ISCTE Business School
Instituto Universitário de Lisboa

Research on Grid Challenges and Smart Grid Development --The Case of Sichuan Grid

XIANG Xiaolei

Thesis submitted as partial requirement for the conferral of

Doctor of Management

Supervisor:

Professor Nelson António, Full Professor, ISCTE-IUL, Departamento de Marketing, Operações e Gestão Geral

Co-supervisor:

Professor LI Shiming, Full Professor, University of Electronic Science and Technology of China, School of Management and Economics

January 2012

Spine –

Research on Grid Challenges and Smart Grid Development
--The Case of Sichuan Grid

XIANG Xiaolei

ISCTE Business School
Instituto Universitário de Lisboa

ISCTE Business School
Instituto Universitário de Lisboa

Research on Grid Challenges and Smart Grid Development
--The Case of Sichuan Grid

XIANG Xiaolei

Thesis submitted as partial requirement for the conferral of

Doctor of Management

Supervisor:

Professor Nelson António, Full Professor, ISCTE-IUL, Departamento de Marketing, Operações e Gestão Geral

Co-supervisor:

Professor LI Shiming, Full Professor, University of Electronic Science and Technology of China, School of Management and Economics

January 2012

Abstract

As the most important driving force of modern social development and a significant symbol of modern civilization, electric power is in booming demand. Furthermore, electric power is a complex system which integrates power generation, power transmission, power distribution and power utilization together and achieves generation, transmission, distribution and utilization instantaneously at the same time. It notably features with network industry and network economy. Power grid is a hub which links electricity production and electricity consumption in the power system. On the basis of basic theories of network industry and network economy, this thesis discusses the development of smart grid from the aspects of "network challenges", resources and energy challenges and new energy access challenges encountered and counter-measures in the development of modern grid. Based on the development environment of China power, especially the Sichuan power grid, and spatial mismatching of power supply and demand (including new energy resources and distribution), this thesis analyzes and explains China (Sichuan) smart grid is strong smart grid which has UHV power grid as the backbone frame, and features information technology, and automation.

Key Words: Grid, Smart Grid Development, Sichuan Grid, China.

Resumo

Devido ao facto de ser uma força impulsionadora do desenvolvimento económico e um simbolo muito importante da civilização moderna, a procura de electricidade tem aumentado consideravelmente nas últimas décadas. Contudo, a energia elétrica é um sistema complexo que integra geração, transmissão, distribuição e implica que a oferta e a procura sejam simultâneas. A indústria da electricidade tem muitas características da economia em rede.

A rede elétrica deve ser vista como um "hub" que liga a produção de electricidade ao seu consumo. Tendo por base, as teorias da indústria em rede e da economia em rede, esta tese discute o desenvolvimento das redes elétricas segundo as perspectivas dos "desafios que se colocam às redes", dos desafios em termos de recursos e dos desafios que se colocam ao desenvolvimento da rede elétrica moderna.

Esta tese estuda de uma forma detalhada os problemas relacionados com a construção de uma rede elétrica inteligente na província de Sichuan, China.

Palvras Chave: Redes Elétricas, Desenvolvimento de Redes Elétricas Inteligentes, Rede Elétrica de Sichuan, China

Acknowledgements

Finally, I finish this thesis at night. I've heard before that preparing a doctoral dissertation is a most miserable period in a life time and I did not take it seriously at that time. Now, I feel it clearly. I suffered from pains and helplessness, paid sweats and enjoyed happiness! By now, I truly understand the significance of research. To explore must be full of thorns. I never regret! I learned science before and now I'm learning business management. In those recent years, I've read thousands of classical documents and professional books and taken part in various academic activities, innovative forums, thesis sessions and themed speeches. I respectfully listened to fabulous lecturing of my supervisor and other teachers, and made discussion with my fellow brothers and sisters. I came to know the charm and value of management much thoroughly by means of enterprise exercises and thesis works. I only wish to make some contribution to development and progression of management science research.

I shall thank my doctor mentor Professor Li Shiming who gives me great instructions for my thesis including the title and thesis direction and writing process, from whom I learned systematic training in science research and his spirits of study in this field. And I will thank foreign mentor Nelson António and Virginia Trigo, whose wide visions and rich knowledge enrich my learning. Their great support will benefit me a lot in my life.

Thank Zeng Yong, president of Management College of Electronic Science and Technology University and Xiao Wen, the president assistant, as well as all the teachers in DBA project. Your great design and excellent work supply us a wonderful learning platform. Thank Mr. Zhou Qingjia. You give me a lot learning time and my colleague Zhang Yonglin, Huang Yaoqun and Li Fuxin for their supports and my friends' assists in this thesis information and document collection.

And I shall thank my husband. Without his help and support, I cannot finish my doctor degree study time so easily. I feel thankful to all the helps in my study of Doctor Degree. Thank you all.

Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Men Is Still in “Electrical Age”

Modern civilization, especially the modern civilization originated from Euramerican countries, can be dated back to industrial revolution. Marked by widespread use of steam engines as power machines, the first industrial revolution started a new era of replacing hand tools with machines. Human society finished the first time of industrial revolution and gave birth to the second industrial revolution marked by widespread use of electric power at the same time.

In the application of electric power, generators and electromotors are two important correlative elements. Generators convert mechanical energy into electric energy, while electromotors, by contrast, convert electric energy into mechanical energy. Principles of generators and electromotors are based on the magnetic effect of an electric current discovered by Danish scientist Oersted in 1819 and the electromagnetism induction phenomenon discovered by British scientist Faraday in 1831 (according to the record, Faraday invented the earliest generators and electromotors for laboratory use in 1821 and 1831). German scientist Siemens has manufactured generators in 1866. Belgian scientist Gelam invented electromotors in 1870. The invention of generators and electromotors realized the inter-conversion of electric energy and mechanical energy. However, electric power was not put into large-scale industrial use immediately until 1882 when French scientist Deprez found out a method for transmitting electricity in distant range; in the same year, American inventor Edison established the first heat power station in New York of America and connected the power station and electrical load into an electric power system or an electric power network through transmission lines. The invention of generators and electromotors, the distant power delivery and transmission network and the inter-conversion of electric energy and mechanical energy enable electric power to become a new energy supplementing and replacing steam power. Thus, human society stepped into the "Electrical Age" from the “Steam Age”. Due to large-scale application of electric power in industry, the development of electric power became the most important and fundamental industry (power industry) in the development of a society. Even up to today, electric power is still the most important industry of a society for supplying energy and power. The time of today is still strongly featured with "Electrical Age".

1.2 Electrical Age Is Also "Network Age"

1.2.1 Power Network

A power network or a power system is an electric energy production and consumption system composed of links of power generation, power transmission, power transformation, power distribution and power utilization, which is functioned to convert the primary energy in the nature into electric energy through a power generation device, supply electric energy to each load centre through a power transmission and transformation system and a power distribution system and convert the energy into different forms of energy such as power, heat and light through various devices for meeting the demand on different powers (energy/power) of power consumers. The major structure of power network comprises a power supply, a power network and a load centre, referring to one of the most important and complex engineering systems in modern society. Power transmission and power grid are significant elements of power industry. Networking has become the most remarkable industrial feature of power industry which is a typical network industry.

The power supply refers to various types of power plants and stations (mainly including boilers, steam turbines, generators and auxiliary production systems of power plants). In the power network or power system, the power supply is mainly functioned to convert different types of primary energies (coal, oil, gas, water, wind, nuclear energy, terrestrial heat, tide, solar energy and bio-energy) into electrical energy, referring to the “production side” and “generation side” of electric energy in the power network.

Electric load refers to the electric power consumed by electric equipment utilizing electric energy, and load centre refers to the area where loads in the power network are centralized. Total load of the power system is the sum of total power consumed by all the electric equipment in the network, referring to the “demand side” or “consumption side” of electric energy in the power network and representing the electric power/quantity needed in industry, agriculture, business, daily life and municipal services in the area covered by the electric network.

Transmission network refers to facilities and devises linking power generation and power consumption in the power network. The power network is mainly composed of a step-up substation of power supply, transmission lines, a load centre substation and distribution lines which are connected into a network, belonging to the intermediate link of power transmission and distribution. Generally speaking, an integrated system which is consisted of supporting system, such as power transmission, power transformation and power distribution, and connects power generation and power consumption, is called power network, or grid for short. Its function is to boost the electric energy from power supply to a certain level and transmit the energy into the load centre substation, then step down to a certain level and distribute the energy to different users through power distribution lines connected with users. The whole process is similar to the “exchange” and “distribution” links in the commodity production and consumption system of mass society.

In the power system, the power transmission network not only performs the functions of “channels” and “pipelines” which are commonly provided by the production system of mass society to “deliver” or allocate commodities (products or services) from producers to consumers, but also has particular functions related to unique features of power industry.

1.2.2 Power Transmission Network

As power supplies and load centers are generally located in different areas, different power supplies are characterized by different electric energy supplies and different power consumers or power loads are characterized by different loads. Mismatches of electric quantity and space-time thereof always exist between the supply characteristics of power supplies and the load characteristics of power consumers. Meanwhile, under current level of techniques and equipment, electric energy cannot be stored in large amount, and the production, transmission, distribution and consumption are thereby finished at the same time and a balance should be kept in the course. Therefore, a unified commanding and dispatching system is needed, which adopts stepping dispatch and hierarchical control and mainly carries out tasks as follows: (1) predicting electric load, (2) allocating and regulating energy production, (3) allocating and regulating electric load and (4) detecting the security of network operation and dealing with working events.

In the power network, there are great quantities of power supplies and power consumer points which are distributed at terminals of network nodes. Therefore, the production and consumption of power networks is difficult to be controlled in an overall way, and it is hard to undertake the dispatching and commanding work of the whole network. The power transmission network can link power production and consumption and get the supply and demand condition and working situation of the network in real time so as to realize the dispatching and commanding of the power network as the central link of the power network. Today, separation of plants (power stations) and networks (power transmission networks) has become the basic type of operation in power industry, and the importance of power transmission networks in the power network is more remarkable. Power transmission networks have become the dispatching and commanding centre of power network, dynamically allocating and regulating the production and consumption of electric energy and realizing the safe and economic operation of power network. Furthermore, power supply points are connected with each other through the power transmission network to form the power network so as to realize energy exchange and regulation among different areas and thereby increase the security and economical efficiency of power supply. By virtue of the power transmission network, it is possible to realize centralized development and dispersed utilization of electric energy and dynamic matching between continuous supply of electric energy and random variation of load. The emergence of electric power and transmission networks thereof enables the high-efficiency, pollution-free, user-friendly and easily controllable electric energy to be applied widely so as to drive changes in various fields of the society and start the electrical age, leading to the second time of technological revolution. Therefore, the scale and technical level of electric power and transmission networks thereof become one of signs of the economic development level of one country.

1.3 "Network Challenges" Faced by Modern Grid

Modern power system faces many challenges and contradictions during the course of developing into a significant sign of scientific and economic development of one country. These challenges and contradictions boil down to following concerns.

1.3.1 Challenges to Grid under Development of New Energy

The development of modern society booms human's demand on energy and electric power: global consumption of primary energy was 9.7 billion tons of oil equivalent in 1999 and up to 12 billion tons of oil equivalent in 2010, and global consumption of electric power was 14.8 trillion KWh in 1999 and up to 21.3 trillion KWh in 2010, totally in a state of explosive growth. The blackhole-like thirsty for energy and electric power of modern economic society will lead to two disastrous results to current energy which mainly depends on fossil energy: first, the exhaustion of fossil energy will be intensified due to rising and nearly unrestrained energy demand; with coal, oil and natural gas as the main body, fossil energy is characterized by non-reproducibility and resource limitation; according to analysis of global energy authorities, remaining mining life of oil is only 41 years, remaining mining life of natural gas is 61.9 years and remaining mining life of coal is 230 years; rapid consumption of fossil energy will lead to "unsustainablility of resources"; second, fossil energy, namely "carbon energy", will discharge large amount of CO2, SO2 and dust, which will generate strong greenhouse effect and global warming and air pollution will be caused. It will consequently threaten global ecology, referring to the key factor of causing environment changes and pollution and leading to unsustainablility of environment and ecology. A global energy crisis is approaching.

In order to relieve energy crisis, countries around the world are all devoted to developing clean and renewable green energies such as wind energy and solar energy. However, as solar energy and wind energy power generation is directly sourced from ecological energies of solar energy and wind energy, the generation is seriously influenced by geographical, geological, seasonal and meteorological factors directly, and would fluctuate quarterly, monthly and daily, even hourly and minutely. It will even fluctuate intensely, which could lead to serious uncertainty and fluctuation of supply and spatial mismatch of power supply and demand. The spatial mismatch, uncertainty and fluctuation of power supply pose great challenges to the security, stability and economical efficiency of grids.

1.3.2 Modern Grid Is More "Vulnerable"

As the most notable feature of modern network, network effect discloses that the value of one network is in proportion to the number of nodes in the network, showing scale effect and positive feedback effect of networks. As for a power network, the number of nodes—including power supply points, power loads and transformation and distribution devices added into the network is greater, the stability and proportionality of power supply may be higher. Therefore, the scale of modern networks, including the power network, is larger and larger, and it is driven by two aspects: one is the drive from exterior of the network; as the demand of modern society for electric energy is increasing, and the requirements for electric energy security are higher, the network is therefore larger in scale; the other one is the drive from interior of the network; in order to create, pursue and realize network effect (including scale effect and positive feedback effect of network), the modern power system and power network is vast and more complex, such as trans-regional even trans-national power networks. The more nodes a network has more complex a network becomes.

