普通高等教育“十二五”规划双语系列教材

Modern Control Theory Lecture

（英文版）

王杰　陈陈　编著

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内 容 提 要

本书将现代控制理论方法与电力工程实践紧密结合，主要介绍了控制系统的状态空间表达式、控制系统状态空间表达式的解、线性系统的能控性与能观性、稳定性与Lyapunov方法、线性定常系统的综合、最优控制等。

本书既可作为高等学校电气工程和自动化专业学生、教师的教学用书，也可作为从事相关专业技术研究人员的参考用书。

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前 言

本书是高等学校电气工程自动化、自动控制、自动化仪表、工业自动化等专业的教材。它是作者经过多年的教学实践并了解学生学习情况，在参阅国内外优秀教材及作者讲授该课讲义的基础上编写的。

本书主要介绍了控制理论的概念、方法和应用；研究状态空间表达式解的存在性和唯一性及相关性质，着重介绍了与解状态空间方程相关的常微分方程基本理论；本书仍保留传统的现代控制理论的章节安排，在关于能控能观方面着重介绍了时间函数的线性无关性和线性时变系统的最小能量控制概念，以便读者能够较好地掌握能控能观的基本要点。由于现代控制的发展和要求，本书重点增加了稳定性与 Lyapunov 方法的内容，尤其是非线性时变系统的稳定性方面的内容。为了使读者更好地掌握现代控制理论的内涵和要点，本书也添加了不少有关线性代数和常微分方程的基本知识，并对书中所出现的定理尽可能给出详细的证明以便满足不同层次的读者需要。在稳定性方面，本书增加了 Lyapunov 及 Hamilton 能量系统稳定性的定义与方法及其在线性与非线性系统中的应用。

全书共六章。绪论部分阐明了控制理论的发展、系统结构要求和控制特点及非线性控制在电力系统中的应用。第一章介绍了基本概念、状态空间表达式的建立、传递函数、组合系统、线性变换，最后给出在工程上较常用的离散系统的状态空间表达式。第二章系统地介绍了线性定常与时变系统齐次与非齐次状态方程的解、方程解的存在与唯一性定理、线性时变系统的几个基本定理、Wronsky 行列式、线性时变非齐次系统的变动参数法、状态转移矩阵及离散时间系统状态方程的解，最后给出连续时间状态空间表达式的离散化方法。第三章系统地介绍了单输入和多输入的线性定常和时变、连续和离散系统的能控能观性判据、能控能观性判据的两种形式、线性定常系统的输出能控性、时间函数的线性无关性、线性时变系统的最小能量控制、能控性与能观性的对偶关系、线性定常系统的结构分解，最后介绍了能控标准型

和能观标准型及系统的实现。第四章首先介绍了时变系统稳定性的基本概念、时变 Lyapunov 函数的基本思想和稳定性方法、渐近稳定性，然后介绍了构造 Lyapunov 函数的一些常用方法、向量 Lyapunov 函数，研究 Lyapunov 方法在线性系统中和在广义 Hamilton 系统中的应用。第五章介绍了状态反馈的定义及其性质、极点配置的理论基础和算法、系统的镇定与解耦问题及全维与降维状态观测器。第六章系统地阐述最优控制基本概念及求解最优控制的变分方法，然后介绍了 Hamilton 函数的确立、波尔札问题、极小值原理、Bang-Bang 控制及工程上常用的连续或离散动态规划法，并研究动态规划与最大值原理及线性二次型最优控制问题。

作者从事研究生必修课《现代控制理论》教学十几年，经过长期的教学实践和经验总结完成了本书的撰写。本书的部分文字和图表整理等工作曾得到硕士生李康和邹彪的帮助，在此向他们表示衷心的感谢！

在撰写本书期间，作者得到了国家自然科学基金（No. 60674035、No. 61074042）的资助，也借此机会向国家自然科学基金委和科技部等有关部门对我们的支持表示衷心的谢意！

