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PREDICTING OUTAGE AND CONTAINING CHAOS IN A POWER GRID

by

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Abstract. Chaotic fluctuations in the voltage available at different nodes in the electric power grid have been observed in connection with unwanted events, such as voltage collapse and power outage. The overall peak power in the grid also fluctuates unpredictably. In this report we consider techniques for controlling, or at least containing, the fluctuations after their appearance, as well as the problem of prediction of the peak load. In other reports, we will consider avoidance stretegies to prevent the appearance of these unwanted events. In all cases, the strategies we consider are based on the theory of complex dynamical systems: chaotic attractors and their bifurcations.

CONTENTS

1. Introduction. We consider the stability of electric power systems [1]. The problem of voltage collapse, in particular, is reviewed in several recent papers [2]. We consider as given a particular system, along with a complex dynamical model [3]. The model is a complex dynamical system (defined by ordinary differential equations) of high dimension, probably having multiple attractors and basins, and fractal separatrices bounding some basins. We consider a fixed model in this report, rather than a family of models parameterized by bifurcation parameters.

2. Voltage collapse problem. In the recent literature may be found several strategies for controlling chaos [4]. That is, consider a model system in a trajectory following a chaotic attractor, and try to perturb it by exogenous forces so that the perturbed trajectory is confined to a small region within the attractor. In an early application, *the OGY method* of stabilization [5] was applied to the chaotic vibration of a magnetoelastic ribbon [6]. A later application, closer in spirit to our own, is to the mammalian medical problem of heart fibrillation [7]. Here, a different method is employed, called *the PPF method.* Both of these methods present problems when the model system has large dimension. In this case, an efficient method has recently been published, *the AGOY method* [8].

3. Peak load problem. Another concern of this project has been the modeling and prediction of the overall peak load of the grid. As is well-known, this power consumption factor fluctuates widely, presenting the utility management and consumers with many practical problems. Exogenous factors such as climate (air-conditioning demand from July to September) or social habits (TV demand during baseball games) create predictable perturbations in the distributed parameters of the grid (and its model) while other exogenous factors may be unpredictable.

Due to the strong nonlinearities of the system, these changes in the parameters, as in the case of a forced oscillator or pendulum, may cause catastrophic or exposive bifurcations in the dynamics of the grid. The explosion of a chaotic attractor is a model bifurcation which we have studied extensively in the past, and which can interfere with reliable prediction of the peak load on the grid.

Available records of daily operations of large urban grids may provide support for the chaotic explosion scenario proposed here, and voltage collapse is just one of the nonlinear phenomena which could be illuminated by the study of a massively complex dynamical model, using the methods of chaos theory.

The methods of chaos theory may be used to make short-term predictions of the peak load as follows.

1. First, we assume a complex dynamical model for the power grid. The creation of a useful model, capable of rapid simulation on a hybrid or massively parallel supercomputer, is a nontrivial task.

2. Given such a model, we assume a reasonable coupling of exogenous factors such as

hot weather, scheduled sports events, and so on, to the distributed loads within the grid.

3. From existing data for the exogenous factors, we make a short-term prediction for the near future of these ambient parameters, using standard techniques of chaos theory.

4. Then we may simulate the effect of these predicted forcing terms with the computer model. Outages, if predicted, might be avoided by securing additional supply sources or restricting power consumption.

4. Future directions. This outline suggests three derivative projects:
(1) the simulation of a massively parallel model of the electric power grid, including the effects of forcing by exogenous parameters such as hot weather,
(2) use of the model to simulate a voltage collapse, and test methods of prediction and prevention, such as the AGOY method,
(3) use of the model to predict peak load, give warning of outages, and test corrective measures such as reconfiguration of the grid.

Under (1) we would create one or more working models of the electric power system, in which nodes of the model have power (positive or negative) as a control parameter changed locally according to a program simulating the real grid: variation of peak load by time-of-day, day-of-week, season, etc. These changes would be made by an auxiliary (chaotic) dynamical system, perhaps with a spatially dependent pattern, simulating the human/social dynamics inherent in the user population.

