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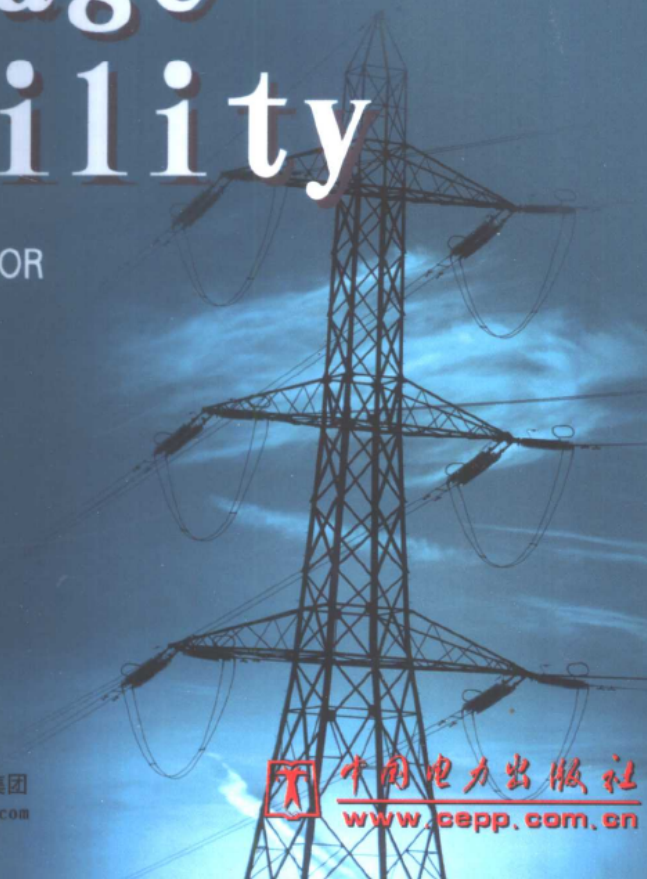
电力系统电压稳定

（影印版）

Power System Voltage Stability

CARSON W. TAYLOR



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EPRI 电力系统工程丛书

- 电力系统稳定与控制
- 电力系统电压稳定

畅销国际电力界的经典之作

——第一部精确阐述电力系统电压稳定问题解决方案的专著

电力系统电压稳定

这本权威专著深入透彻地论述了电力系统的电压稳定问题，可以帮助读者从事电力系统规划和运行工作。本书是在EPRI的资助下出版的，其内容涵盖了电力系统的暂态和长期行为，提供了解决电力系统常见失稳问题的有效方案。

Carson W. Taylor是国际知名的电压稳定问题专家。作为邦那维尔电力局的专职工程师，作者从事了大量太平洋西北系统和邻近区域的电压稳定研究；同时作者还参与了西北系统协调委员会（WSCC）、北美电力可靠性委员会（NERC）、IEEE、CIGRE和EPRI等组织的电压稳定工作。本书正是作者多年来实践与研究成果的总结。

本书描述了电力系统中输电系统、发电系统和配电／负荷系统的设备特性，同时给出了不同设备的建模方法；此外，以小型等值电力系统和大型实际电力系统为例，本书分别论述了应用计算机进行电压稳定静态和动态仿真的方法，并分析了包含HVDC联络线电力系统的电压稳定问题。

本书的独特之处是针对电压问题提出了电力系统规划和运行的导则、应用潮流和动态仿真程序分析电压稳定的方法，以及描述了世界许多电力系统实际发生的电压失稳事件。

作为从事电力工作人员的必备工具，本书包括了解决电力系统和发电厂电压稳定问题所必需的知识和能力。

为适应中国电力工业的快速发展，满足中国广大电力专业在校师生特别是高年级本科生和研究生以及科技人员直接阅读国外科技专著、掌握第一手资料的需要，中国电力出版社与麦格劳－希尔教育出版（亚洲）公司合作，在中华人民共和国境内（不包括香港、澳门特别行政区及台湾）出版发行本书的影印版。本书的出版必将会为中国电力工业在21世纪的发展起到应有的促进和推动作用。