However, when the network is increasingly huge and the network structure is more complex, the network has not become consequently safer, but more vulnerable on the contrary. Through "the butterfly effect"[1], small incident will cause huge disaster. For example, at about 4:10 on August 14th, 2003, due to a software error, the power monitoring and control management system subordinated to First Energy Corporation of Ohio in United States caused a strong current which should deliver from the west to the east over the Great Lakes to turn to the west suddenly and thereby lead to automatic shutdown of one or several power transmission lines due to overload. Several seconds later, power transmission lines in parallel also shut down due to overload and the shutdown of power transmission lines then leads to

[1] . The Butterfly Effect refers to in a dynamic system, a slight change under the initial condition may trigger a long-term tremendous chain reaction to the whole system.

shutdown of power plants. Shock waves generated by shutdown of power transmission lines and power plants spread to Canada at the speed of over 100km/s and spread to New York then. Finally, in only 9 seconds, dozens of power transmission lines, one hundred power plants including 22 nuclear power stations and a large generator group with installed capacity up to 61.80 million KW shut down. In the accident, several power systems which should have been separated from each other failed to separate, but lead to shutdown one by one in seconds. It is said that this wide range of power cut occurred in northeast areas of America and east areas of Canada—America and Canada Power Cut is the widest range of power cut in the history of North America. Power in eight states of America and Ontario of Canada was shut down, and about 10 million people in Canada (1/3 of the population) and 40 million people in America were influenced by the power cut. The power cut also caused great economic loss, up to 30 billion dollars.

1.3.3 Increasing Influence of Emergency on Modern Grid

As modern society depends more on the power network, the loss caused by network destruction is far beyond the network itself, but magnified sharply for "network effect". Therefore, power network has become a weakness of the socioeconomic system that will be easily attacked by natural disasters, wars and terrorists. For example, the "5.12" Wenchuan Earthquake of Sichuan in 2008 caused heavy casualties and property losses in power system: nearly one thousand people died or went missing, and about 470 hydropower stations, over 300 substations and more than 1500 various types of power transmission lines were destroyed. The direct economic loss reached to over 60 billion RMB. Furthermore, the destruction of power system also hindered the rescue of lives and related earthquake relief work and the power facilities become the main force to save lifes in the stricken areas.

Another example, in the 78 days of Kosovo War from March 24th to June 10th in 1999, NATO (North Atlantic Treaty Organization) firstly attacked the power transmission networks of South Yugoslavia with graphite bombs, causing power cut in 70% areas of the country, which greatly weakened the resistance of Yugoslavia and compelled Yugoslavia to surrender.

The above challenges faced by modern power network raised stronger, more flexible and more intelligent requirements for modern grid.

1.4 Outline of this thesis

1.4.1 Study Questions

Essential facts faced by modern human society are as follows: on one hand, modern human civilization is closely linked with electric power and power grid plays a more important role in the development of social economy; on the other hand, the development of power grid steps into a “paradox”, that is power networks become huger and more complex, also become more perfect, but power networks which encounter more challenges become more and more vulnerable in front of the structural problem of itself and various natural and human destructions. It is the demand of the time to solve the paradox for the development of grid enterprises.

Viewed from power systems, especially grids, study questions of this thesis are defined as studying, analyzing and disclosing working environments and working characteristics of modern power networks based on theories of network and network industry; analyzing challenges of security, stability and economic efficiency in the operation of power networks from the power supply side, transmission side and demand side to disclose and analyze contradictions therein and evolutions thereof; and developing case and fact study on smart grids with the largest and most particular Sichuan Grid in Western China as the study objective to discover new opportunities to challenges for grid enterprise so as to serve better the social development and to provide ideas for continuously stabilizing enterprises.

1.4.2 Study Guideline

Basic study guideline of this thesis is as follows:

(1) On the basis of theoretical thinking about practical problems, develops and defines the basic theme studied in this thesis;

(2) Around the study theme, collects related literature, understands research achievements of theoretical circle in the area related to the theme and acquires theoretical and methodological examples and references;

(3) Clearly understands theoretical basis and framework of the study, needed data resources, access paths and channels, and designs corresponding resource data treatment, analysis and research methods;

(4) From two dimensions of theory and reality, analyzes and investigates challenges faced by current grids from several aspects, to study and analyze challenges in security, stability and economic efficiency of the operation of Sichuan Grid from the establishment and evolution of Sichuan Grid and a new grid – smart grid for coping with the challenges;

(5) Taking Sichuan Grid as an example, to discuss and study the development of Sichuan Smart Grid from the establishment, evolution and encountered challenges of Sichuan power structure.

1.4.3 Framework of theThesis

According to above study questions and study outline, this thesis is divided into six chapters:

Chapter I: Introduction: introduces the background of the study and discloses the theme of the study.

Chapter II: Literature Review: understands forefront of the study and lays a theoretical basis for the study.

Chapter III: Design of theoretical basis of the study, data requirement and acquisition, and study methods.

Chapter IV: In combination with the development of electric power in China and Sichuan, studyies and analyzes the development of electric power and grid.

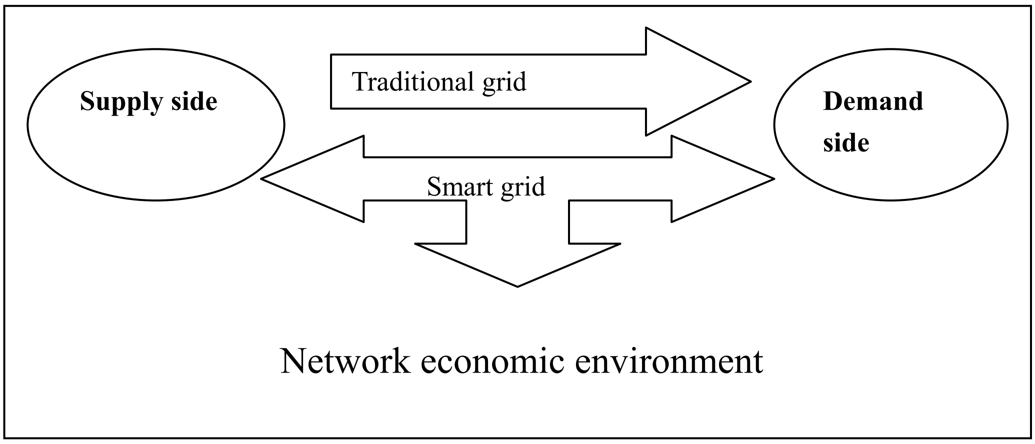
Chapter V: Viewed from challenges faced by the development of grid and strategies thereof, studies the construction of smart grid.

Chapter VI: Conclusion.

Chapter 2: Literature Review

Based on research contents of this thesis, the part of literature review describes the basic theories of industrial chain, network, network industry, network economy, smart grid and relations thereof, with smart grid as the main subject. Power industrial chain is an important part of network economy, while grid is the basis of power industrial chain. Therefore, the development of the grid influences the progress of national economy directly. But due to the extremely strong externality of grid, the development of the grid is greatly influenced by environment (as shown in Figure2-1). Literature reviews the environment characteristics at home and abroad of the development of grids, makes a conclusion on the history and experience in the development of smart grids in each country and proposes the concept of smart grid. On that basis, the object of study in this thesis is proposed, namely the development of Sichuan Smart Grid under the background of network economic era.

Figure 2-1 Grid and Network Economy



2.1 Industrial Chain

An analysis on enterprise strategies will help enterprises to seize the industrial trend and understand its surrounding environment thereof from the industrial chain at the macro level, which will pose a significant directive effect to the formation of enterprise strategies. Therefore, it is necessary to discuss the power industrial chain from the aspect of power industry.

2.1.1 Definition of the Basic Concepts

Research on industrial chain can be dated back to the research did by classical mainstream economists in late middle 17th century who mainly focused on discussing the influence of division and specialization of labor on the economic development at the macro level. Many foreign scholars are devoted into study at the mircro level, scuh as value chain and supply chain, but rarely set foot in study on industrial chain at the middle level. This thesis will first discuss theories related to value chain and supply chain, and then analyze industrial chain in detail.

2.1.1.1 Value Chain

As a whole, the research on the structure of value chain is basically developed along a track of point, line and plane, starting from the “point” of enterprise value chain to the “line” of industrial value chain, then to the “plane” of global value chain.

Baud (1997) describes the value chain as a set of various activities carried out by an enterprise for designing, producing, marketing, delivering and maintaining its products. The value of an enterprise is created by a series of business activities and all the business value activities form a "value chain". The value chain of an enterprise includes main activities and related support activities to create value for the customers.

Each enterprise has an internal value chain belonging to the enterprise itself and the link between enterprises is the link between value chains of enterprises. In business competition, the value chain of any enterprise exists in one “value system” composed of many value chains (Zhang Wenxuan, 2008). Value chains of enterprises in one business or one industry are connected with each other to form a business value chain or an industrial value chain.

Kogut (Kogut, 1984; Kogut, 1985) published two papers on Sloan Management Review in 1984 and 1985. The two papers, which focused on value-added chain from the perspective of global strategy, are regarded as the starting point of global commodity chain (GCC) (Gary Gereffi, 1999) and global value chain (GVC) (Fang Hong, 2006). In the study on global commodity chain, resource chain, supply chain and customer all expand into the global space, while in the global value chain; each link of the value chain breaks the boundaries of nations and regions to form a global trans-enterprise network organization.

2.1.1.2 Supply Chain

Study on supply chains can be dated back to 1960s. The father of supply chain design Jya Forrester (1969) regarded a supply chain as a process of manufacturers from external purchasing to producing and marketing, then to utilization. Charles and Stephen (1996) regarded supply chain as a system of organizations for delivering their products and services to consumers, referring to an organization structure composed of suppliers, manufacturers, distributors, retail markets and consumers which are mutually connected (upstream and downstream customers). Lin F R (1998) regarded supply chain as an enterprise network system including suppliers, manufacturers and distributors and involving material flow, capital flow and information flow. Wallace J. Hopp (Hopp, 2009) defined supply chain as a goal-oriented network composed of a process for delivering goods and services to customers and storage sites. In China, definitions of supply chain and supply chain management are as follows: a network chain structure is formed between upstream and downstream enterprises for supplying products or services to final users in the process of production and distribution (Standard Logistics Terms of the People's Republic of China, 2005).

2.1.1.3 Industrial Chain

It was Fu Guohua who first proposed the concept of industrial chain in China in the course of selecting subject for the study on Hainan tropical agricultural development during 1990-1993 (Fu Guohua, 1996). Later, other Chinese scholars developed corresponding researches. Yang Gongpu and Xia Dawei (2002) suggested that an industrial chain is a network that is formed according to forward and backward association relationships. Li Xinqin and Li Shiming (2004) regarded an industrial chain as a strategic relation chain with value-added function, structured by enterprises having competitiveness or competitive potential in an industry and enterprises in related industries in a certain geographic region, with enterprises having competitiveness or competitive potential as the chain core and products, techniques and capitals as ties. Yu Yihong (2005) defined an industrial chain as an entire production chain structured by each links in the production process of a final product-from original natural sources to final products then to consumers. Liu Fugui and Zhao Yingcai (2006) indicated that an industrial chain was characterized by static property, motion and dynamic property, based on analysis on the concept of industry and study on basic characteristics of industrial chains. Cao Qun (2009) defined an industrial chain as a network structure model, which consists of value chains, supply chains and knowledge chains. Hu Guoping (2009) proposed that industrial chains are interlaced with each other, always showing a network structure of multilayers, with primary chains and secondary chains.

2.1.2 Differences and Connections of Value Chain, Supply Chain, Industrial Chain

From definitions of value chain, supply chain and industrial chain, the three are not only related, but also different (Cao Qun, 2009; Fan Yuncui, 2009).

A value chain is a strategic decision method, focusing on the value added process of enterprises and aiming at how enterprises search the source of competitive advantages from each link of value chain so as to reach a competitive strategy of minimizing cost, diversifying products and centralizing targets.

A value chain is formed on the basis of industrial chain, referring to a process of forming a value flow based on the transfer of values in products during the transition process of products from the upstream to the downstream of the industrial chain. A value chain system is the core of an industrial chain and the value chain is the final development target of an industrial chain.

A supply chain is a tactic management method, mainly referring to the operation management of specific businesses so as to bring benefits for related enterprises. Therefore, supply chain management is a tactic method and measure for achieving value chain management. Supply chain management focuses on efficiency of enterprise, with a concept of catering to enterprise efficiency and a management objective of reducing cost and increasing productivity.

Industrial chain and supply chain are both the provision chain and delivery chain of customer value. An industrial chain comprises several supply chains which are formed by the relation between supply and demand structured by enterprises on the industrial chain longitudinally in each node. Supply chains serve the industrial chain. Generally speaking, connections of supply chains are the basis of the generation of an industrial chain, while an industrial chain is rightly a complex whole of several supply chains.

In combination with study and comparative analysis on related concepts, we have a preliminary understanding on concepts and structures of industrial chain. Therefore, an industrial chain can be defined as a complex network structure that is structured by related enterprises featured with strategic alliance on the basis of time and space, tied by related resources of products, techniques, knowledge and capitals and guided by customers, for realizing value enhancement.

2.2 Network Economy

2.2.1 Network Industry

2.2.1.1 Concept of Network Industry

As for the definition of network industry, Liu Jiejiao (2001) regarded a network industry as “an industry with strict vertical relations in links of production, transmission, distribution and consumption of products or services, in which manufacturers can deliver products or services to users and users can use products or services produced by manufacturers only by virtue of a transmission network”. Furthermore, Liu, Jiejiao specially emphasized that the network in network industry should not be interpreted as Internet only. Xiao Xingzhi and Chen Yanli (2003) called network industry as a network-type industry and defined it as an infrastructure industry in need of a fixed physical network to transmit products and services. Liu Zhonghua, Zhou Jieru (2005) and Jiang Meichun (2005) suggested that an industry with network externality is a network industry, which not only includes the computer hardware and software industry, online game industry and telecommunication industry based on digital technique, broadband techniques and wireless communication technique, but also includes industries with physical network features, such as aviation, electric power, tap water, postal service, coal, gas and railway.