限于作者水平，本书一定存在一些不妥之处，敬请各界同仁和读者给予批评和指正！

作者

2010 年 10 月于上海交通大学

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Contents

Introduction

0. 1 Development of control theory

The development of automatic control theory goes mainly through the following stages: classical control theory, the frequency method and root locus method in the 1930s and 1940s. Classical control theory uses Laplace transform as a mathematical tool to get the system transfer function; it generally uses the feedback control (closed-loop control system). In the 1950s the modern control theory is the starting point and foundation of the development. R. Bellman● for optimal control of dynamic programming; Lev Semenovich Pontryagin● for the maximum principle (optimal control); R. E. Kalman● for state-space method, controllability and observability. In the 1960s and 1970s the large scale system theory and intelligent control theory were developed. H. H. Rosenbrock●—multivariable frequency domain control theory. Since 1980s, there has been differential geometric control, fuzzy control and chaos control, etc.

Most control systems have non-linear characteristics in practical engineering applications. For example, the gear drives servo system has backlash and dry friction, etc. Many implementing agencies can not infinitely increase its output power; therefore, there is saturation nonlinearity. In fact, this nonlinear system imperfection is inevitable. Some non-linear dynamic characteristics of the system is inherent. For example, there is coupling Coriolis force between the various joints of the robot in high-speed movement. This coupling is nonlinear, so we must consider nonlinear coupling factor which must study the control of regulating movement of the robot; The sine of the

● Richard Ernest Bellman was an applied mathematician, celebrated for his invention of dynamic programming in 1953, and important contributions in other fields of mathematics. He was awarded the IEEE Medal of Honor in 1979, "for contributions to decision processes and control system theory, particularly the creation and application of dynamic programming." His key work is the Bellman equation.

● Lev Semenovich Pontryagin was a Soviet Russian mathematician. He was born in Moscow and lost his eyesight in a primus stove explosion when he was 13. He made major discoveries in a number of fields of mathematics, including the geometric parts of topology. His maximum principle is fundamental to the modern theory of optimization. He also introduced there the idea of a bang-bang principle, to describe situations where either the maximum "steer" should be applied to a system, or none.

● Rudolf Emil Kalman is a Hungarian-American electrical engineer, mathematical system theorist, and college professor. He is most noted for his co-invention and development of the Kalman filter that is widely used in control systems, avionics, and outer space manned and unmanned vehicles.

● H. H. Rosenbrock is British automatic control experts, the Royal Society. Multivariable Frequency Domain with one of the founders. From the 1980s, he began working on the social impact of automation and control theory approach will be applied to quantum mechanics.

phase angle difference between transmission power and the generators is proportional in power system. We must consider the impact of non-linear characteristics if we want to study a wide range of movement in power system; although there is a class object itself is linear, but in order to effectively control it, often introduce intentionally nonlinear control law in the control system, such as the minimum time control is necessary to use the nonlinear bang-bang control. Nonlinear phenomenon is the most universal system of nature, while the linear system is only one special case. Because of the complexity of nonlinear characteristics, it is impossible to have a unified approach of general application. Linear system can be described by linear ordinary differential equations, solving linear ordinary differential equations has haven proven methods, so the linear system control theory has made great achievements. However, nonlinear differential equations have analytical solutions only in several cases; this nonlinear control system will bring a lot of unexpected difficulties.

The motion in linear control system can only be several situations: such as the decay or divergence of the oscillation or oscillating operation, or the critical oscillation and so on. The movement of non-linear system is much more complex, it can be oscillating or not oscillating, such oscillations can not necessarily be strictly harmonic functions to represent; It can be stable or unstable, this stability can be global, it may be partial; It may have one or several oscillation limit cycle, may also occur chaos, we can see that the topology of nonlinear systems structure is more complex and diverse. Taking into account the nonlinear nature of many control systems is harmful to the running of system, it should be managed to overcome its harmful effects. Some non-linear is useful and should be considered in the design. For a long time in the nonlinear control system that has been accumulated a lot of results. However, due to the complexity of nonlinear systems, research in this area there are considerable difficulties, the study results still can not meet the actual needs, there are many issues to be examined. In recent years, the actual engineering requirements and people to improve the control system intelligent attention, nonlinear systems control theory has been made much new and important progress.