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Power System Voltage Stability

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Carson W Taylor

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Power System Voltage Stability

影印版序一

在环境保护、电网互联和放松电力管制的要求下，电力系统的运行正越来越接近其极限状态。除了传统的功角稳定性问题以外，电力系统的另一类稳定问题——电压（负荷）稳定正在日益引起人们的重视，并且在可以预想的未来将继续保持其挑战性。

“Power System Voltage Stability”一书出版于1994年，是国际上首部关于电压稳定的著作。该书针对近十几年来世界各地相继出现的电压失稳和电压崩溃事故，从工程实际的角度出发，详尽而全面地阐述了电力系统的电压稳定问题。书中着重从物理和工程概念方面理解电压稳定问题，而不是纯粹从数学的角度来看待这个问题；它不仅从基本概念上解释了电压稳定问题，更为重要的是针对实际电力系统的电压稳定问题提出了解决方案。

作者Carson W.Taylor是国际知名的电压稳定问题专家，他在长期从事电压稳定工作和学术活动中积累了丰富的知识和经验，在总结近年来大量电压稳定问题研究成果的基础上完成了该书。

目前，国内还缺乏全面论述电压稳定问题的专著，该书影印版的出版在一定程度上弥补了这个遗憾。该书体系结构合理，循序渐进，易于理解和掌握，不但物理概念和工程实践观点均很强，并且在论述上也注重了严谨性和直观性的结合。影印版避免了翻译中的不确切，有利于更好地理解作者的观点。即使读者的英文基础和数学功底都不很深，但在阅读这本文字朴实流畅、内容深入浅出的著作时，并不会感到困难重重或者枯燥无味。

该书共分9章和6个附录，从体系结构上可分为四部分。第一部分包括第1～2章，主要介绍了电压稳定的定义和基本概念，将电压稳定分为暂态和长期两大类。第二部分覆盖第3～5章，阐述了与电压稳定关系密切的各类设备的特性和模型。在第三部分中，第6章和第7章两章用静态和动态的计算机仿真方法分别研究了小的等值系统和大系统的电压稳定性，而第8章阐述了与超高压直流输电系统相关的电压稳定问题。由第9章组成的第四部分提出了电力系统规划和运行中应该遵循的准则，并介绍了电压问题的解决方案。附录讨论了潮流计算方法、电压静态稳定性指标和长期稳定性的动态

分析方法，最后介绍了世界各国发生的重大暂态电压失稳事故和长期电压失稳事故。

该书的主要对象是从事电力系统运行和规划工作的工程技术人员，但同时也给该领域的研究人员提供了很好的背景材料和研究工作的出发点，对相应专业的学生来说也是很好的教材和参考书。

薛禹胜

国家电力公司电力自动化研究院

2001 年 8 月

Power System Voltage Stability

影印版序二

“Power System Voltage Stability”一书出版于1994年，属美国电力科学研究院（EPRI）的电力工程丛书之一，是国际上有关电力系统电压稳定性的第一本专著。

在20世纪70、80年代中，世界范围内曾发生过大量与电压不稳定有关的电力系统事故，其中形成电压崩溃的就有10多起，有的造成大面积、长时间的停电，引起电力工业界和学术界的广泛重视并对此进行了大量的研究。90年代初，国际大电网会议（CIGRE）第38（电力系统分析和技术）专业委员会相继组织了四个特别工作组（Task Force），对有关电压稳定性的定义、数学模型和分析方法、电压稳定性指标和准则、电压崩溃的发生机理和防止对策等进行了广泛的调查和研究，所发表的研究报告基本上反映了当时对电力系统电压稳定性的认识过程并归纳了当时有关的主要研究成果。本书的作者Carson W.Taylor参加了这些特别工作组并作为其中两个组的召集人，而本书中的内容则反映了这些研究报告的精髓和作者本人的研究成果及实践经验。