2.2.1.2 Characteristics of Network Industry

Liu Zhonghua and Zhou Jieru (2005) suggested that economic characteristics of the network industry can be decribed by characteristics of high fixed cost, low marginal cost and demand side scale economies and various forms of connections (physical or virtual), and mainly reflected in supply side scale economies and demand side scale economies .

(1) Supply side scale economies. The fixed cost of network industry is very high, while the marginal cost is quite low. Once a product is developed or produced, the marginal cost in duplication is low and the increase of output will share the fixed cost. Therefore, scale economies, namely supply side scale economies, are remarkable.

(2) Demand side scale economies (network externality). The value of each user connecting to a network depends on the number of other users connected to the network. The value of a network is increasing along with the increase of users, and this is the network externality, namely demand side scale economies (Liu Jiejiao, 2001; Tao Aiping (2009).

(3) Internal coordination. Any interference in connecting lines and a stationary point in a network may influence other elements of the network. Interest gained from the investment on some node of a transmission network largely depends on products or service flow and capacity of supplying services on other nodes.

(4) Vulnerability. Based on the study on complex network theory, capability of bearing external turbulence decreases due to the complexity and hierarchy of network structure and wide distribution area of networks. Furthermore, as nodes are connected with each other, an error on one node will influence the whole network (Chen Xiaogang).

(5) Specificity and deposit of investment. The network industry provides services through a transmission network system which is a combination of transmission facilities and products or services applied thereon. Investment in transmission facilities is featured with strong specificity and deposit, wherein specificity refers that transmission facility only can deliver one or one type of products or services, while deposit refers that once the investment is formed, it can not be transferred for other purposes or transferred to other industries.

(6) Products or services supplied by the network industry have a property of private goods because products or services of network industry all have two properties of private goods: competitiveness—once some user is connected with the transmission network, competition degree of the user in consuming each unit of product or service to other users depends on the service cost (including peak time cost) imposed to current users or suppliers; exclusiveness—the product can only be consumed under the condition that users have a certain equipment or access to a certain network, the consumption can be measured by devices such as meters and charged accordingly, and users can be decided by the market mechanism.

(7) Continuity of supply and unbalance of consumption of products or services. Continuity of supply refers that the supply of products or services should be continuous without interruption and the cost for producing unit product or service under continuous production is lower than that under interrupted production. Unbalance of consumption refers that demand of users on products or services are unstable, varying along with seasons, months, even hours.

The study on characteristics of network industry will help us to understand the related properties of power industry so as to lay a foundation for the study on the construction of smart grid.

2.2.2 Network Economy

2.2.2.1 Concept and Development Background of Network Economy

Network economy refers to a new economic form with modern information techniques as the core on the basis of computer network (especially Internet). Broadly speaking, the so called network economy is a new economic trend and form featured with multimedia information and developed on the basis of network techniques, including various revolutions on current economic laws, industrial structures and social life and referring to the most centralized and general representation of the information-based society (He Shuzhen, 1999).

U.S. Bureau of Economic Analysis divides network economics into three layers: an infrastructure layer of electronic commerce, an electronic operation layer and an electronic transaction layer (Robert H. Reid, 1998). (1) The infrastructure layer of electronic commerce refers to the part of the network infrastructure for electronic operation and electronic transaction, including hardware, software, telecommunication network, human capital and various support services. (2) The electronic operation layer refers to operation activities of commercial organizations, including profit-seeking and non-profit-seeking organizations and government agencies on the computer network, wherein product-centered online activities comprises the process of purchasing, order and automatic transaction of stocks, electronic financial activities of suppliers, automatic control in the process of production and electronic commerce activities. (3) The electronic transaction layer refers to transaction activities of products and services carried out on network in forms of B2B and B2C. At present, the three layers are all developed to a varying degree. But the development situation of specific industry is not totally the same.

2.2.2.2 Influence of Network Economy on Industry Development

Due to special development background, network economy is featured with directness, swiftness, penetrability, external economies and globality (Wei Zaolian, 2009). These features of network economy determine that it will bring in profound and lasting influence to the development of traditional industry.

Network economy and traditional industry are interacted and mutually promoted. At first, network economy can not completely replace traditional economy, and the development of network economy also needs the material support, talent support and market support of traditional economy. The development of computer software and hardware and production of various information devices in network economy are all developed on the basis of traditional industry. Furthermore, the innovation of traditional economy should be promoted and driven by network economy which takes information techniques as the core. Under the support of network information techniques, traditional economy provides a brand new mode of thinking, and we can meet various human needs better with new production ways and new products (Wei Zhaolian, 2009).

For traditional industry, network economy breaks through the boundary of regional markets and national markets and makes the development of enterprises out of the limitation of geographic location; meanwhile, network economy greatly promotes the development of productivity and decreases the production cost of enterprises to make the distribution of resources more reasonable. By virtue of the development of network economy, the construction of smart grid will be promoted, and the progress of the whole power industry will thereby be promoted.

2.3 Smart Grid

2.3.1 Background

With the progress of marketization reform, development of network economy, deterioration of climatic environment and further expansion of global energy crisis, the power industry in the 21st century faces great challenges. Moreover, the grid which plays a critical role in the power system is an extremely complex physical network that operates non-linearly, dynamically and uncertainly (EPRI, 2003; EPRI, 2004). The problem faced by traditional grid is how to stably realize its functions and adapt to further demand under changes of environment. In 2003, the large-scale powercut occurred in America and Canada attracted global attentions. How to monitor grid, improve self-healing capability of grid to increase safety performance of grid and optimize the allocation of resources, has become the focuses of researchs (Horowitz, 2003; LiZaihua, 2007; Carreras, 2003). Meanwhile, along with the influence of information techniques, the concept of smart grid is proposed and attracts attentions.

2.3.2 Development Impetus and Features of Smart Grid

2.3.2.1 Development Impetus of Smart Grid

According to Massoud Amin (2005) and Yao Jianguo (2010), the reasons and objectives of countries around the world in constructing smart grid are different, and definitions of smart grid in different countries are also different. In generally, the main reasons are as follows:

(1) Global energy and environment problem. Along with the increasing growth of global energy demand and excessive consumption of unrenewable resources, it becomes an inevitable trend to largely develop renewable resources of wind energy, solar energy and biomass energy. Intermittency and instability of new energy raises requirements for the technical innovation of grid.

(2) Demand for grid security and flexibility. Along with the increase of power demand and development of network techniques, the operation process of grid is increasingly complex. How to effectively fight against various serious accidents, reduce risks and hazards, has posed great challenges to the security of each link in planning, operation and management of the power system. Therefore, the grid in the future must be featured with high stability and flexibility.

(3) Pressure from financial crisis. The outbreak of financial crisis urges many countries to release economic stimulation packages. Taking power system as the basic industry for developing economy, upgrades of the grid are not only closely related to national interest and people's livelihood, but also able to drive the development of industries in related areas (information industry, material industry and equipment manufacturing industry). It can promote economic growth and relieve employment pressure. Therefore, economic crisis has become a symbolic event for driving the rapid development of smart grid, especially after Obama administration of America proposed the development strategy of smart grid, the concept of smart grid gains worldwide recognition and attention gradually.

(4) Demand on economic operation of grid under the circumstance of market economy. In front of the demand of developing a resource-saving and environment-friendly society, the grid not only needs to fully improve the utilization of energy efficiently, but also needs to be energy-saving and environment-friendly so as to realize the economic operation of power systems. Therefore, the smart grid becomes an advisable option.

(5) Development of new technique. Along with the continuous emergence of modernized new theories, new techniques and new devices, advanced new techniques and devices of information, communication, network, computer, new energy, energy storage and power electronics are widely used in the power system to provide technical support for the intelligent operation and control of the grid so as to make it possible to realize the smart grid (Novosel, 2008).

2.3.2.2 Features of Smart Grid

America pays more attention to the safety performance of grid, especially the safety self-healing capacity of grid when facing turbulence, while European countries pay more attention to reduction of environment pollution through smart grid and mainly focus on research on the access of distributed energies and renewable energies.

Due to the distribution of primary energy and load centers is quite unbalanced in China, extra-high voltage grid should be taken as the backbone of the grid to transmit the electric power from the power supply centre to load centers in high-capacity and long-distance. Therefore, we put forward the definition of smart grid with Chinese characteristics. The State Grid Corporation of China first proposed the concept of “strong smart grid”. Taking an extra-high voltage grid as the backbone rack, it is based on strong grid with each level of grid coordinatedly developed, and uses advanced communication, informatization and automation technologies to build the self-innovated and globally advanced strong smart grid with Chinese characteristics. It is featured with information, automation and interaction (Shuai Junqing, 2009). The smart grid mainly has the following key features (Yu Yixin, 2009; Momoh, 2009; European Commission, 2008; Ding Mincheng, 2008; Xie Kai, 2008):

(1) Safe. The safety performance of smart grid comprises real-time prevention, detection and response to dangers to greatly improve the operation stability of grid.

(2) Self-healing. Smart grid dynamically collects information of the power system in real time, discovers and rapidly diagnoses possible hidden dangers in time, predicts relevant events, carries out risk assessment and takes corresponding treatment measures.

(3) High-quality. Meet demands of users in high-quality and allocate power quality and price in hierarchy.

(4) High-efficiency. Reasonably utilize and allocate power through online monitoring operation situations with network techniques to improve the utilization efficiency of energy.

(5) Interactive. Compared with traditional “mono-directional grid”, smart grid can realize the response function of demand side to encourage users to take part in the operation and management of power system. A bi-directional real-time communication system is established

between the supplier and the user of power to inform users the cost of power consumption, real-time power price, current situation of grid, and power cut information under plan and other service information in real time. Thus, users can prepare their own power utilization plans according to this information, which is beneficial to balancing the relation of supply and demand and guaranteeing the reliability of the system.

(6) Compatible. Smart grid breaks with the traditional simple far-end centralized generation and realizes compatibility of centralized generation and dispersed generation. The distributed generation and storage system of various kinds of renewable energies are integreated into the smart grid in form of “plug and play”. It broadens the range of available sources in the regulation of the system operation and meets the requirements of harmonious development of grid and natural environment.

(7) Diversified. The smart grid which takes power transmission and distribution grids as the physical entity and integrated, high-speed and bi-directional communication network information system as the platform, and integrates monitoring, control, maintenance, energy dispatching, power distribution management, market operation and enterprise resource planning systems of the power system together on the large platform of smart grid. On that basis, interaction and integration of various services are realized.

2.3.3 Development of Smart Grid

In America, power systems have potential safety hazards for various reasons, so it is necessary to prevent great powercut. America pays attention to the upgrade of power facilities in the construction of smart grid in order to improve the stability of grid operation and support the new energy access.

In 2002, American Power Academy of Sciences officially proposed the concept of “Intenigrid” and focused on the development of overall information communication framework of smart grid, the business innovation and the research and development (Hu Xuehao, 2009) of power distribution sides. In November, 2008, the former American vice president Gore proposed a proposal of “unifying the national smart grid" and pointed out tremendous benefits of the proposal in the aspect of optimizing allocation of resources, economy revitalization and employment promotion. At the beginning of 2009, Obama proposed an energy development strategy of taking smart grid as the core to cope with the global warming and international financial crisis. On May 18th, 2009, US commerce secretary Gary Locke and energy secretary Steven Chu announced the first batch of standards for the construction of American smart grid, which marks the formal beginning of American smart grid. In August of the same year, Obama (Rahana, 2009) proposed a proposal of “building a stronger and more intelligent power grid which can transmit power at the east and west coastlines”.

As Europe’s demand on power becomes saturated gradually, low-carbon economy is the main driving force for smart grid to be developed in Europe. Meanwhile, European power enterprises face competitive pressure from the open power market. Therefore, it becomes one of the key points in the construction of European smart grid to improve operation efficiency, reduce power cost and enhance interaction with customers.

In 2005, the European Commission first proposed the concept of “smart grid” and established the “ SmartGrids European Technology Forum”; in 2006, the Forum published three important documents: “Prospect and Strategy of European Future Grid”, “Strategy Research Agenda (SRA)” and " Development Strategy of European Future Grid ", which described a route chart for the development of European smart grid, guided each European country to develop relevant projects, and promoted the realization of smart grid (EuroPean smart-grids technology, 2006). At present, Britain, France and Italy are promoting the planning and construction of smart grid (Charter, 2008).

In Asia, Japan and Korea, which are developed countries, have been carring out research in smart grid. The key point of smart grid defined by Japanese government is to develop new energy such as solar energy in large scale to ensure a stable power grid system. Japanese government planed to launch the construction test of smart grid in large scale in a solitary island in 2010. The test will focus on how to control the wave of power and frequency uniformly and projects such as energy storage technology under the condition of utilizing solar energy in large scale (Koizawa, 2009; Metering, 2010). Korea focuses on the supply and demand interaction system of power industry, largely develops networking and storing technology for renewable energy generation, and improves the reliability and applicability of the whole grid (Metering, 2009). Korean government planed to establish a smart grid comprehensive test project (Wang Chengshan, 2008) in Jizhou Island before 2011 and become the first smart grid country in real sense by 2030.

The construction of smart grid in China is divided into three stages. A complete, uniform and strong smart grid will be built in 2020. The period from 2009 to 2010 was the planning experiment stage to perform smart grid planning, set management and technology standards, research key technology and develop main equipment, and start experiment projects in each part; the period from 2011 to 2015 is the overall construction stage for accelerating the construction of extra-high voltage and electric distribution network, realizing key technology and key breakthrough of equipment, and building a service system of smart grid preliminarily; and the period from 2016 to 2020 is the improvement stage to fully build a uniform strong smart grid(Shuai, Junqing, 2009).

