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Geometrical Methods for Power Network Analysis

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To our parents and teachers

Preface

This book presents an intrinsic geometric model for power system planning and operation. This problem is generally large scale and nonlinear. We have thus developed an intrinsic geometric model for network reliability and voltage stability, and applied it specifically to the IEEE 5 bus system. The robustness of the proposed model is illustrated by introducing variations of the network parameters. Exact analytical results demonstrate the accuracy as well as the efficiency of the proposed solution technique.

Moreover, from the perspective of intrinsic state-space geometry, we explore power system instability problems introduced by the competitive market mechanism, system failures, and contingency effects, i.e., unforeseen and unexpected events involving system devices, in the face of the widespread deregulation of the global power industry. From the perspective of electrical engineering, we examine the state-space formulation pertaining to:

- voltage regulation phase shift corrections,
- voltage instability of the maximum deliverable power for a given load in the steady-state sinusoidal regime, and
- stabilization of a large-scale voltage instability under the power law characterization.

Finally, regarding the formulation of the intrinsic geometry, we offer a detailed account of complex power optimization in both the steady and nonsteady state regimes. The book can be summarized as follows.

In Chap. 1, we explain the motivation for power network flow analysis and introduction of the geometrical method. The goal of this research is to advance the state of the art in power system reliability and voltage stability. Indeed, power system stability is a potentially attractive target in the emerging deregulated power market, not only to maintain efficient operation of power systems while meeting the demand, but also to optimize the economics of the power system. In addition, deregulation of the electricity market has introduced power flow uncertainty, and hence also fluctuations. This means that power system planners and operators are required to run electricity network components close to their physical capacities, under a given equilibrium operation point. Our scheme maintains system performance with almost stable system voltage profile and transmission line efficiency by improving impedance angle and steady-state controls and by avoiding blackouts. In this respect, planning aimed at providing a stable power supply has recently been in wide demand in power system technology. From the perspective of transmission theory, we report new developments involving power flow properties as a function of the power factors of a finite parameter network configuration.

In Chap. 2, we show how to formulate the intrinsic geometric characterization of admissible component(s) and discuss the associated theoretical motivations from the perspective of circuit planning, and the validity of the proposed model.

In Chap. 3, we provide an intrinsic geometric characterization by incorporating the proposed methodology. We begin with a brief introduction to the network fluctuation problem, recalling the underlying motivation for the intrinsic geometric analysis, and setting up the notation for the computations in subsequent chapters. Implementing the notation for a given network local equilibrium, we can fix a set of optimal values of the network parameters, e.g., L, C, and R, and the corresponding phases of the chosen power network. The logic simply follows from the fact that the sum of the three angles of a triangle is constant. To illustrate these intrinsic geometric considerations, we derive exact formulas for the case of the two- and three-parameter statistical configurations. We also outline the above notion for a network with finitely many parameters.

Chapter 4 discusses current research trends and knowledge of the intrinsic geometric model in an accessible manner for application to the solution of power system planning and operation. This problem is large scale and nonlinear, in general. In order to test network reliability, we have developed an intrinsic geometric model for network reliability and examined it for the IEEE 5 bus system at the forefront of research on the physical aspects of local and global flow properties. In fact, the robustness of the proposed model is illustrated by introducing variations of the network parameters. The exact analytical results here offer a compact and up-to-date discussion of the accuracy and efficiency of the statistical technique.

Chapter 5 extends the aforementioned techniques of intrinsic geometry and examines the problem of voltage stability in network theory. In order to carry out this investigation, we formulate the problem of voltage stability by following the previously described mathematical specifications of the three-parameter model. Hence, in order to test for voltage stability, we describe this innovation for single component LCR networks and show that the voltage stability achieved using the results proven by the proposed work lies within the desired accuracy limits. From the outset of the present investigation, we offer specific remarks and outlook for further research prospects.