Control performance under a specific input by applying the method transforms the various dynamics involved in performance of the system to best meet the specific needs of the theory and technology in general. Advances in control technology will always depend on the development of control theory. Control theory so far, is mainly through the classical feedback control theory, modern control theory and nonlinear control theory of three stages.

The first stage is complex or frequency domain of the classical control theory. It is mainly with respect to the rapid development of the new control theory system in the early 1960s. This complex field of control theory system is largely by the mathematical model of the theory (modeling theory), response analysis, stability analysis and comprehensive correction of four parts.

Classical control theory is mainly used to solve the analysis and design of the controller in question of feedback control system and the main research on the linear time-invariant systems. The frequency method and root locus method widely used in classical control theory are built on the basis of the transfer function. The transfer function of linear time-invariant system is the ratio of the Laplace transform of the system output and the input under the zero initial conditions, which is a frequency domain model that describes the system. Transfer function describes only the system input and output relationship and has no denotation of internal variables. A typical classical control theory includes PID control, Smith control, decoupling control, Dalin control, cascade control and so on. Classical control theory, although in principle only suitable to solve the SISO system analysis and design problems, however, is still active in a variety of industrial control field. In fact, the classical control theory is still missing the value and practical significance, further study is still the bases of modern control theory and nonlinear control theory.

The second stage, it is commonly known as modern control theory. Rather, it should be called linear multivariable control theory. The theory of this system acquired a rapid development since the early 1960s; today it is still active in the wide range of international applications. As a result of the rapid development of computer technology since the 1960s, it provided the technical conditions for complex large-scale numerical analysis. These became the second phase of control theory—background conditions of linear multivariable control systems development. The book—R. Bellman's "Introduction to Matrix Analysis" published in 1960 and the paper—R. E. Kalman, "Mathematical Description of Linear Dynamic System" published in 1963 made important contributions on the foundation of control theory. The main feature of this theoretical system is the combination of state-space modeling theory and mathematical methods of linear algebra.

Modern control theory is gradually developed to overcome the limitations of classical control theory. Modern control theory is essentially a "time-domain method", which introduced the "state" concept, with "state variables" (within the system variables) and the "state equation" to describe the system, which better reflect the inherent nature and characteristics of the system. From the mathematical point of view, the state variable method of modern control theory is simply to transform higher order differential equations describing the system into a first-order differential equations in the form of simultaneous, or the motion of the system directly as first-order differential equations. The first-order differential equation is called equation of state. After using the state equation, the main advantage is that it will be so simple in form, the concept of clear, easy operation of the system equations of motion using vector and matrix form, especially it is obvious for multi-variable, time-varying systems. Especially in regard to controllability, observability and maximum theoretical concept, the modern control theory is toward a more in-depth study. There are mainly the linear system theory, optimal filtering theory, system identification, optimal control and adaptive control branch in modern control theory.

The second phase of the control theory has these notable features: First, it is described by the differential equations of first-order linear variable for time t and its mathematical model and analysis method is time domain; Second, the main mathematical tools are the linear theory of ordinary differential equations and linear algebra theory, unlike classical control theory is mainly the applications of Laplace transform and polynomial algebraic equations; Third, it is theory and mathematical modeling approach which makes this system suitable for control theory of linear multi-input multi-output system; Fourth, it establishes a set of principles and methods of optimal control, so the obtained control law can guarantee the system performance to extreme; Fifth, the linear systems that their parameters may change in a wide range, combined with optimal control design method and consistency of linear system parameter identification technology, can obtain adaptive or called control system which automatically seek the most optimal point. These are the second phase of control theory—the occurrence and development of the background and main features of linear multivariable systems control theory. Theoretically, modern control theory solves the system controllability, observability, stability and control of many complex systems. However, with the rapid development of modern science and technology, the increasing scale of production systems, the formation of a complex large system, leads to a control object, the controller and control tasks and the purpose of increasing complexity, and leads to modern control theory results rarely applied in practice. Classical control theory and modern control theory in the application have encountered many difficulties, which make their practical application to be affected, the main reasons are as follows.