全书包括9章和6个附录。第一章介绍和回顾了电力系统中有功功率和无功功率的传输。第二章论述了电压稳定性的定义、机理和分类等基本概念，并简单介绍了将电压稳定性视为静态问题时的P-V或Q-V曲线分析方法。第3～5章介绍了输电系统和配电系统中的主要元件、负荷以及发电机组等的特性和它们的数学模型。第6章和第7章分别介绍了两个小等值系统和一个大规模实际系统有关电压稳定性的静态和动态仿真结果，以说明电压稳定性的计算机仿真方法。第8章介绍了高压直流输电对电压稳定性的影响。最后，在第9章中探讨了电力系统规划和运行中有关电压稳定性的一些准则，概括了在输电系统、配电系统以及负荷等方面提高电压稳定性和防止电压崩溃的措施。在附录中除了作为正文的辅助内容以外，介绍了部分电压不稳定事故的实际发生和发展过程。

本书的写作特点是：紧密联系电力系统电压稳定性的工程实际而不拘泥于抽象的理论和烦琐的数学推导，使读者易于理解电压稳定性的物理现象及

其规律，并便于在自己的生产实践活动中应用；通过大量的例题引入有关的概念、数据、分析和计算方法，使读者易于了解和掌握正文中的内容；每章都附有详尽的参考文献，便于读者查阅。因此，对于我国从事电力系统规划、设计、运行和控制的工程技术人员和研究人员，以及高等院校的有关教师和研究生来说，是一本很有价值的参考书。

应该指出的是，本书出版以后，有关电力系统电压稳定性的研究仍在继续和深入，每年在国内外都发表了大量的论文。关于电压稳定性的动态本质越来越被人们所认识和接受，并发展了相应的分析方法；在提高电压稳定性的措施和对策方面也有很大的发展，特别是电压稳定性的预测和监视以及在线进电压稳定性的安全分析、预防控制和校正控制等方面。

夏道止

西安交通大学电力工程系

2001 年 8 月

Power System Voltage Stability

影印版序三

由 Carson W. Taylor 教授编著的“Power System Voltage Stability”一书出版于 1994 年，是美国电力研究院组织编写的电力系统工程丛书之一，也是国际上介绍有关电力系统电压稳定性相关问题的第一本专著。该书共分为九章，比较系统地介绍了有关电压稳定性的基本概念、相关影响因素、分析与控制方法等方面的内容。其中，第一章和第二章重点介绍了有关电力系统中无功功率传输及电压稳定性的基本概念；第三章至第五章重点描述了输电系统、发电系统、配电以及负荷系统中的设备特征及建模方法；第六章和第七章给出了电力系统电压稳定性问题的静态和动态仿真结果；第八章分析了电力系统中直流输电环节对电压稳定性问题的影响；最后，第九章介绍了为避免出现电压稳定性问题，在系统规划与运行时所应遵循的技术原则。

本书作者是一位国际知名的电力系统电压稳定性分析方面的专家，在相关领域积累了丰富的研究和实际工程经验，该书是作者多年工作成果的总结。本书问世以来，以其内容的基础性和实用性而被众多从事电压稳定性方面的研究者所引用，是电力系统电压稳定性研究方面的重要参考书之一。该书主要具有以下几个特点：

（1）强调电压稳定性的物理或工程概念，用最简单的数学模型来分析电压稳定性相关问题的机理，这非常适合于帮助刚刚进入电压稳定性问题研究领域的读者对这一复杂的问题有比较清晰的认识。

（2）重点强调实用化计算机分析方法的应用，而非复杂的数学分析方法的描述。其目的是让读者对电压稳定性问题有一个总体的认识。书中提供的许多有关电压稳定性问题的背景材料、计算机仿真结果，对研究者了解电压稳定性问题很有帮助。