We would also try to obtain the most detailed data available for a real power grid, for comparison with our simulated data. We would relate peak power to statistical measures of the exogenous factors of the user population (temperature, sports events, etc.) and try to find a predictive function relating the entropy, Liapunov exponents, and fractal dimension of the driving parameters to the peak power fluctuations of the driven grid. Our extensive experience with the resonant bifurcations of the driven oscillator will be useful in this regard.

Assuming some success in (1) in tailoring the model to realistic data, we would attempt under (2) to stabilise the chaotic behavior of the model grid, in the presence of chaotic forcing applied to the local power parameters at the nodes. Similarly, in (3), we would try to find defensive measures, specific to the power grid model, to avoid outages due to excessive peak loads.

5. Conclusion. Assuming, eventually, some success in the programs described above, we could dream of an experimental intervention in a real power system, attempting to avert a voltage collapse or outage due to excess loading. Although there are some dangers inherent in any intervention in a real system by an experimental method, we may emphasize that the methods envisioned here involve only very subtle variations in the load parameters at a few key nodes of the grid. Certainly this is safer than a electro-surgical manipulation of a human heart in a living and critically ill patient. And in fact, methods perfected in the power grid of a large urban area, besides obtaining greater reliability for the consumer network, may provide theoretical and technical byproducts for the other technologies (physical, biological, social, economic, psychological, etc.) which share the basic structure of the electric power grid: a massively parallel, distributed, and chaotically driven, complex dynamical system.

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Notes

[1] See (Ueda, 1992) and the references therein for the history of research in this area.

[2] See (Chow, 1990) for example.

[3] See (Abraham, 1984) for an introduction to the theory of complex dynamical systems. The equations of (Chiang, 1990) might be the basis of a typical power grid of generators and loads, for example.

[4] See (Auerbach, 1992) and references therein.

[5] First described in (Ott, 1990) .

[6] See (Ditto, 1990) .

[7] See (Garfinkel, 1992) .

[8] See (Auerbach, 1992) .

References

Abraham, 1984.
Ralph H. Abraham, ''Complex dynamical systems,'' pp. 82-86 in *Mathematical Modelling in Science and Technology*, ed. X.J.R. Avula, R.E. Kalman, A.I. Leapis, E.Y. Rodin,Pergamon (1984).

Auerbach, 1992.
Ditza Auerbach, Celso Grebogi, Edward Ott, and James A. Yorke, ''Controlling chaos in high dimensional systems,'' *Phys. Rev. Lett.* **69** pp. 3479-3482 (1992).

Chiang, 1990.
Hsiao-Dong Chiang, Ian Dobson, Robert J. Thomas, James S. Thorp, and Lazhar Fekih-Ahmed, ''On voltage collapse in electric power systems,'' *IEEE Trans. Power Systems* **5(2)** pp. 601-608 (May 1990).

Chow, 1990.
J-C Chow, R. Fischl, and H. Yan, ''On the evaluation of voltage collapse criteria,'' *IEEE Trans. Power Systems* **5(2)** pp. 612-620 (May 1990).

Ditto, 1990.
W. L. Ditto, S. N. Rauseo, and M. L. Spano, ''Experimental control of chaos,'' *Phys. Rev. Lett.* **65** p. 3211 (1990).

Garfinkel, 1992.
Alan Garfinkel, Mark L. Spano, William L. Ditto, and James N. Weiss, ''Controlling cardiac chaos,'' *Science* **257** pp. 1230-1235 (1992).

Ott, 1990.
E. Ott, C. Grebogi, and J. A. Yorke, ''Controlling chaos,'' *Phys. Rev. Lett.* **64** p. 1196 (1990).

Ueda, 1992.
Y. Ueda, T. Enomoto, and H. B. Stewart, ''Chaotic transients and fractal structures governing coupled swing dynamics,'' pp. 207-218 in *Applied Chaos*, ed. Jong Hyun Kim and John Stringer,John Wiley, New York (1992).