mathematical physics”. Several interesting results have been derived in [1] based on assumptions of uniformity.

Nonuniformity: The continually increasing density of interconnections justifies renewed interest in large power system studies based on a continuous distributed parameter representation. The investigation reported in [2] relaxes the constraints on uniformity, in particular isotropy is not required in the authors’ formulation: there are distinct coefficients for the terms $\frac{\partial^2 \delta}{\partial x^2}$, $\frac{\partial^2 \delta}{\partial y^2}$. These

reflect the fact that the power density p transmitted is not simply proportional to

$$-\text{grad } \delta \text{ (meaning } p_x = -k \frac{\partial \delta}{\partial x}, p_y = -k \frac{\partial \delta}{\partial y} \text{) but } p_x = -k_x \frac{\partial \delta}{\partial x}, p_y = -k_y \frac{\partial \delta}{\partial y}.$$

The fact that k_x, k_y can be different is implicit in the derivation (2) in [2] where x and y appear as distinct, main directions. It would however be more realistic to admit any other two directions as principal axes (transmission lines are not in either direction x or y !).

To permit any arbitrary set of orthogonal directions, we may write

$$\begin{bmatrix} p_x \\ p_y \end{bmatrix} = - \begin{bmatrix} k_{xx} & k_{xy} \\ k_{xy} & k_{yy} \end{bmatrix} \begin{bmatrix} \frac{\partial \delta}{\partial x} \\ \frac{\partial \delta}{\partial y} \end{bmatrix} \quad (1)$$

For example, if the matrix in (1) is proportional to

$$\begin{bmatrix} 3 & 2 \\ 2 & 3 \end{bmatrix}$$

then the main (geographical directions of the) axes are SW-NE and SE-NW with 5 times stronger ties along the first principal axis.

With (1), the PDE

$$m \frac{\partial^2 \delta}{\partial t^2} = \text{div } p = \frac{\partial p_x}{\partial x} + \frac{\partial p_y}{\partial y} \quad (2)$$

that gives the machine dynamics, becomes:

$$m \frac{\partial^2 \delta}{\partial t^2} = - \left(k_{xx} \frac{\partial^2 \delta}{\partial x^2} + k_{yy} \frac{\partial^2 \delta}{\partial y^2} + 2k_{xy} \frac{\partial^2 \delta}{\partial x \partial y} \right) \quad (3)$$

in contrast to the simpler but incomplete form of [2]:

$$m \frac{\partial^2 \delta}{\partial t^2} = - \left(k_{xx} \frac{\partial^2 \delta}{\partial x^2} + k_{yy} \frac{\partial^2 \delta}{\partial y^2} \right) \quad (3a)$$

Relaxing the constraints on uniformity, permits the continuous model to be more closely representative of an actual power system. Some essential features, such as for instance propagation at a speed between that of light and of sound, will still be preserved.

Conclusions: A uniform model may lead to more general results and better insight into some basic phenomena, while a nonuniform — nonhomogeneous and/or nonisotropic — model may permit a more concrete analysis of a given system.

References:

1. A. Semlyen, "Analysis of Disturbance Propagation in Power Systems Based on a Homogeneous Dynamic Model," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-93, March/April 1974, No. 2, pp. 676-684.

2. J.S. Thorp, C.E. Seyler, M. Parashar, A.G. Phadke, "The Large Scale Electric Power System as a Distributed Continuum," *IEEE Power Engineering Review*, Vol. 18, January 1998, No. 1, *Power Engineering Letters*, pp. 49-50.

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The Energy Market in Norway and Sweden: Congestion Management

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Abstract: This Letter gives an expanded discussion of congestion management in the deregulated electric power system in Scandinavia (presently Norway and Sweden). Previous Letters [1-2] provided an overview of the Nordic power system and deregulated structure and described spot and futures market operation for the uncongested case.

Overview: Congestion can be defined as the inability of the transmission system to accommodate the energy flows arising from an unconstrained market settlement. The two independent system operators (ISOs) in the Nord Pool market area have different philosophies for congestion management. In Norway, the spot market is split into *price areas* to deter congestion. Congestion arising after market settlement is controlled by ISO purchase of generation adjustments (buyback). In Sweden, buyback is the primary congestion control method, but the point tariff has a geographic component, which deters congestion. These different approaches coexist without conflict.

Price Area Congestion Management: Because of the topology of the Norwegian transmission system, most congestion will appear as overloads in certain transmission corridors. When congestion is expected to appear, the system is divided into *bid areas* separated by the corridors. This division is declared by the ISO (Statnett) prior to spot market bidding. A prediction of bid areas is published for each week at noon on Thursday of the preceding week. As the week progresses, the ISO can revise bid areas for a given day by notifying market participants by 10.00 on the preceding day (bids are due by noon). The number of bid areas ranges from two to five. They are presently declared, and boundaries established, based on operator wisdom and experience, without analytical tools.

Spot market bids are submitted by organizations rather than by physical generator or load. When bid areas are declared, each bidder must submit separate bids for each area. Bidders that own generation and/or load in only one bid area need not split their bids. Larger bidders must separate their bids by area. The spot market is first resolved as if uncongested, and the generation and load in each bid area is determined. If transfer between bid areas does not exceed limits, then this uncongested solution, with one system-wide market price, is used. It will be identical to the solution obtained if no bid areas had been declared.

If transfer between bid areas exceeds limits, then each area is separately settled using only the bids for that area and the transfer constraint. The price in areas with excess generation is lowered, reducing generation and increasing load in the area, compared to the unconstrained case. The price in areas with excess load is raised, reducing loads and increasing generation, until transfer limits are satisfied. Bid areas with different prices after market settlement are called *price areas*.

Example: Consider two bid areas, A and B, each having aggregate generation (G , in MWh) and demand (D , in MWh) bid curves which are linear functions of price (P , in NOK). Specifically, let

$$D_a = 250 - P_a$$

$$D_b = -2.86 P_b + 629$$

$$G_a = 3 P_a - 50$$

$$G_b = 2 P_b \quad (1)$$

In the unconstrained case, the prices are equal and the total generation must equal the total demand

$$P_a = P_b = P$$

$$G_a + G_b = D_a + D_b \quad (2)$$