2.3.4 Inevitable Trend of Developing Smart Grid in China under Background of Networking Economy

(1)Increasing rise of power demand

Although power industry in China develops rapidly, the average installed capacity and average power consumption is less than half of the world average level and just 1/6 to 1/10 of the level of developed countries, because China has a large population. Therefore, the power load has large room for growth. According to the prediction of relevant parties, the power demand in China from 2005 to 2020 will keep a rapid growth rate; the average annual power utilization growth rate will be above 6% from 2005 to 2020; and the average annual growth rate will be 5% from 2011 to 2020 (Wu Jingru, 2005).

(2) Continuous growth of newly increased installed capacity

China is building a well-off society in an allround way. The gross domestic product (GDP) in 2020 is predicted to reach 4,000 billion dollars. The continuous and rapid growth of economy requires abundant power supply. Total electricity consumption in China will reach up to 4,600 billion KWh and the required installed capacity will be about 1 billion KW in

2020. That is to say, the annual average newly-increased installed capacity in China will be over 33 million KW and the annual electricity power consumption growth will reach 160 billion KWh during the following several years. The grid in China will have to face arduous tasks of continuously increasing delivery capacity and delivering large-scale power from the energy side to terminal users safely and reliably.

(3) Imbalance of energy distribution

In order to meet the requirement of growth of future electric load, firstly, we have to ensure the adequate supply of primary energy source. Energy resource in China is characterised by large total quantity, little average quantity and imbalanced distribution (Research Group for Energy Strategies of China, 1996). It raises corresponding demands in the development of power resources in China. Hydraulic energy and coal resources are rich but oil and gas resources are poor, which determines that the power supply structure of China will focus on coal electricity and water electricity. Energy resource per capita is relatively small, only 40% of the world average level; energy resources and productivity development are distributed reversely, that is the area rich in energy is far from the area with developed economy. More than 2/3 of developable resources and clean resources in China are distributed in Sichuan, Tibet and Yunnan and more than 2/3 of the coal resources is distributed in Shanxi, Shaanxi, Neimenggu and Xinjiang. The eastern area has developed economy and large energy consumption, but is lack of the energy resource.

(4) Power structure is badly in need of innovation

The rapid growth of power demand brings in an opportunity for the development of national power grid and also poses new challenges (Zhang Yunzhou, 2003; Wang Meiyi, 1991; He Zhao, 2004; Yuan Jixiu, 1999), mainly reflecting in the following aspects: primary energy and renewable energy sources are far from the load centre, so the high-capacity and long distance power transmission is imperative; the traditional power grid can not meet the requirement of optimum distribution of resources; the safe and reliable operating performance of existing power grid is not good; problems in dynamic stability of long-chain power grid structure are serious; the grid at receiving side has problems in direct current placements and voltage stability; and the power system has high risk of having chain reaction when the voltage is low under the condition that the long-chain grid has serious trouble.

It is clear that the existing grid structure is difficult to meet the requirements of the development of national economy and power industry is difficult to adapt to the change of future energy flow. Table 2-1 compares technologies of smart grid and traditional grid. It shows that comparing with traditional grid, smart grid is more reliable in communication; it is capable of self-healing, and is more advanced. Therefore, to build a strong smart grid is an important guarantee for the safety and stability of power grid, and is a necessary condition for realizing the optimum distribution of resources on a larger scale and building a more flexible power market platform, and is also the only way to realize the sustainable development of power grid in China.

Table 2-1 Comparison between Smart Grid and Traditional Grid

Project	Traditional Grid	Smart Grid
Communication Technology	No communication exists between the power grid and the user, or only the power grid can send control information to the user. There isn't interactive information between the power grid and the user.	Two-way communication is adopted between the power grid and the user, and the two parties can exchange information in real-time.
Measurement Technology	Electromagnetic meters and reading systems thereof are adopted; and the power supply network is of radial shape.	An intelligent solid-state meter capable of two-way communication is adopted; and the power supply network is of network shape.
Device Technology	The device operation management is checked manually; power will cut off after the device is breakdown; and manual intervention is required for the recovery of power supply.	The device operation management adopts a remote monitoring system; self-adaption protection and islanding start after the device is breakdown; and the device is self-healing for the recovery of power supply.
Control Technology	The control way of power is a way of centralized electricity generation; and the control way of tidal current is single, flowing from the electricity generation side to the electricity supplying side.	The control way of power is a way of centralized and distributed electricity generation; the control way of tidal current is multiple.
Decision Support Technology	The operator analyzes and deals with emergencies of power grid based on experiences.	Data display technologies such as cartoon, dynamic colouring and virtual reality are adopted to help the operator to analyze and deal with emergencies.

Source: (Meng Fanchao, 2009)

2.4 Brief Summary

Through literature review, we can easily see that with the development of global economy, science and technology and informatization, the breakout of financial crisis, and the emergence of global energy and environment problems, it is a new task and challenge posed to all countries as how to stimulate economic development and adjust energy strategies to meet requirements of sustainable development in the future. It has become a common choice of the international power industrial circle to positively cope with future challenges by using modern information, communication and control technology to develop the smart grid actively. Power enterprises and relevant research institutes at home and abroad begin to explore and develop smart grid. Power sectors in different countries face different problems and challenges, so power enterprises in different countries and regions choose different ways to make developing plans of smart grid that adapts to each country.

At present, power grid in China faces great challenges as well as great development opportunities. It is necessary and urgent to develop the smart grid to solve the great pressure existing in current power grid in aspects of technology, environment protection, safety and resource utilization, so as to provide a reliable guarantee for the increasing power demand. Based on the research achievements in early stages, this thesis sets out on the height of overall strategy to research, demonstrate and plan problems existing in the development and construction of Sichuan smart grid.

Chapter 3: Study and Design Method

3.1 Theoretical Basis for Thesis Study

The world has stepped into the era of network. The two simplest numbers and signs of human society, 0 and 1, build a wonderful and magic digital and network era of human society. Networking has double meanings: one is “network exists everywhere” in human society, various visible and invisible, real and virtual networks, including communication network, grid, transportation network, logistics network, water network, river network, Internet, relation network and social network exist, and human beings are living and working in various networks everyday; the other one is “one cannot win without network”, one will succeed easily with networks and lose without networks: in today’s world, network economy and network industry have not only become important constituent parts in the development of economic society, but also play a central role in the development of social economy. It has become the most important resource and competitiveness of countries and enterprises to own and control networks. American futurologist Toffler predicted that the one who holds information and controls network will own the future world, which increasingly become a real portrayal and description of the network economic time.

Power system is a network and grid is a typical network industry, so the theoretical basis of any research on the challenges of grid in front of modern society is the network theories. The most notable feature of network industry and network economy is network effect, value chain effect and externality.

(1) Network Effect

Network economy has notable network effect which is also called positive feedback effect, demand scale effect and Metcalfe law2. Network effect reveals that the value of a network is equal to the square of the number of network nodes, which illustrates that benefits generated and brought by network will increase exponentially along with the growth of

[2] Matcalfe Law refers to network value increases at a speed of square of the number of users.

network users, and larger the scale of a network is, greater value the network has for network and network users, thus more network users can be attracted into network; people can find notable network effects in network industries of communication network, Internet and power network clearly. Due to network effect, in network industry, the Matthew Effect[3] of stronger becomes stronger and weaker becomes weaker. Therefore, in the network time, especially in network industry, it has become the first law for competition to build a large and strong network.

Therefore, as for the grid with typical features of network industry, network effect is the theoretical basis for development. It is the major measure for enterprises to expand supply area and market occupation, get user resources and improve enterprise competitiveness to constantly expand the scale and coverage of network. Meanwhile, through expanding and improving power network, power supply (electric power supply) and load (electric power demand) switched into the grid can be balanced and guaranteed in a larger range so as to improve the stability and balance power and reliability of supply and create greater value for nodes (power supply and load) integrated into the grid.

(2) Value Chain Effect

In the network era and network industry, on one hand, the upstream and downstream of industry are mutually influenced to generate interactive effect, for example, the stability, safety and economical efficiency of grid operation are largely influenced by the supply feature of power supply and load feature of power users; on the other hand, the supply of commodity (products or services) always cannot be achieved without several links, as each link can add value, thus the value chain of the industry is structured. Therefore, first, enterprises, especially leading enterprises and key enterprises in the industry, should not only focus on the value enhancement of some links or branches of the value chain, but focus on the integration of value chain and value enhancement of the whole value chain so as to realize value maximization of value chain; second, although each link of value chain realizes value enhancement, enterprises, especially leading enterprises and key enterprises in the industry,

[3] Matthew Effect refers to a phenomenon that that the stronger becomes stronger and the weaker becomes weaker, opposite to the natural law of “balance”.

should well position its value chain link on the value chain, which matches resources, capacity, status and objectives of the enterprise, realize value maximization of the enterprise and promote overall value optimization of the value chain, and undertake or take part in value management to realize constant and high-efficiency operation of value chain.

For power system or power network, power generation, transmission, distribution and consumption are integrated together and finished at the same time. Each member of the network shares a common interest and common destiny. The realization of respective value not only depends on efforts of one party, but also depends on other participants of power network, with obvious value chain effect. Therefore, in the industry and areas with obvious value chain effect, value and interest game among parties of the value chain is not a "zero-sum game" 4, but an "interest and density community", all lose or all win. As the central link of power system, power enterprises should not only focus on their own values and interests, but also devote themselves to value management and treatment of value chain so as to maximize the value of power system, which is not only a "social responsibility" of power enterprises, but also a sustainable strategy for maximizing and optimizing their values.

(3) Externality Effect

At present, the loss of network damage is far from being caused by the network itself, but is cutely amplified for the "network effects", and therefore becomes the "Achilles heel" in socio-economic system which is the most vulnerable to natural disasters and war, and the attack of terrorist incidents. For example, in early 2008, the blizzards of south China resulted breakdown of 36740 10 KV and above power lines and 1743 substations of China Southern Power Grid and State Grid Corporation, resulting in blackout which affects 33.48 million families, more than 100 million population. The disaster caused 50 days of grid failure, and about 40 billion yuan of direct economic losses for China's power system. Power system damage results in paralysis of the electrified railway, traffic outage, power station suspended, factories closed, and millions of migrant workers returning home at Chinese New Year blocked, and losses of related industries reach up to hundreds of billions.

[4] Zero-sum game refers to for each party taking part in game, under rigorous competition, profit of one party inevitably means loss of the other part, and sum of profit and loss of each party in the game is always "zero".

Network externality: the “network externality”, which brings far more losses than capitals and properties of the network itself through damage of network, poses two challenges to power enterprises:

At first, “Murphy's Law”5 asserts that “as long as the cause of an accident exists, the accident will happen”, and “no matter how slight the possibility is, it will happen and lead to the utmost loss”. A good material condition of network system cannot eliminate network accidents. No matter how good techniques are and how perfect regulations are, quality and sense of responsibility of person cannot be replaced in actual operations. On the contrary, through transfer, magnification and catalysis of network, “butterfly effect” will spread all over the world, and cause great social disasters and emergencies. Therefore, the prevention of network accidents has posed constant and great challenges to power enterprises.

Secondly, Hayne Law 6discloses that behind each serious accident, there must be 29 slight accidents, 300 abortive omens and 1000 potential accident; occurrence of an accident is the result of quantitative accumulation. Even if accidents cannot be eliminated completely, specially serious and large accidents always show some clues, and have certain causes and omens. It is the social responsibility as well as the survival way of enterprises to eliminate and reduce network emergencies.

The “Bible” or “only way” for the operation of network industry is to vigorously increase the “positive externality” of network industry and eliminate the “negative externality” of network industry, and it has become the important theoretical basis of this study.

3.2 Data and Acquisition Channels

(1) Information Related to Global World and Relevant Countries

It mainly includes economy, energy, electric power and structures of the world, main countries and regions, and data, literature and study report of environmental ecology,

[5] Murphy's Law refers to if anything can go wrong, it will.

[6] Hayne Law: a definition presented by the German Pabus. Hayne, it is a rugulation about the aviation safty. First, the occurance of any incident is a result and acculations of quantitive issues. Second, no matter how good the technology is, how perfect the regulation is defined, at practical level, it can not replace the virture and responsibility of people.

discharge of waste water, gas. This information is mainly obtained from open publications, international organization, government websites and commercial websites, or purchased database and research analysis report.

(2) Information Related to China and Sichuan Regional Economy

It mainly includes China Macro Economy Data (GDP, GDP structure and industry structures) and Sichuan regional economy data (GDP, GDP structure and industry structures) and data, relevant research and analysis report related to energy consumption and environmental ecology. The information is mainly acquired from open published statistical yearbook, relevant research, analysis report and government websites.

(3) Information Related to Energy and Power Industry

It mainly includes national and regional energy resource, production, consumption and investment structures, electric energy output and power supply structures, power demand and structures, regional (Sichuan) power structures, demand structures, problems existing between supply and demand, national macro energy and power polices, development situations of national and regional new energies, information of new energies development in China and the world, relevant literatures and materials about structural reform of global power and China power, materials, data and information on global energy crisis and the development of new energies. The information is mainly acquired from professional yearbooks, literatures, research reports and purchased or customized relevant information from relevant research consultancies.

(4) Information Related to Sichuan Power and Sichuan Grid

In China, the development of Sichuan power industry is unique. Information related to Sichuan Power and Sichuan Grid for researching Sichuan Smart Grid mainly comprises: (1) unique development background of Sichuan power industry and development; (2) power supply structures and demand structures of Sichuan and Evolutions of Sichuan; (3) establishment of Sichuan Grid, structure of Sichuan Grid and evolutions; (4) statistic materials, data and information of Sichuan Power and Sichuan Grid. Above materials are partially acquired from open literatures and websites and then processed through vast on-site field surveys, wide interviews and questionnaire surveys under special support and assistance of relevant authorities, relevant power enterprises and Sichuan Power Corporation.