(1) The control system design and analysis are based on the base of precise mathematical model, but there are the uncertainty, incomplete, fuzzy, time-varying, nonlinear and other factors in the actual system, in general it was difficult to obtain accurate mathematical model.

(2) To study these systems, one must make the assumption that some of the more demanding, and often these assumptions and the actual application does not match.

(3) In order to improve the control performance, the control system becomes extremely complex. It not only increased the investment in equipment, but also reduced the reliability of the system. This requires one to search for new theories and methods of control.

The third stage, nonlinear control theory. Since most of the engineering control systems are nonlinear, although many of the part of the project can basically meet the conditions required to be approximately linear at a equilibrium point, it can be applied to the linear system theory and methods of analysis and synthesis. But there are some systems, such as power system, when a large disturbance in the analysis of its stability and dynamic quality is considered, which can not approximate it as a linear system processing, otherwise the effects of control would not be satisfactory. Other examples are of certain systems, such as robot control, aircraft autopilot system and some of the chemical process control systems. They use the linear approximation of the mathematical model for controller design. The controls are difficult to achieve the desired accuracy requirements. In short, the development of science and technology of production urgently requires the establishment of a new system of nonlinear control theory.

Nonlinear control system theory is theoretical system based on nonlinear system as the controlled object; it will generate the corresponding control sequence using the appropriate mathematical tools and combined with the linear control technology or other control strategies, the output of the system will achieve desired control objectives that

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research focuses on nonlinear control are in nonlinear systems analysis and synthesis, nonlinear systems analysis is usually used to describe nonlinear systems, including the describing function method and series method and stability analysis of nonlinear systems of the mathematical model. Currently, a comprehensive nonlinear systems typically include linearization method, nonlinear geometric control method, variable structure control method, approximate method and the backstepping design method. Exact linearization method is commonly used exact feedback linearization, exact input-output linearization methods so that the complex nonlinear system is linearized and then the linear control techniques are used, the nonlinear system is into a comprehensive problem synthesis problem of linear systems, so that it is simplified of the complex nonlinear systems integration issues; Nonlinear geometric control method is commonly used methods based on differential geometry to achieve control of nonlinear systems, which include nonlinear control system without drift and nonlinear control systems with drift; Variable structure control method is usually the core of sliding mode to construct suitable switching function and variable structure control law, so that the nonlinear system in a certain period of time to achieve the desired control objectives; Approximation method is commonly used to nonlinear systems which can not satisfy the condition of linearization, common methods include pseudo-linearization, extended linearization method, linearization family, approximate input-output linearization method, the average method and so on; Backstepping design method is a relatively new control method by gradually revised algorithm to construct stabilizing controller to achieve global tracking or regulation of nonlinear systems, which can be commonly used in state feedback linearization or the strict parameters feedback uncertainty system.

In the past 20 years, combination of design on modern differential geometry and nonlinear control system forms a new discipline system that is the geometric structure theoretical system of nonlinear control systems. University of Rome, Professor A. Isidori had pointed out: As the introduction of Laplace transforms and transfer functions before 1950s, and the introduction of the methods of linear algebra to control theory in a single input-output and multi-variable linear systems arising from the significant achievements in the 1960s, the introduction of differential geometric methods in nonlinear control systems, control theory will be to bring a breakthrough. A set of new theoretical system has been formed from the nonlinear system controllability, observability to a variety of design methods and algorithms, it can be expected in the near future, any theory of multi-variable linear control systems in all the major achievements of the system can be found in the new system found in nonlinear control theory. The applications of differential geometry have been throughout the aviation, robotics, power systems, chemical engineering and other areas.