（3）书中提供了大量的例题，其中，许多具有实际背景的数据可供电压稳定性问题的研究者进行相关问题研究时引用。事实上，书中一些算例已经成为电压稳定性问题研究的经典算例。

（4）内容系统性强，详略适宜。对于与电压稳定性相关的基本概念，力求详尽具体，通过计算实例加以阐明。对于电压稳定性问题相关的技术，重

点介绍目前现状及未来的发展方向。

（5）书中提供了大量电压稳定性问题相关的参考文献，为读者进一步了解该领域所取得的研究成果提供了便利。

本书可以作为电力系统及其自动化专业大学高年级本科生和研究生的选修课教材或教学参考书，也可供从事电力系统规划与运行的工程技术人员阅读。

王成山

天津大学电气自动化与能源工程学院

2001 年 8 月

To my parents

Preface

Power transmission capability has traditionally been limited by either rotor angle (synchronous) stability or by thermal loading capabilities. The blackout problem has been associated with transient stability; fortunately this problem is now diminished by fast short circuit clearing, powerful excitation systems, and various special stability controls.

Voltage (load) stability, however, is now a major concern in planning and operating electric power systems. More and more electric utilities are facing voltage stability-imposed limits. Voltage instability and collapse have resulted in several major system failures (blackouts) such as the massive Tokyo blackout in July 1987.

Voltage stability will remain a challenge for the foreseeable future and, indeed, is likely to increase in importance. One reason is the need for more intensive use of available transmission facilities. The increased use of existing transmission is made possible, in part, by reactive power compensation—which is inherently less robust than "wire-in-the-air."

Over the last ten to fifteen years, and especially over about the last five years, utility engineers, consultants, and university researchers have intensely studied voltage stability. Hundreds of technical papers have resulted, along with many conferences, symposiums, and seminars. Utilities have developed practical analysis techniques, and are now planning and operating power systems to prevent voltage instability for credible disturbances. All relevant phenomena, including longer-term phenomena, can be demonstrated by time domain simulation.

While experts now have a good understanding of voltage phenomena, a comprehensive, practical explanation of voltage stability in book form is necessary. This is the first book on voltage stability.

Power System Voltage Stability is an outgrowth of many two–three day seminars which I began offering in 1988. As a full-time engineer of the Bonneville Power Administration (BPA), the book is influenced by my work on voltage stability problems in the Pacific Northwest and adjacent areas. It is

also influenced by my participation in voltage stability work of the Western Systems Coordinating Council, North American Electric Reliability Council, IEEE, CIGRE, and EPRI.

Although voltage stability is fairly well understood, there are many facets to the problem, ranging from generator controls to transmission network reactive power compensation to distribution network design to load characteristics. The physical characteristics and mathematical models of a wide range of equipment are important.

Power System Voltage Stability emphasizes the physical or engineering aspects of voltage stability, providing a conceptual understanding of voltage stability. The simplest possible models are used for conceptual explanations. Practical methods for computer analysis are emphasized. We aim to develop good intuition relative to voltage problems, rather than to describe sophisticated mathematical analytical methods. The book is primarily for practicing engineers in power system planning and operation. However, the book should be useful to university students as a supplementary text. University researchers may find the book provides necessary background material on the voltage stability problem.

Many references are provided for those who wish to delve deeper into a fascinating subject. The references are not exhaustive, however, and generally represent recent publications which build on earlier work. In keeping with the intended audience, most of the references are quite readable by those without advanced mathematical training.

Outline of book. The book is divided into nine chapters and six appendices. Chapter 1 is introductory with emphasis on reactive power transmission. Chapter 2 introduces the subject of voltage stability, providing definitions and basic concepts. Voltage stability is separated into transient and longer-term phenomena.

Chapters 3–5 describe equipment characteristics for transmission systems, generation systems, and distribution/load systems. Modeling of equipment is emphasized.