(5) Information Related to Smart Grid

It mainly includes information about current and future trend of international energy conservation and emission reduction, development of energy conservation and emission reduction in power system, representative cases of grid emergencies in modern countries and analysis research report, key measures to face grid challenges, analysis research report of smart grid, development status of smart grid in the world and research analysis report of further development trend, policies of countries all over the world on the development of smart grid and development planning of China smart grid.

(6) Information Related to Sichuan Power Company

It mainly includes information about the development evolution of Sichuan Power Corporation of China State Grid Corporation (one subsidiary of China State Grid Corporation) and operation materials (including development history and introduction, current situation, planning, future development, and evolution of operation area, market share, operation and financial data). Beside some open published literatures, yearbooks and research analysis reports, these data are mainly provided by Sichuan Power Corporation.

3.3 Study Tools and Methods

Basic guideline of this thesis is to do a targeted theoretical applied research on practical problems and practical demands that the author faces in daily work, so as to determine the basic study method of this thesis: acquire rational knowledge on practical problems based on analysis of large amount of materials, information and data, so as to seek a solution to these problems on the basis of rational knowledge. Therefore, besides general methods of theoretical deductive analysis and causality logic analysis (including related causality analysis model, method and tool), main research methods and tools are as follows:

1. Case demonstration analysis method. Through analysis on great disasters and social loss caused by a large number of grid faults at home and abroad, vulnerability and externality

of grid are obvious; some problems and challenges in the development of traditional grid can be discussed through case study.

2. Material, data and figure demonstration method. Through analyzing and comparing a large amount of materials and data which reflect different power supply features and different power user demand features, it reveals the mismatch of supply and demand between the power generation side and demand side in modern power society. It also reflects challenges of power supply and demand to the safe, stable and economic operation of grid.

3. Material and data quantitative analysis method. Through collecting relevant data, compiling and organizing mass data with questionnaire surveys and interviews, and carrying out comparative analysis and statistic analysis with relevant analysis software, relevant information and matching situation of the power supply market and user demands are discussed.

Chapter 4: Power Development and Grid

4.1 Electricity and Power Revolution

4.1.1 Birth of Electricity

Electricity is the basic sign of modern society and mass application of power is the basic feature of modern civilization. However, human beings have been focusing on electricity phenomenon for a long time. A brief review on the generation and development of modern electric power will help us analyze and solve problems.

Early in 600 B.C., Greek philosophers knew the static phenomenon that friction of amber can attract hair or wood dust. Chinese people in the Eastern Han Dynasty wrote down records about static in the first century. However, scientific knowledge and application of electricity started in modern times.

In 1600, British doctor Gilbert (1544-1603) discovered the phenomena of "electric power" and “electric attraction” after many years of experiments. He was the first to use terminologies of “electricity” and “electric attraction”. In 200 years after Gilbert, human beings have carried out many experiments to constantly accumulate knowledge of the electricity phenomenon.

In the middle of 18th century, American scientist Franklin (1706-1790) did many experiments to further reveal features of electricity and for the first time proposed the term of “electric current”. In order to deeply reveal features of electricity, Franklin did the kite experiment of “capturing atmospheric electricity” in 1750. This remarkable experiment proved that the lightning in the sky is the same as electricity on the ground, which has made great contribution to the development of electrical science.

In the spring of 1800, Italian scientist Volta (1745-1827) discovered the famous “Volta batteries” which enabled human beings to gain manually controllable continued current for the first time, laying a material foundation for the research on electric current phenomenon, and opening a prospect for the research and application of current effect.

The greatest contribution of British scientist Faraday (1791-1867) is the discovery of electromagnetic induction and law of electromagnetic induction, which laid a scientific foundation for the development of electrochemistry, nuclear science and electronics. In 1821, Faraday completed a significant electric invention: invention of the first electromotor in the world; in 1831, Faraday invented the earliest generator in the world.

In 1845, three basic experiment laws related to electromagnetic phenomenon were summed up: Coulomb's law (1785), Ampere-Biot-Savart's law (1820) and Faraday's law (1831-1845). From 1855 to 1865, Maxwell (1831-1879) introduced mathematical analysis method to the research area of electromagnetics on the basis of overall review on the three laws of electromagnetics, so as to lead to the birth of Maxwell's electromagnetic theory: mathematical equations—Maxwell's equations of electromagnetic field theory which combines Coulomb's law, Ampere-Biot-Savart's law, Faraday's law of electricity, Gauss's law and Ampere's law to theoretically prove Faraday's law of electromagnetic induction and predict the existence of electromagnetic wave.

In 1866, the German engineer scientist and inventor Siemens (1816-1892) proposed the working principle of generator and made the first industrial generator in human history. In the same year, Siemens further invented the first direct current generator which enabled the application of electricity to step from labs into industries.

In 1875, the first power station around the world was established in Paris, France. In 1878, France also established the first hydropower station in the world. On October 21st, 1879, American scientist Edison invented the first electric light with utilization value in the world. On November 1st, 1879, Edison got the patent of electric light. In 1881, Edison started to establish a central power plant. In 1882, Edison set up a power plant, which had 6 direct current generators with total capacity of 670KW in the Pearl Street of New York, America to supply power to electric light with 110V direct current.

4.1.2 Power Revolution and Power Development

Marked by the application of electricity, human society stepped into the electric revolution and electric age from the steam revolution and steam age. Electric revolution and electric age have greatly promoted the progress of human civilization. In 1913, global output of electricity reached 50 billion KWh. In 1950, global production of electricity increased to 958.9 billion KWh.

After about 100 years of development, the world total power generation capacity reached 2.024 billion KW by 1980, with an annual generating capacity of 8.2473 trillion KWh. Table 4-1 shows the development of global power since 1980. We can see from Table 4-1 that:

First, in recent 20 to 30 years, the global electricity industry has developed very quickly. From 1980 to 2010, the global installed power generation and electricity generating capacity increased by 2.45 and 2.49 times respectively, which promoted the global GDP growth by 5.7 times.

Second, thermal power stations (coal, oil and gas-fueled power plants) are dominant in global power plants. The installed capacity of thermal power stations is nearly 70% of the total, which poses a grave challenge to the fossil energy and the environmental ecology.

Table 4-1 Development of Global Power Industry

Year	Installed capacity	Energy output	GDP	Year	Global total installed capacity (10,000 KW)				
	10,000 KW	100 million KWh	100 million dollars		Total	Thermal power	hydropower	Nuclear power	terrestrial heat
1980	202417	82473	110273	1990	276179	177906	64418	33030	825
1985	241869	97117	123344	1991	279659	180167	65508	33117	867
1990	275785	117738	217281	1992	285724	184276	67111	33402	934
1995	306384	129903	290764	1993	297085	188259	72007	35821	998
1997	319900	139487	296965	1994	299633	194287	69701	34645	1000
1998	326045	148326	294302	1995	306384	199082	71097	35067	1138
1999	330070	148390	308763	1996	313225	204388	71802	35624	1412
2000	337281	165484	315607	1997	319900	209628	72608	36136	1528
2001	353798	148326	312953	1998	326045	214210	73706	36252	1877
2002	374867	157655	324923	1999	330070	217174	74295	36564	2037
2003	387722	166931	364606	2000	337281	222204	75600	36876	2601
2004	403141	175635	415518	2001	353798	237842	76381	36321	3254
2005	370856	183388	456028	2002	374867	253940	79743	37093	4090
2006	436867	190560	489478	2003	387722	264188	81312	37240	4982
2007	459628	199432	557314	2004	403141	275138	84690	37490	5824
2008	469802	203420	613054	2005	370856	260728	69329	35112	882
2009	489360	201355	582282	2006	436867	301498	88921	38451	7998
2010	495468	213251	629093	2007	459628	318988	92430	38501	9710

Source: elaborated by the author according to International Statistics Yearbook of National Bureau of Statistics of China

To alleviate the shortage of electrical energy, human beings discovered and expanded the scope of use of nuclear power. In 1954, Soviet Union built the first nuclear station in the world: Obninsk, with installed capacity of 5000KW. In1960, five countries established 20 nuclear stations with installed capacity of about 1.28 million KW. In 1970s, influenced by oil crisis, the development of global nuclear power was accelerated. At the beginning of 1980, there were 228 nuclear power stations under running in the world with total capacity up to 131.056 million KW. In 1980s, influenced by nuclear accidents of American Three Mile Island and former Soviet Union Chernobyl nuclear power stations, the construction of nuclear power stations in the world was slowed down. However, until 1991, there were still 423 nuclear motors constructed in about 30 countries and regions around the world with total capacity of 327.5 million KW with electric output accounting for about 16% of the total electric generation of the world. Upon entering the new millennium, stimulated by resource constraint and environmental ecology, the development of nuclear power attracts more attentions. By the end of 2010, 443 nuclear power units of global nuclear power stations were under running, with installed capacity up to 377,750 megawatt. However, in March 2011, the accident of FukushimaNuclear Power Plant in Japan raised severe challenges to global nuclear power stations.

4.2 Power Development in China

4.2.1 Power Development in China

（1）Development and Structure of China Power

In 1897, the construction of the first power station of China was started in Shanghai. On July 26th, 1882, the dark night sky of the Bund was pierced by 15 lighting electric arc lamps, which marked that electricity steeped into China. Six years later, Qing government installed lamps in Zhongnanhai, Beijing. The first hydropower station of China mainland was the Shilong Dam Hydropower Station located in Kunming, Yunnan province in the southwest frontier of China. The Shilong Dam Hydropower Station was founded in 1908 and put into production in April 1912 with installed capacity of 480 KW. Therefore, the development history of China power is not short. In the 68 years from 1882 to 1949, the development of China power was quite slow, lagged far behind the development of global power. Up to the establishment of People's Republic of China in 1949, installed capacity of power generation devices in China mainland was 18.486 million KW with annual energy output of 4.31 billion KWh and there were only 6,475 km of power transmission line of 35 kv or above with power transformation capacity of 3.46 million KVA.

According to data in China Statistics Yearbook, after the establishment of the People's Republic of China, through about 60 years of construction, China power industry has gained great progress. By the end of 2010, the installed capacity of China power station reached 962 million KW and the annual energy output reached 4.14 trillion KWh, which are 540 times and 1002 times as much as that in 1949 respectively, wherein the installed capacity of hydropower is 213 million KW and the annual energy output is over 720 billion KWh. In hydropower, the installed capacity of small hydropower station is over 59 million KW[7], accounting for 27.7% of the hydropower capacity; and the annual energy output is 204.4 billion KW, accounting for 27.8% of hydropower output. The development and basic structure of China power in the 60 years are shown in Table 4-2[8]. From the table 4-2, we can see that:

(1) from 1952 to 2010, in less than 60 years, China's industry developed rapidly, and the installed capacity of power increased by 488.4 times and power generating increased by 567.3 times, which support China's economy to increase by 590.9 times;

(2) Thermal power is dominant in the installed capacity of power, which accounts for about 75% of the installed capacity of power plant. Power generating is mainly in form of thermal power, which accounts for about 81.5% of power generating capacity.

[7] In China, the division standard of small hydropower station is varied in different periods. At present, the standard of small hydropower in China is as follows: located at the upstream or main stream tributary of rivers, the hydropower station with installed capacity of single power station less than 50,000 kw is called small hydropower station.

[8] In this thesis, for easy to state, unless specified otherwise, the mentioned China refers to the People's Republic of China founded in 1949 in the time and 31 provinces and cities and autonomous regions in China mainland in the region.

Table 4-2 Development and Structure of China Power Industry

	Power station capacity				Energy output				China
	Total	Hydro power	Thermal power	Nuclear power	Total	hydropower	Thermal power	Nuclear power	GDP
	10,000 KW	%	%	%	100 million KWh	%	%	%	100 million RMB
1949	185	7.6	92.4	---	43	11.8	88.2	---	400
1952	197	9.6	90.4	---	73	17.8	82.2	---	679
1965	1508	20.2	79.8	---	676	15.4	84.6	---	1716
1970	2377	26.3	73.7	---	1159	17.7	82.3	---	2253
1980	6587	30.8	69.2	---	3006	19.4	80.6	---	4546
1990	13789	26.1	73.9	---	6213	20.3	79.7	---	18668
1991	15147	25.0	75.0	---	6775	18.4	81.6	---	21618
1992	16653	24.4	75.6	---	7542	17.4	82.6	---	26638
1993	18291	24.5	75.5	---	8384	18.1	81.9	---	35334
1994	19780	24.8	75.2	---	9138	18.3	81.7	---	48198
1995	21512	24.0	75.1	0.9	9942	18.5	80.2	1.3	60794
1996	23444	23.5	75.6	0.9	10650	17.3	81.3	1.4	71177
1997	25214	23.5	75.6	0.9	11198	17.2	81.6	1.2	78973
1998	27495	23.5	75.8	0.7	11431	17.6	81.1	1.3	84402
1999	29640	23.4	75.9	0.7	12176	17.3	81.5	1.2	89677
2000	31689	24.9	74.4	0.7	13510	17.8	81.0	1.24	99215
2001	33849	24.5	74.8	0.7	14839	17.6	81.2	1.18	109655
2002	35300	24.14	74.47	1.048	16541	16.38	81.74	1.51	120333
2003	38212	24.24	74.03	1.62	19110	14.81	82.88	2.46	135823
2004	44070	24.48	74.45	1.552	21943	15.08	82.52	2.3	159878
2005	50841	23.02	75.56	1.347	24747	15.97	81.55	2.11	183217
2006	62210	20.67	77.82	1.101	28344	14.7	83.16	1.92	211924
2007	71329	20.36	77.73	1.241	32559	14.95	82.86	1.92	257306
2008	79250	20.87	78.36	1.148	34334	15.36	80.94	1.99	314045
2009	87407	22.51	74.6	1.039	35965	14.26	83.04	1.95	340903
2010	96219	22.18	73.44	1.125	41413	15.99	80.30	1.77	401202

Source: elaborated by the author according to China Statistics Yearbook of National Bureau of Statistics of China

（2）Energy Dependence of China Development

1）Energy consumption structure of China

The energy consumption structure of China is shown in Table 4-3. From Table 4-3, we can find that the energy structure of China mainly focus on coal. Meanwhile, from Table 4-2, we also can find that thermal power (mainly from coal fired power plant) takes about 75% of power station capacity and generates over 80% of power. Coal is an unclean energy with low efficiency. The power structure of taking coal as major energy shows that energy and power industry of China will face pressures of low thermal electrothermal efficiency and high emission to environment.