0. 2 Structural requirements and control features of the system

Throughout the history of control theory, it can be seen that the fields of control theory have the following four main features.

(1) The rapid development of control theory is strongly impinged by a powerful

high-tech needs. Many challenging issues have been presented to control theory such as the aerospace, aviation, marine, .industrial processes, socio-economic areas, For example: Apollo lunar module flight along the optimaltrajectory of navigation; Soft landing on the moon; Mobile high-performance, open-loop unstable new fighter design; On the paraboloid antenna and radar arrays, solar receiver, space telescopes and other large space structure of the high-precision targeting and stabilization; The robustness of robot control and cooperative control dobby; Random uncertainties of the system control to power systems; The temperature control of steel rolling production process control, which are presented on a new topic for control theory, and in these systems, control theory has indeed played a key role.

(2) The development of control theory relies on mathematics, while promoting the development of mathematics. Ordinary differential equations, partial differential equations and functional equations, algebra, geometry, function theory, probability and statistics, variation method, discrete mathematics, numerical calculation of the branch in modern mathematics are the important tools in control theory. For example, the martingale is a critical foundation to establish stochastic adaptive system theory; Lie algebra is an important tool to characterize the controllability of nonlinear systems; Functional analysis is the study of the basic means of infinite dimensional systems and so on. On the other hand, control theory and mathematics have an important impact in many areas. For example: the deepening of the maximum principle leads to a lot of abstract variation principle; Non-smooth analysis developed in conjunction with non-smooth optimal control theory plays an important role in the analysis and mathematical programming; Boundary control and the exact controllability of hyperbolic equations result in the new results under the weak conditions on the regularity of solutions; The solution of optimal stochastic control representation plays an important role in the theory of viscosity solutions; The study of the Riccati equation and linear multi-variable system promotes the development of boundary value problems and operator theory; Stochastic control theory has significant impact for Markov process theory of large deviations and the financial mathematics; Robust control proposed significant new issues for operator theory and complex function; The study of nonlinear control led to the new results of the integrability of a singular distribution, the interaction between system Lie brackets structure and variation is found, and etc. , all are powerful promotion of mathematics itself on the development of control theory.

(3) Control theory and other areas of extensive cross (penetration) of the character will be continue. Scope of application of control theory from the pure technology, penetrate into the social, economic, demographic, and environmental and life sciences in the fields of control and will continue to expand. For example, the control theory of general interest energy and environmental issues can also make an important contribution. From saving energy and reducing pollution from the new energy development (such as artificial controlled thermonuclear fusion), to the reasonable regulation of the natural environment, it is necessary for the coordination between human and nature and so the demand for the existence of control theory. In addition, with the development of life sciences and the biological role of physiology and the increase of internal non-linear

action, control theory approach would help to improve the adaptive feedback regulation within the organism understanding of the law, and it will give a variety of hormones, drugs and radiation therapy, better designs, and to promote the development of new medical devices.

(4) The problem of control theory of complex systems will be increasingly attracted to pay attention. The main features of complex systems can be summarized as follows: Dynamic model uncertainty; the roughness measurement information and incomplete; the randomness of the dynamic behavior or disturbance; Discrete levels and continuous level of hybrid; highly nonlinear system dynamics; State variables and distribution of high-dimensional; Subsystem and the level of diversity and the strong coupling between subsystems. Control of complex systems in size, complexity and flexibility will be greatly exceeded the automatic control of the traditional conceptual and methodological limitations. It requires the control system dynamics model of the controlled object should be to learn and the ability to identify changes in the environment and disturbances have to adapt and sound capabilities.