From the perspective of network theory, Chap. 6 illustrates how the parametric intrinsic geometric description exhibits an exact set of pair correction functions and global correlation volume, with and without the inclusion of the imaginary power flow. The Gaussian fluctuations about the equilibrium basis for the phases of a power network system generate a well-defined, nondegenerate, curved regular intrinsic Riemannian surface for the purely real and the purely imaginary power flows and their linear combinations. An explicit computation demonstrates that the underlying real and imaginary power correlations involve ordinary summations of the power factors, with and without their joint effects. The novel aspects of intrinsic geometry allow one to propose stable designs for power systems.

In Chap. 7, we examine the phase shift correction under the hypotheses of fluctuation theory. In particular, from the state-space perspective for the voltage instability of a connected power system, we illustrate how, for 2 bus systems, the voltage of the relevant buses, i.e., bus 1 and bus 2, varies in the same way as the transmitted power. In the sequel, we explore the state-space formulation pertaining to voltage regulation and phase shift correction. In the state-space formulation, some assumptions have been made, i.e., the shunt admittance has been neglected, no reactive support on the load bus is allowed, the generator terminal voltage phasor is assumed to coincide with the rotor position, and the load is defined by the real and reactive power demand.

In Chap. 8, we analyze the voltage instability pertaining to the maximum deliverable power and the complex power optimization problem for a given load. We thus illustrate the role of state-space geometry in complex power flow optimization. In the fast-growing and competitive power market, optimization is essential in order to define the loadability limit of the power network. Here, one must consider not only the real power, but also the reactive support.

Chapter 9 uses the intrinsic state-space geometry to explore power system instability problems introduced by the competitive market mechanism, system faults, and contingency of instruments in the face of the widespread deregulation of the global power industry. From the standpoint of electrical engineering, we examine the state-space formulation using the notions from (1) the voltage regulation phase shift correction and (2) the voltage instability of the maximum deliverable power for a given load in the steady-state sinusoidal regime to discuss the stabilization of the large-scale voltage instability under the power law characterization. In the proposed formulation of this problem, the same assumptions are made as in Chap. 7. Finally, regarding the intrinsic geometry formulation, we offer a detailed account of complex power optimization of large-scale voltage instability in both the steady and non-steady state regimes.

Chapter 10 brings together the conclusions from the intrinsic geometric approach for the power network stability problem and discusses the outlook for future research in the subject. The main highlight of the present intrinsic geometric model is that it can be applied to analyze random variations of circuit parameters. It can be used for planning and operation of networks, so a variational analysis can be described from the perspective of operation and maintenance. For a unified analysis of electrical networks, the proposed geometric model offers simultaneous consideration of the following three scenarios: (1) lossless power networks, (2) networks with power loss, and (3) voltage collapses occurring in the network.

The present model is technically sound and could be directly implemented by the technological application of intrinsic Weinhold geometry. Furthermore, such models are robust and are intrinsically parameterized in terms of the reactance, resistance, and capacitance of the considered network. Since we offer a nonlinear improvement of the stability and reliability of the power system, the present investigation eliminates the disadvantages inherent in standard regression techniques. Moreover, the voltage instability results from the fact that the operating point lies beyond the maximum deliverable power. Beyond this limit, the maximum deliverable power leads to a varying load. Thus, a more realistic outage regarding the deliverable power flow is obtained when one takes into account (as in the present nonlinear analysis) fluctuations in the voltage, occurring along with fluctuations in the input real and imaginary power. Finally, in the previously mentioned hypothesis of complex power optimization (see for instance Chap. 8), there exists a set of computational disadvantages, viz., integration with the existing methodologies, lack of economic analysis, and lack of sensitivity analysis, together with possible combined effects. By considering the state-space geometry, several of these problems are nonlinearly improved. Using the results of the present model, it should be possible to produce an engineering demonstrator application. In short, this book gives an accurate load-shedding strategy with respect to network reliability and system instability.

As a bridge between advanced graduate study and the forefront of engineering research, we offer here a detailed examination of intrinsic geometry, network analysis, and statistical configurations aimed at postgraduate students and nonspecialist researchers in physics and related applied areas.

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