Table 4-3 Energy Consumption Structure of China

Year	Total of energy consumption	Proportion in the total of energy consumption (%)			
	10,000 tons of standard coal	Coal	Oil	Natural gas	New energy
1978	57144	70.7	22.7	3.2	3.4
1980	60275	72.2	20.7	3.1	4.0
1985	76682	75.8	17.1	2.2	4.9
1990	98703	76.2	16.6	2.1	5.1
1991	103783	76.1	17.1	2	4.8
1992	109170	75.7	17.5	1.9	4.9
1993	115993	74.7	18.2	1.9	5.2
1994	122737	75.0	17.4	1.9	5.7
1995	131176	74.6	17.5	1.8	6.1
1996	135192	73.5	18.7	1.8	6.0
1997	135909	71.4	20.4	1.8	6.4
1998	136184	70.9	20.8	1.8	6.5
1999	140569	70.6	21.5	2.0	5.9
2000	145531	69.2	22.2	2.2	6.4
2001	150406	68.3	21.8	2.4	7.5
2002	159431	68.0	22.3	2.4	7.3
2003	183792	69.8	21.2	2.5	6.5
2004	213456	69.5	21.3	2.5	6.7
2005	235997	70.8	19.8	2.6	6.8
2006	258676	71.1	19.3	2.9	6.7
2007	280508	71.1	18.8	3.3	6.8
2008	291448	70.3	18.3	3.7	7.7
2009	306647	70.4	17.9	3.9	7.8
2010	325000	69.0	18.0	4.4	8.6

Note: New energy refers to hydropower, nuclear power and wind power;
Source: China Statistics Yearbook of National Bureau of Statistics of China (2011)

2) Single regression equation

As the energy and power structure of China mainly focuses on coal, we selected China GDP from **1995 to 2010** and data of consumption of the primary energy of raw coal and the secondary energy of power, wherein these raw data are from China Statistics Yearbook over the years. We take GDP as a dependent variable Y and consumptions of power as independent variables X1-X2 respectively. At first, we analyze the correlation among them to get the analysis result (see Table 4-4).

Table 4-4 Correlation Coefficient between Economic Growth and Energy Consumption in China

Correlation Coefficient	Y	X1	X2
Y	1 -----		
X1	0.961931 0	1 -----	
X2	0.990225 0	0.965667 0	1 -----

Note: X1 represents the consumption of raw coal and X2 represents the consumption of power.
Source: elaborated by the author on the basis of data processing

From Table 4-4, we can see that the selected dependent variable and independent variables is highly correlated, and the correlation coefficient is at least greater than 0.96, wherein the economic growth of China has the highest correlation with the power consumption up to 0.9902. Its correlation coefficient with consumption of raw coal is 0.9619. From Table 4-4, we also can find that different independent variables are highly correlated. For example, the correlation coefficient between power resource consumption and raw coal consumption is 0.9657. It is because that the proportion of coal power generator units in China's power supply structure is up to over 73% (see Table 4-2), and over 50% of raw coal consumption is for power generation.

Now, let us set up a regression model between GDP and consumption of raw coal, raw oil and power. The regression result is as shown in Table 4-5.

Table 4-5 Regression Model between GDP and Consumption of Raw Coal, Raw Oil and Power

Dependent variable Y	Variable	Coefficient	Std. Error	t-Statistic	Prob.	R-squared	Note
Equation1	X1	14.01076	1.063848	13.16989	0	0.925312	Through examination
	C	-83205.21	20607.74	-4.037571	0.0012		
Equation 2	X2	9.918463	0.37339	26.56326	0	0.980545	Through examination
	C	-41147.44	8807.277	-4.671982	0.0004		

Source: elaborated by the author on the basis of data processing

In Table 4-5, numbers in the third line represent the regression coefficients (referring to estimated coefficients); numbers in the fourth line represent the estimated standard errors of regression coefficients (referring to estimated value of the standard error); numbers in the fifth line represent the estimated values of t through calculation under the hypothesis that the real total value of each regress coefficient is zero; numbers in the sixth line are values of p, which is calculated according to the estimated values of t. When the value of p is less than a given significant level, we refuse null hypothesis, which means that theregression coefficient is not zero. The coefficient of determination R^2 is a measurement of goodness of fit. It measures the proportion or percentage taken by the part interpreted by regression model in the total variation of Y. Taking equation 2 for example, in the equation, the value 9.918463, which represents the slope of regression line, means that within sample X from 1007 billion KW to 4206.5 billion KW, when the consumption of raw coal increased by 1 billion KW, the average GDP is estimated to increase by 0.9918463 billion KW. Intercept parameter -41147.44 is the average influence of all the variables omitted in the regression model on Y. R^2=0.980545 means that about 98% variation of GDP can be illustrated by power consumption.

Based on Table 4-5, the regression model between China GDP and consumption of raw coal and power can be obtained:

Y = 14.01076232*X1 - 83205.2108296

Y = 9.91846289883*X2-41147.4366698

3) Multivariate regression model

Table 4-6 shows the data of economic development and energy consumption of China between 1995 and 2010. It is mainly used to analyze the relationship between China’s economic development and energy comsumption. The result is shown in Table 4-7.

Table 4-6 China Energy Output and Consumption Table

Year	GDP	Raw coal (100 million tons)		Raw oil (10, 000 tons)		Natural gas (100 million cube)		Power output
	100 million RMB	Output	Consumption	Output	Consumption	Output	Consumption	100 million KWh
1995	60793.7	13.61	13.63	15005	16714	180	180	10070
1996	71176.6	13.97	14.00	15733	17995	201	203	10813
1997	78973	13.73	13.75	16074	19621	227	229	11356
1998	84402.3	12.50	12.52	16100	18832	233	234	11670
1999	89677.1	10.45	10.47	16000	19661	252	260	12393
2000	99214.6	9.98	10.00	16300	23327	272	279	13556
2001	109655.2	11.61	11.63	16396	22422	303	310	14808
2002	120332.7	13.80	13.91	16700	23641	327	336	16540
2003	135822.8	16.67	16.78	16960	26084	350	359	19106
2004	159878.3	16.06	16.25	17450	29723	415	424	21302
2005	183217.4	18.24	18.50	18084	30766	509	516	24146
2006	211923.5	23.82	24.20	18368	32885	586	596	28344
2007	257305.6	25.36	25.87	18666	34982	692	733	32777
2008	300670	26.22	26.62	18973	36861	803	850	34047
2009	340506.9	30.50	31.76	18900	39279	853	930	37147
2010	397983	32.40	34.05	20300	44231	968	1099	42065

Source: China Statistics Yearbook of National Bureau of Statistics of China (2011)

Now, let us analyze the relationship between economic development and energy consumption in China.

This thesis selected gross domestic product (GDP) during 1995-2010 and data of total consumption of four energies: raw coal, raw oil, natural gas and hydropower, nuclear power and wind power (called power for short), wherein these raw data are from China Statistics Yearbook over the years. We take GDP as a dependent variable Y and consumptions of four energies as independent variables X1-X4 respectively. X1 represents the consumption of raw coal, X2 represents the consumption of crude oil, X3 represents the consumption of natural gas, and X4 represetns the consumption of power.

Totally 15 equations are obtained by means of eviews6.0 software (see Table 4-7).

Table 4-7 Regression Equation Table

Variables	Equation	Significance 0.01	Significance 0.05	Significance 0.1	A	B
1	Y = 1.86614084609*X1 - 99061.5993311	1			1	1
	Y = 8.17710951111*X2 - 165127.656882	1			1	1
	Y = 28.1923305917*X3 + 4869.55539474	1			1	1
	Y = 16.8007714984*X4 - 69645.5829801	1			1	1
2	Y = 1.38797603826*X1 + 2.19222923595*X2 - 119780.960073	1			2	1
	Y = -0.0895326467254*X1 + 29.4620751162*X3 + 10295.6017712	1			1	1
	Y = -0.227678151487*X1 + 18.7480246313*X4 - 64688.9780153	1			1	1
	Y = 0.535850243521*X2 + 26.523970116*X3 - 7220.93347149	1			2	1
	Y = -0.389401272479*X2 + 17.5376005457*X4 - 64254.9935664	1			1	1
	Y = 21.0307085049*X3 + 4.3284672007*X4 - 14867.9345645	1	1		2	2
3	Y = -0.340022291846*X1 + 1.28260331272*X2 + 29.021135105*X3 - 3463.31368284	1	1	1	2	2
	Y = -0.230646747477*X1 + 0.0195899955903*X2 + 18.7363456257*X4 - 64895.5407298	1			2	1
	Y = 0.0550966686672*X2 + 21.0813525452*X3 + 4.19417817326*X4 - 15498.7429409	1			3	1
	Y = -0.297819958986*X1 + 21.5257639534*X3 + 6.58202551652*X4 - 7094.88005968	1	2		2	2
4	Y = -0.42941208877*X1 + 0.846942947572*X2 + 22.5230022272*X3 + 5.51347962808*X4 - 13357.0975058	3		1	3	3

Note: A refers to the number of independent variables with economic meaning; B refers to the number of independent variables with both economy and significance;
Source: elaborated by the author on the basis of data processing

In Table 4-7, through comparing all the regression equations, there are at most 3 variables that can meet both economy and significance at the same time. Therefore, the optimal regress model between China Economy and energy consumption is as follows:

$$Y = -0.42941208877*X1 + 0.846942947572*X2 + 22.5230022272*X3 + 5.51347962808*X4 - 13357.0975058$$

Table 4-8 Comparison on Verified Value and True Value of GDP

obs	1995	1996	1997	1998	1999	2000	2001	2002
Y	60794	71177	78973	84402	89677	99215	109655	120333
YF	64918	71513	73188	78672	94225	99023	113797	120549
obs	2003	2004	2005	2006	2007	2008	2009	Average absolute error
Y	135823	159878	183217	211924	257306	314045	340903	
YF	133911	160489	181148	214464	259322	310443	341661	2.48%

Note: Y is the true value of GDP, YF is the predicted value of regression equation, and average absolute error $=\left(\sum\left|(Y_i - Y)/Y\right|\right)/15*100\%$,

Source: elaborated by the author on the basis of data processing

Meanwhile, we make use of the data of China economic (GDP) growth and energy consumption from 1995 to 2010 for verification. Table 4-8 shows comparison between the verified value and true value of GDP. Table 4-9 shows the estimated result of optimal regression model, and the the optimal regression equation is shown in Figure 4-1. We find that: (1) the average absolute error of this model on verified value and true value in the 15 years is only 2.48% at least; (2) In the optimal regression equation, regression coefficient of raw coal consumption is negative, unable to meet the demand of economy. The possibility of causing this result lies in that coal is mainly consumed for power in China and coal (also called thermal coal in China) consumption of coal consuming units for power generation accounts for 50% of the coal consumption of the whole country. Therefore, raw coal consumption is relatively related to power consumption, or function of raw coal in economic growth is replaced by power.

Figure 4-1 Verification of Optimal Regression Equation

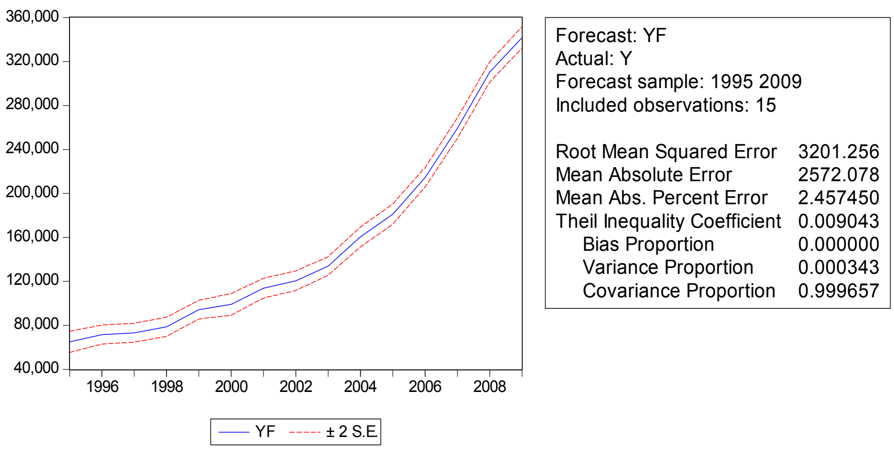


Table 4-9 Estimated Result of Optimal Model

Variable	Coefficient	Std. Error
C（constant term）	-13357.1	8116.036
X1（raw coal consumption）	-0.429412***	0.126939
X2（raw oil consumption）	0.846943*	0.437312
X3（natural gas consumption）	22.523***	2.475892
X4（power consumption）	5.51348***	1.747431
Adjusted R-squared	0.998079	
F-statistic	1819.77	
N	15	

Note: ***, ** and * respectively represent significance at the level of 1%，5%，10%.
Source: elaborated by the author on the basis of data processing

（3）Efficiency of Energy in China's Economic Development

In China, the utilization efficiency of energy is quite low. Table 4-10 shows the comparison between China and the world in economic output and comsumption of primary energy. It shows that:

(1) ratio of the proportion of China's consumption of primary energy in global consumption of primary energy to the proportion of China's GDP in global GDP is fluctuating among 2.10-3.36 (namely the minimal and maximal values of B/A in Table 4-10), which shows that energy efficiency of China is only 1/3-1/2 of global average level, quite low.