Various methods of control theory have great impact in the development of modern technology. Based on the classical theory of single-loop control system, and the first generation of adaptive controllers have been used in many industrial applications, these controllers are also full of facilities in our daily life. Control system has been able to get such a wide range of applications, not only thanks to modern instrumentation and electronic hardware, but also because control theory dealing with the model and output signals with the uncertainty of dynamic systems. Control theory has been improved in various ways and been widely used at the same time, advanced methods and applications of the theory are still concentrated in high-tech as the space works as aspects. Of course, due to the rapid development of computer technology and the world of intense industry competition, this situation will change, new computer technology provides a control algorithm to achieve more sophisticated tools, the competition in the industry maintains the advanced position of the desire to promote a more sophisticated, efficient and reliable control. In addition, it is the factor that more and more engineering and technical personnel are demanded with a strong mathematical background.

In general, the development and establishment of new theories and concepts have been applied with a certain delay between the control problem and the concept and their success in practice, in some cases, today's applications are often created by the theory before a few decades ago. Many advanced control technologies are all the achievements which are directed at the needs of a particular research. Such as electricity production is often affected by many uncertain factors, the uncertainty of the power load and power plants may stop. In hydropower production, the effective amount of water depends on rainfall fluctuations. France, INRIA, Institute of Computer Science and Automation, studied a lot of electricity production management control issues, including the power generation systems with eight thermal power plants and a dam in New Caledonia. The target of study is to choose a feasible production plan (the equivalent of feedback control) to be the least cost to meet the demand for electricity. Model identification work included the estimates of the drift and diffusion coefficients of a random differential equation. The most number of feedback controls is obtained to solve differential equations and dynamic programming in the inequality. Control difficulty of large power plants is the dimension. The study can be obtained from a conceptual framework that engineers can start to solve the power problem of production control.

In general, the control of a dynamic system has the following four basic steps.

1. Modeling (mathematical model based on physical laws)

To choose a mathematical model of a system is the project's most important work in control engineering. When the system is not entirely clear, it is quite difficult to create a mathematical model for this system. In some cases, one can write the dynamics of a system of precise mathematical formula, but it may be very complex, so it can not be based on the model to design a control law. Fortunately, the model is not entirely clear but also better handling, we have learned from numerous practices: A complex system can success by feedback control in very simplified models. Thus, the model of control engineering problems and model problems in physics is completely different. In control theory, the key is to find a suitable refined mathematical model, which can be effectively solved by the data obtained by system identification.

2. System identification (based on input-output measured data to construct a mathematical model)

System identification can be defined as a dynamic system used in the observed input and output data to determine its model of the process. If the model structure has been given, but its parameters are unknown, the system identification becomes parameter estimation. Identification is an inseparable part of control theory; it belongs to the inverse problem in applied mathematics. System identification often needs to make the following experiment: Records of an input signal and output signal. There are many statistical methods and computational techniques which are used to process data and models. Identification of the current system of research focused on the following various basic questions: The solvability of identify problems and appropriateness of proposed question, method of parameters estimation for various model.

3. Signal processing (with filtering, prediction, state estimation approach to output)

Signal processing is an independent discipline outside the control theory, but these two disciplines have many overlaps, and the control community made important contributions to signal processing, particularly in the areas of filtering and smoothing. This field is to study the problems how to reconstruct the original information from the observed signal that was polluted by the noise. They have a wide range of applications, such as communications, recourse from satellite data, language processing, image reproduction and more. Without such a computerized image reproduction capability, then the images of outer planetary are sent back from other Mariner and Pioneer spacecraft will be useless.

4. Integrated control input (integrated with a variety of control law input)

Integrated control is to generate control laws for the control system; it is related with the model, identification, signal processing, control objectives and the use of integrated methods.

Power system operating state affects directly the actual level of security in grid. Therefore, to improve the reliability of power supply, we must pay great attention to the safe operation of the control problem. Under different operating conditions, power system operating status can be divided into five categories.

(1) Normal state.

(2) Warning state.

(3) State of emergency (accident state).

(4) System crash.

(5) Restore state (after the accident state).

With the change in operating conditions, the power system will be transfered between various states. Power system security control is to adopt actively various control measures and means to ensure power system in a normal state.