Chapters 6 and 7 describe computer simulation examples for both small equivalent power systems and for a very large power system. Both static and dynamic simulation methods are used. Both transient and longer-term forms of voltage stability are studied using conventional and advanced computer programs.

Chapter 8 describes voltage stability associated with HVDC links. Here the reactive power demand of HVDC inverters is important.

Chapter 9 provides planning and operating guidelines, and potential solutions to voltage problems.

The appendices include description of computer methods for power flow and dynamic simulation, and description of voltage instability incidents.

Voltage stability is still a fresh subject and many advances in understanding, simulation software, and on-line security assessment software will be made in future years. In fact, the book was frequently updated until the submission deadline. It's likely that a revised edition will be called for. I invite comments on the book and suggestions for revised editions. Please write to me at 252 Northwest Seblar Court, Portland, Oregon 97210.

For those interested in desktop publishing, I used a Macintosh IIci computer and FrameMaker technical publishing software. I also used several other programs such as DeltaGraph and Canvas. The manuscript was submitted to McGraw-Hill on diskettes.

Acknowledgments. I am indebted to many seminar participants, BPA colleagues, and industry colleagues. To a large extent, the book is a synthesis of a large body of literature and practical knowledge. Through papers, correspondence, and discussions, Walter Lachs, Harrison Clark, Dr. Thierry Van Cutsem, Dr. Mrinal Pal, and others have provided many helpful insights. On an international level, I have been privileged to participate in the work of two CIGRÉ task forces investigating voltage stability. As part of EPRI software development projects, discussions with Dr. Prabha Kundur and colleagues at Ontario Hydro were very important.

Dr. Kundur and Mark Lauby reviewed the manuscript and provided many helpful suggestions. I, however, am solely responsible for the final version.

The Electric Power Research Institute sponsored the book. I deeply appreciate the support at EPRI from Dr. Neal Balu, Mark Lauby, and Dominic Maratukulam.

Although this was an off-hours project, I thank BPA engineering management for encouraging advances in power system engineering, for providing the opportunity to work on problems in the field of voltage stability, and for the privilege of participating in industry and professional society study of voltage stability. This work, however, is my own and does not necessarily reflect the views of the Bonneville Power Administration.

Finally, I thank my wife, Gudrun Taylor, for her encouragement, proofreading, and patience during many hours at the computer.

Carson W. Taylor
Portland, Oregon
December 1992

Foreword

Electric utilities have been forced in recent years to squeeze the maximum possible power through existing networks due to a variety of limitations in the construction of generation and transmission facilities.

Voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all nodes in the system under normal and contingent conditions. A power system is said to have entered a state of voltage instability when a disturbance causes a progressive and uncontrollable decline in voltage.

Inadequate reactive power support from generators and transmission lines leads to voltage instability or voltage collapse, which have resulted in several major system failures in recent years. Hence, a thorough understanding of voltage stability phenomena and designing mitigation schemes to prevent voltage instability is of great value to utilities.

The author, Carson Taylor, is an internationally recognized expert on power system voltage stability. He not only has a thorough understanding of the fundamental concepts of voltage stability but also has demonstrated his skill in developing practical solutions to real life problems of voltage instability. Carson has taught many courses and written numerous technical papers on the subject of power system voltage stability.

It gives me great pleasure to write the Foreword for this timely book, which I am confident will be of great value to practicing engineers and students in the field of power engineering.

Dr. Neal J. Balu
Program Manager
Power System Planning and Operations Program
Electrical System Division

ABOUT THE AUTHOR

Carson W. Taylor is Principal Engineer with the Bonneville Power Administration in Portland, Oregon. His areas of expertise at BPA include power system control and protection, system dynamic performance, ac/dc power system interaction, and power system planning. In 1986, he established Carson Taylor Seminars, a company specializing in electric power system education. Mr. Taylor is a Fellow of the IEEE, and the author or coauthor of many IEEE and CIGRE papers.

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