Table 4-10 International Comparison on Output of China's Economic Development and Consumption of Primary Energy

Year	1999	2000	2001	2002	2003	2004
A：proportion of GDP，%	3.56	3.4	3.71	3.77	3.72	4.67
B：proportion of consumption of primary energy，%	8.1	10.42	10.7	11.1	12.5	13.83
C：B/A	2.28	3.06	2.88	2.94	**3.36**	2.96
Year	2005	2006	2007	2008	2009	2010
A：proportion of GDP，%	4.96	5.13	5.54	6.95	8.84	9.65
B：proportion of consumption of primary energy，%	15.66	16.76	17.52	18.03	19.25	20.26
C：B/A	3.16	3.27	3.16	2.59	2.18	**2.10**

Source: elaborated by the author according to International Statistics Yearbook of National Bureau of Statistics of China over the years.

(2) Although the energy consumption level of China's GDP increases rapidly during the period of "Eleventh Five-Year Plan" from 2006 to 2010, it is still over 2 times as much as the global average level in 2010, and 3-5 times as much as the level of Europe and America. This comparision shows that China still has big distance comparing with Western and USA in economy output and one time energy comsumption.China's pressure on energy-saving is quite high, and the space on energy-saving is also great.

In order to further reveal structural problems of China power, we comparatively analyze the proportion of new energy in power structures of China and several other countries. Table 4-11 shows the proportion of power outputs of several counties in global power output (called output ratio for short), the proportion of wind power photovoltaic capacities of several counties in global wind power photovoltaic capacity (called wind photovoltaic ratio) and wind photovoltaic ratio/output ratio, wherein the wind photovoltaic ratio/output ratio shows the proportion of new energy of wind power generation and photovoltaic power generation of one country in electric power.

Table 4-11 Power Structures of Several Countries in the World

	%	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Output ratio	America	23.22	22.39	21.89	20.82	20.59	20.29
	China	13.63	15.04	16.45	17.04	18.45	19.73
	Germany	3.38	3.34	3.2	3.13	2.95	2.91
	Spain	1.6	1.59	1.57	1.56	1.47	1.41
	Portugal	0.25	0.26	0.24	0.23	0.25	0.26
	Denmark	0.2	0.24	0.2	0.18	0.18	0.18
Wind photovoltaic ratio	America	14.9	15.07	17.1	19.13	20.1	17.88
	China	2.05	3.28	5.77	8.88	14.32	19.09
	Germany	28.85	26.25	23.96	20.57	18.48	18.67
	Spain	12.82	12.51	11.89	13.17	10.96	10.11
	Portugal	0.91	1.34	1.66	1.56	1.55	1.61
	Denmark	4.76	3.8	2.99	2.24	1.72	1.59
Wind photovoltaic ratio/output ratio	America	64.17	67.31	78.12	91.88	97.62	88.12
	China	15.04	21.81	35.08	52.11	77.62	96.76
	Germany	853.55	785.93	748.75	657.19	626.44	641.58
	Spain	801.25	786.79	757.32	844.23	745.58	717.02
	Portugal	364	515.38	691.67	678.26	620	619.23
	Denmark	2420.64	1586.65	1521.93	1249.63	959.48	879.14

Source: elaborated by the author according to International Statistics Yearbook of National Bureau of Statistics of China and State Power Information Network of China

From Table 4-11, we can find that:

(1)The proportion of China’s power generation is about 13% to 20%, only second to U.S,

(2) The proportion of new energy of wind power generation and photovoltaic power generation in the energy structure of China is much lower than that of Denmark, Germany, Spain and Portugal. It is an urgent task that China power industry faces now to optimize energy structure and improve the proportion of new energy of wind power generation and photovoltaic power generation.

Actually, the backward of power structure will lead to serious resource and environmental ecological crisis. In China, thermal power generation consumed over 50% of raw coal in China and the massive coal consumption will also lead to tremendous discharge of carbon dioxide, sulfur dioxide, smoke and dust. According to data in China Statistic Yearbook, during 14 years from 1995-2009, China power industry had discharged 19.91% solid waste, 33.73% industrial waste gas, 53.62% sulfur dioxide and 43.35% industrial dust in China when provided 7.90% industrial added value. As it is shown in Table 4-12, the change of structure of pollution emission ratio from 2005 to 2010 in China Power Indursty is not obvious. Therefore, China has become the country which comsumes the largest energy in the world, as well as the country which discharges the most carbon dioxide and sulfur dioxide in the world. Energy saving and emission reduction becomes severe challenges of China's economic development. In fact, in front of global resource, energy and environmental ecology crisis, energy saving and emission reduction has become the global responsibility and obligation of each country.

On September 22nd, 2009, on the opening ceremony of United Nations Climate Change Summit, Chinese president Hu Jintao promised in his speech on the subject of *Coping with Climate Change Hand in Hand* that the proportion of renewable energy (excluding hydropower in total energy consumption) will reach 15% by 2020; on December 18th, 2009, Chinese premier Wen Jiabao made a speech on the subject of *Building Consensus, Strengthening Cooperation and Promoting Historical Process to Cope with Climate Change* when attended Leaders' Meeting of United Nations Climate Change Conference (Copenhagen Climate Summit, Copenhagen Climate Change Session Summit Conference) to make a promise to the world again on behalf of Chinese government that on the basis that unit gross domestic product carbon dioxide emission intensity has a 46% decrease in the year 2005 as compared with the year 1990, unit gross domestic product carbon dioxide emission intensity will have a 40-45% decrease in the year 2020 comparing with the year 2005. China's promise is solemn, and the process of implementing the promise is also hard.

In China, the development of power industry should solve some structural contradictions. On one hand, energy is in shortage; on the other hand, efficiency of energy is low. Meanwhile, the level of power structure is quite low and the proportion of new energy needs to be improved. Energy (including power) reform in China is imperative.

Table 4-12 Proportion of Pollution Emission of China Power Industry

Proportion of power industry	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Industrial added value	7.91	7.31	8.20	9.66	10.02	9.17	9.52	9.59
Solid waste emission	18.82	19.94	21.57	14.87	15.44	16.27	18.19	19.29
Industrial waste gas emission	35.52	38.49	34.77	34.6	34.33	35.12	33.27	33.32
Sulfur dioxide emission	51.09	56.43	56.55	43.67	44.17	42.41	53.89	55.01
Industry smoke emission	53.03	59.24	49.81	28.63	31.67	31.21	43.67	45.32
	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Average**
Industrial added value	8.59	8.96	7.92	7.59	7.54	7.26	6.93	7.90
Solid waste emission	22.11	21.01	20.62	20.51	22.88	23.48	23.67	19.91
Industrial waste gas emission	34.17	33.62	32.96	33.51	31.25	30.08	30.95	33.73
Sulfur dioxide emission	57.97	56.97	58.93	58.14	56.6	56.48	56.01	53.62
Industry smoke emission	46.89	43.8	47.4	44.74	42.65	41.42	40.79	43.35

Source: elaborated by the author according to China Statistics Yearbook (1996-2010) of National Bureau of Statistics of China

4.2.2 Development of Local Power in China

Comparing with other courtries in the world, China's power system is very different. To be specific, due to large geographical span and wide coverage of area, the power system of China is huge. Besides, as the geographical conditions, the endowments and types of power resources, and economic development levels are different in eastern, middle and western China, the power system is large. Adapted to this situation, in different regions of China, the development route and mode, even management system is quite different. The difference is mainly reflected in that the power system in China is divided into "the state power" (also called national power, the grid constructed by the state power is called sate grid, unified management network and big network) and "local power" (also called regional power, the grid constructed by the local power is called local grid and small grid) [9].

For long-distance power transmission and supply, a big grid not only needs a stable power supply, but also large amount of capital and advanced technology. At the beginning of 1950s when the People's Republic of China was just established, China experienced long-term hardship of war, and was in need of full scale construction. However, it was low in economic and scientific development level and weak in financial strength. Furthermore, broad rural areas, especially poor and remote western villages located at areas inhabited by the minority nationalities, were far away from arterial traffic and sparsely populated without any modern industry and commerce. To cover these areas with state power system, we not only faced technical difficulties in power generation and transmission, but also great economic pressure, as the investment was huge. But western villages, which were rich in hydropower resources and poor in traffic conditions, were in hope of changing the poor and backward situation through the development of power. Therefore, as a small hydropower station, the rural hydropower has special development background, space and condition:

On one hand, according to the result of the latest hydropower resource survey published by the Ministry of Water Resources of the People's Republic of China, theoretical reserve of hydropower of rivers in China is 694 million KW and annual theoretical power output is 6.08 trillion KWh; technically developable quantity of Chinese hydropower resources is 542 million KW and annual power output is 2.47 trillion KWh; economically developable quantity is 402 million KW and yearly power output is 1.75 trillion KWh; while developable quantity

[9] In China, power facilities constructed by the central government and affiliated enterprise investments are called "state power"; power facilities built by local government (including province, prefecture, county and township) and village and social investments is called "local power". The local power is subordinated to the water conservancy system on administrative division and management. Therefore, for water conservancy system, local power is developed from rural hydropower-small hydropower-middle small hydropower-local power, mainly focusing on rural hydropower and small hydropower.

of hydropower in China's rural areas is 153 million KW, developable quantity of small hydropower resource of 50,000 KW and below is 128 million KW, and the annual power output can reach 400 billion-450 billion KWh. Hydropower resource in rural areas is mainly distributed in western areas, areas inhabited by the minority nationalities, border areas and especially poverty-stricken areas. More than 1700 counties (municipalities, districts) in China's 2300 counties (municipalities, districts) have rural hydropower resource. These areas are wide and sparsely populated. As loads in these areas are sparse, it is quite difficult for big grids to cover these areas under the supply and demand conditions at that time, and it is also unadvisable for big grids to transmit and supply power in such a long distance. Therefore, spare development of rural hydropower in small scale can be carried out easily and economically for supplying power to regions nearby; furthermore, as the construction of rural hydropower needs little investment, short construction period and low power generation cost, it is beneficial to arouse enthusiasm in many aspects and quite suitable for local, collective, enterprise and individual development, with irreplaceable advantages.

On the other hand, the Chines rural areas, especially areas inhabited by the minority nationalities, border areas and poverty-stricken areas are thirst for development. Electric power serves as the driving force of modern cultivation. Rural hydropower is an important constituent part of rural energy and rural water conservancy projects, as well as an important basis and platform for the development of "three rural" (rural area, agriculture and farmer). Through the development of rural hydropower, production and living conditions of "three rural" can be improved through providing energy and power for the development of lighting, processing of agricultural and sideline products and rural industry; furthermore, as a clean and renewable energy resource, rural hydropower can be developed to implement the project of replacing fuel with small hydropower and protect and improve ecological environment of areas of returning farmland to forests or grasslands, natural forest protection, nature reserve and soil erosion treatment, which is quite beneficial to the coordinated development of population, resources and environment. Therefore, for the development of Chinese rural areas, especially western rural power industry, Chinese government encourages local governments to develop power with society together.

Therefore, the development of western China and rural power industry in China is along with the development of local power. According the data elaborated by the author on recent years China Electrical Yearbook:

By the end of 1949, there were only 33 rural small hydropower stations below 500KW in China, with installed capacity of 3634KW. In 1950s, China set forth a principle that the power development in rural areas should be guided by “Three Principles” of small scale, social development and production orientation and “Ttwo Steps” of “developing driving force at first and power secondly” to meet demand of living and production at first. By the end of the “First Five-Year Plan” (1957), there were over 500 small hydropower stations established, with installed capacity of about 20,000 KW. By the end of 1959, nearly 6000 small hydropower stations were established in China with installed capacity of 15,000 KW. Development of rural hydropower in China started.

In 1960s, in combination with river treatment and water conservancy development, China determined that the development guideline of rural hydropower should focus on bases of commodity, provisions and cotton, centre on power for irrigation and drainage, give priority to power supply of power grids and develop grid with rural small hydropower stations together and formally incorporate rural hydropower development into state planning. By the end of 1969, about 19,000 hydropower stations were established with installed capacity of 729,500 KW.

In 1970s, China strived to promote the policy of “who establish, who possess, who manage and who will be benefited” and “support power with power” to further motivate farmers and local governments to develop power and manage power. Newly added capacity of rural hydropower increased to over 800,000 KW in each year on average in the later period of 1970s from 400,000 KW in each year on average in the early period of 1970s. The annual increase of the year 1979 reached 1,120,000 KW and the accumulated installed capacity reached 6329,400 KW.

In the 30 years from 1949 to 1979, the main purpose of developing rural hydropower is to solve the problem that millions of farmers can not use electricity since ancient times (no electricity available). During this period, more than half of the counties around the country developed rural hydropower stations. For a considerable time, these counties use electricity which is mainly supplied by the rural hydropower stations. In accumulation, nearly 500 million people are able to use electricity finally. The history without electricity is ended.

In 1980s, Chinese government carried out the policy that rural small hydropower stations should be established, controlled and used by oneself and “small hydropower stations should have independent power supply areas” and set up a management system that water conservancy (hydropower) departments should shoulder the responsibility of establishment and management uniformly, and rural hydropower (or local power) enterprises should be responsible for the power generation and supply uniformly. By the end of 1987, installed capacity of small hydropower stations in the country reached 11.1063 million KW, with power output of 24.045 billion KWh; meanwhile, Chinese government began to start the construction of 100 Chinese-style rural electrification pilot counties. During the “Seventh Five-Year Plan” (1986-1990), 109 counties passed the acceptance check and reached the standard of rural hydropower primary electrified county. According to statistics at the end of 1998, national hydropower installed capacity in the water conservancy system reached 25 million KW with power output of 80 billion KWh, accounting for 40% of total hydropower of the country, including more than 44,000 small hydropower stations with installed capacity of 22 million KW and annual power output of 78 billion KWh.