Power system security control is as much as possible so that the power system is in normal operation. Computer control technology in power system security control is playing an increasingly important role. Its function is mainly in three aspects: first, security monitoring, power system operation is carried out to monitor the security situation in the state; Second, safety analysis, it is the safe operation of the power system to evaluate and determine the level of the system and the ability to damage from accident; Third, security control, it is the moment of the accident quickly determine and control of system failure for early rejection and exclusion, to maximize the security of the system. With the complex increasingly in the combination of electrical power system equipment and power plants, as well as the exaltation of control requirements. If the information of all power plants and substations in the whole system is collected to a central dispatching station for processing, it will be reasonable on technology and economy, because the development of computer technology, the hierarchical control can be used for the more decentralized information that needs to be monitored, the dispatching center, regional dispatching, power control center, substation control center and other hierarchical control center need to be established. Dispatching center makes the whole power system integrated estimation and control, and the region responsible for scheduling and power plants and substations to maintain the exchange of information and control; Regional dispatching accepts the control command of center scheduling, and makes comprehensive judgments and control to the system in the region, power plant and substation control centers for information exchange and control. Power plant and substation control centers receive the instruction of regional dispatching center by scheduling to monitoring and control directly owned units and equipment. In order to reasonably monitor the growing power systems, the timely processing of the whole system of accidents and anomalies, power system control center SCADA system must be taken to remote monitoring and control, and communication techniques to master the operation of power system status and information, computer equipment and corresponding remote system, it is mainly used to complete the power system operation state monitoring, remote switching, automatic generation control and economic operation, and the tabulation and statistical records and other functions. SCADA is an organic whole composed of multiple subsystems, one can not, it involves a wide range of systems engineering that is difficult to achieve. In recent years there have been real-time operation of the power system energy management control systems and power distribution system used in the scheduling and automation system for management and planning management information system that combines an integrated automatic control system, it can achieve the complementary configuration for the different levels of power system automatic control functions and daily scheduling program management functions, the power system security, reliability and economy will be improved to a new level.

0.3 Nonlinear control in power system

A power system stability issue, namely security and reliability of the dynamic problem, is the important issue of power system operation. If the stability of large power systems was destroyed, then it may cause power accident to one or more major regional power which will make them into paralysis and confusion, and it will maybe be seriously to endanger the whole country, it will be catastrophic loss to the national economy and people's lives. Therefore, the improvement of power system stability, dynamic reliability is still an urgent and arduous task. The primary means of improving and enhancing power system stability is control. For many years, to improve power system control technology and development, people carried out vast research work. The continuity of the generator control, for example, is in this regard for generator excitation control and turbine governing valve control. For the excitation control technology before 1970s, it used mainly single-variable feedback method, which adopts the generator terminal voltage deviation as the feedback amount control. The manners of this single-input control have mainly proportional control and proportional integral derivative (PID) control both. Both the amount of feedback control is generator terminal voltage deviation.

With the development of power system, people feel the lack of single input control, so the PSS (power system stabilizer) control was born in the 1970s, this control method increases the voltage deviation outside an auxiliary feedback variables, the amount of assistance can make the generator speed foodback error, generator frequency deviation or the generator active power deviation, thus the generator excitation control is developed into double-input control system from a single - input control system. In China, on the one hand the introduction of PSS excitation control, on the other hand we have developed our own linear optimal excitation control (LOEC), this control method used voltage bias, speed (or frequency) bias, and active power deviation as feedback variables, gain coefficient of the feedback variable is the solution of the "linear quadratic Riccati (LQR) problem", the LOEC excitation control of large power plants had been successfully applied.

The power system is highly nonlinear, when the system operating point is changed (such as load fluctuations or serious failure), the dynamic characteristics of the system will been changed significantly. When the actual state is far off initial point, then the approximate linearizing mathematical model can not correctly express the actual control system, thus the designed controller can not work correctly and effectively, this design

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