In 1990s, Chinese government continued to promote the construction of rural hydropower electrified counties in rural areas. Based on the experiences of the first batch of 109 pilot counties, the State Council of China determined to carry out the construction of the second batch of 200 rural hydropower primary electrified counties during the “Eighth Five-Year Plan” (1991-1995) in 1990. In 1996, Chinese government started the construction of the third batch of 300 rural hydropower primary electrified counties during the “Ninth Five-Year Plan” (1996-2000). By the end of 2000, 335 counties in the third batch passed the acceptance check. Thus, totally 653 rural hydropower primary electrified counties were constructed from the “Seventh Five-Year Plan” to the “Ninth Five-Year Plan” (1986-2000) in the three batches, involving in 252 million of population and covering an area of 2.74 million sq.km., wherein 82% of the area is located in middle western areas, 252 counties are counties of minority nationality and 100 counties are located at boarder areas. Rural hydropower and electrification industry of China has realized two leaps from single-station generation to networking operation for “constructing county grid” and from constructing county grid to “constructing rural hydropower primary electrification". Rural hydropower is widely developed in combination with middle and small river treatment to transfer resource advantages into economic advantages, liberate and develop rural social productivity, greatly promote the economic development social progress of Middle Western areas and stricken areas.

In the 10 years of 1990s, newly added installed capacity of rural hydropower in China water conservancy system reached 13.87 million KW. From 1997 to 2000, the scale of rural hydropower under construction kept at 5-8 million KW in each year and the scale of launch is over 1.5 million KW in each year on average. By 2000, installed capacity of rural hydropower reached 24.85 million KW, accounting for 32.4% of total capacity of hydropower in the country and annual power output reached 80 billion KWh. By 2000, rural hydropower capital reached over 150 billion RMB, annual operation revenue in power generation and supply was over 40 billion RMB and annual tax profit was more than 7 billion RMB. From 1998 to 2000, a total of 11 provincial hydropower group corporations and more than 70 trans-county regional hydropower group corporations were established and totally 10 corporations went public. Before June of 1998, in over 2,300 counties in the country, about 1/3 were direct-management and direct-supply counties, 1/3 were bulk sale counties and 1/3 were self-management and self-supply counties.

Entering the new millennium, the development of Chinese local small hydropower stepped into a new stage. During the “Tenth Five-Year Plan”, Chinese government started the construction of 400 hydropower rural electrified counties to meet the demand of building a well-off society in an all-around way. 80% of these 400 counties are distributed in Middle Western areas and 85% are stricken areas, involving nearly 200 million of people in 25 provinces (districts and cities) and Xinjiang Production and Construction Group, which cover 2 million sq.km. Moreover, the government promoted the reform of rural power system and rural grid. From June of 1998 to the end of 2003, investment in the national rural grid construction and reform project reached 288.4 billion RMB and capital invested in the county grid reform project in 2003 is 33.42 billion RMB. By the end of 2003, totally 42,266 middle small hydropower stations have been established with installed capacity of 35.86 million KW, wherein capacity of power station below 50,000 KW is 28.49 million KW and more than 400 high-standard hydropower electrified counties are constructed. In 2003, in nearly 2,300 counties of the country, 1,600 counties developed rural hydropower stations to form a relatively improved county-level power distribution network with 100kv power transmission networks as the backbone rack and form over 40 trans-county inter-county regional grids through mutual connection for exchanging power mutually. There are more than 800 counties with rural hydropower supply as main power source in the country. Rural hydropower is widely spread in 1/2 area, 1/3 counties and cities and 1/4 population of the country. In 2003, the scale of rural hydropower into production reached 2.3 million KW and the total installed capacity of hydropower in the water conservancy system reached 38.7 million KW, wherein installed capacity of rural hydropower reached 31.1 million KW, annual power output of small hydropower is 103.7 billion KW, total cash equivalent value exceeds 202 billion RMB, and annual profit is over 35 billion RMB, accounting for over 35% of total quantity of hydropower and equal to the scale of hydropower installed capacity in the whole country at the end of 1980s and the scale of capacity of national power industry at the beginning of 1970s.

During the "Eleventh Five-Year Plan", China promoted the construction of 400 extra-high standard hydropower rural electrified counties to further expand the construction and implementation range of the ecological protection project of replacing fuel with small hydropower and continuously carry out the construction and reform of rural grids. Meanwhile, the project pilot of replacing fuel with rural hydropower is developed. In 2010, rural hydropower installed capacity of the country reached 59 million KW and power output reached 204.4 billion KWh.

The development of Chinese rural hydropower and its proportion in national power are as shown in Table 4-13.

First, it shows that China's installed capacity and power generation is increasing every year, and the proportion of rural hydropower installed and thermal power generation is also increasing.

Second, the power comsuption in rural area was increasing according to the enonomy development during 1949 to 2010.

Due to the development of local power, the management of power in China has two different "lines": one is the "national power line" concentrating on longitudinal management and central management, while the other one is the "local power line" concentrating on transverse management and local government management. "National power" takes the former Ministry of Power Industry as the industrial authority and implements national monopoly, centering on thermal power and large-scale hydropower; "local power" takes the former Ministry of Water Conservancy as the industrial authority and mainly implements local and social investments, centering small thermal power and small hydropower, especially small hydropower. In China, the national power mainly supplies power for areas of large and medium-sized cities and east middle areas, while local power mainly concentrates on developing small hydropower resources in remote rural areas in Middle Western areas and mountainous areas and supplies power for nearby towns and farmers. Therefore, local power is the main body of rural hydropower, which takes county-level administrative regions as the supply areas. Local power is also called rural power and the management thereof is also called country-level rural power management.

Operation mode of country-level rural power management can be divided into three types, as follows:

(1) The operation mode of direct-supply and direct-management. Power enterprises of a county is a grassroots "workshop" of provincial power enterprises and persons, properties and materials are all directly managed by provincial power enterprises.

(2) The operation mode of bulk sale. County power enterprises are subordinated to local government. Persons, properties and materials belong to local areas. The relationship between county power enterprise and big power grid is buying and selling.

(3) Self-management mode of independent small grid. Independent small hydro (thermal) grid is not connected with big grid, but works independently. These enterprises generally supply power with small hydropower. They establish, manage, generate and use hydropower by themselves.

There are more than 2,300 counties in China, including about 700 counties under direct-supply and direct-management, accounting for about 30% of all; about 900 counties are under bulk sale, accounting for about 40% of the total; and about 700 counties are self-managed outside of the grid, accounting for about 30% of all.

Table 4-13 Development and Status of Rural Hydropower in China

Year	China Power		Proportion of rural hydropower			
	Total capacity	Total output	Total capacity	Hydropower capacity	Total output	Hydropower generation
	10,000 KW	100 million KWh	%	%	%	%
1949	185	43	0.22	2.89	0.46	3.92
1950	188	52	0.27	3.33	0.49	3.33
1955	350	135	0.37	2.00	0.41	1.57
1960	1250	530	1.60	8.51	0.85	5.00
1965	1508	676	2.32	11.59	1.08	7.02
1970	2377	1159	3.58	13.62	1.55	8.78
1975	4341	1958	7.14	23.08	3.47	14.29
1980	6587	3006	10.32	33.46	4.16	21.48
1985	8705	4107	10.57	34.84	4.63	20.56
1990	13789	6213	9.57	36.62	5.07	24.94
1995	21512	9942	7.74	31.90	5.57	29.64
2000	31689	13510	7.84	31.32	5.92	32.91
2001	33849	14839	8.27	33.74	5.83	32.51
2002	35300	16541	8.82	36.84	6.30	38.44
2003	38212	19110	8.94	38.51	5.74	38.75
2004	44070	21943	8.65	35.23	5.24	34.74
2005	50841	24747	8.48	36.98	5.05	31.63
2006	62210	28344	7.33	35.47	4.87	33.12
2007	71329	32559	6.77	33.26	4.61	30.82
2008	79250	34334	6.44	30.84	4.49	29.19
2009	87407	35965	6.31	28.01	4.45	31.21
2010	96219	41413	6.13	27.65	4.94	30.87

Source: elaborated by the author according to China Statistics Yearbook of National Bureau of Statistics of China

Along with the development of Chinese economy and society, national power gradually develops from the urban to the rural areas and from the East part to the Middle West part to continuously encroach the market share of local power. Therefore, the power structure in Western China, especially western outlaying rural areas and mountainous areas, is quite complex, national power is interlaced with local power and national grid (big grid) co-exists with local grid (small grid). According to data from China Electrical Yearbook, there are 2,510 county-level rural power enterprises in the country, including 1,669 enterprises under the management of Ministry of Electric Power, accounting for about 66% of all, and 620 enterprises under the management of Ministry of Water Resources, accounting for about 25% of all. According to the data of Ministry of Water Resources, in 2,316 counties of the country, power of 793 counties (under the management of Ministry of Water Resources) is supplied by local middle and small hydropower stations and power grids thereof, accounting for about 34% fo all.

As for the whole country, based on data from China Electrical Yearbook, the author made a statistic that, there were 1,685 county power supply enterprises under the systematic "management" of State Grid Corporation of China in recent years, including 763 "mandate" county power supply enterprises, 655 direct-management and direct-supply county power supply enterprises, 26 wholly-owned subsidiaries, and 241 joint-stock county power supply enterprises; there are 343 country power supply enterprises under the systematic management of China Southern Power Grid Corporation, including 199 "mandate" county power supply enterprises, 90 direct-management and direct-supply county power supply enterprises, 7 wholly-owned subsidiaries, and 47 joint-stock county power supply enterprises.

Due to limited capital strength, small, sparse and disordered power supply, poor competitiveness, and poor security capacity of power supply, the development of local power with rural hydropower, which is the core, faces new and severe challenges.

Local power has become one "national condition" of China. The development of local power not only provides driving forces for the development of outlaying rural areas, mountainous areas and territories of nationality of China, but also makes the structure of grids in China, especially grids in western China, more complex.

4.3 Development of Sichuan Power and Grid

4.3.1 Development of Sichuan Power

Table 4-14 shows Sichuan power installed and its structure. Before 1980, Sihcuan power structure is mainly thermal power. This illustrated that, after 1980, Sichuan used its hydropower resources and change the installed electrical capacity and sturucture. Hydropower has been greatly developed and became the leading power for power generation.

Table 4-14 Capacity of Sichuan Power and Structure thereof

Year	Installed capacity of power generation in Sichuan (10,000KW)			Proportion of Sichuan power (%)		GDP
	Total	Hydropower	Thermal power	Hydropower	Thermal power	100 million RMB
1950	4.66	0.24	4.42	5.20	94.80	24.65
1955	10.80	0.76	10.04	7.00	93.00	43.22
1960	66.44	15.88	50.56	23.90	76.10	55.92
1965	83.47	22.39	61.08	26.80	73.20	86.49
1970	152.4	26.4	126.0	17.30	82.70	102.3
1975	289.0	127.2	161.8	44.01	55.99	136.9
1980	396.8	200.2	196.7	50.44	49.56	229.3
1985	462.6	244.9	217.7	52.94	47.06	421.2
1990	749.0	342.7	406.2	45.76	54.24	891
1995	1215	559	656	46.01	53.99	2505
2000	1710	1101	609	64.38	35.62	4010
2005	2246	1496	750	66.62	33.38	7385
2006	2718	1765	952	64.95	35.05	8690
2007	3175	1986	1189	62.55	37.45	10562
2008	3501	2224	1277	63.52	36.48	12601
2009	3804	2583	1221	67.89	32.11	14151
2010	4235	2979	1256	70.33	29.67	16899

Source: elaborated by the author according to State Power Information Network of China, Sichuan Statistics Yearbook of Sichuan Bureau of Statistics and Sichuan Power Yearbook of Sichuan Power Corporation

Sichuan is located in the southwest part of China, covering a total area of over 485,000 sq.km. With Qinghai-Tibet Plateau at the west, perilous peaks of the Three Gorges at the east, Bashan and Qingling Mountains at the north and Yunnan-Guihzou Plateau at the south, Sichuan Basin is known throughout the world. Sichuan Basin includes the Middle Eastern part of Sichuan province and a large proportion of Chongqing Municipality, referring to the main area of Sichuan-Chongqing area. Area of Sichuan Basin is over 260,000 sq.km., accounting for 46% of the area of Sichuan province. Sichuan Basin is located at the middle section of east edge of great western China and west to the Qinghai-Tibet Plateau and Hengduan Mountains, also called western Sichuan plateau. Ground elevation of the western Sichuan plateau is 4000-4500m. The western Sichuan plateau is also the source of Changjiang River and its main branches Jinsha River, Yalong River, Dadu River and Minjiang River. Therefore, the western Sichuan plateau of Sichuan is rich in rivers and rushing current, with the most abundant hydropower resources in China. According to Sichuan Power Yearbook, theoretical reserve of hydropower in Sichuan Province is 143,514.7 MW and annual energy output reaches 1,257.189 billion KWh; technically developable quantity reaches 120,040.0MW, and annual energy output reaches 612.159 billion KWh; economically developable quantity reaches 103,270.7MW and annual energy output reaches 523.289 billion KWh. Sichuan province is rich in power and hydropower in Middle Western China. Hydropower has become the core of the development of Sichuan Power (see Table 4-14).

The difference in power supply structures of Sichuan power system shows that on one hand, power supply structure of Sichuan is cleaner and greener; on the other hand, volatility of hydropower is greater in comparison with coal consuming plants under the influence of climate and precipitation, thus the Sichuan power system has more uncertainty and risk and there are greater challenges to the stability and safety operation of grid.

4.3.2 Sichuan Rural Hydropower

In the hydraulic resource of Sichuan, small hydropower resource accounts for a considerable proportion. Under full development, installed capacity of small hydropower can reach 25.32 million KW, ranking the first of the country. Therefore, Sichuan is the key area of developing national rural hydropower all the time and a big rural hydropower province in China. The data sortted out by the author according to *Sichuan Power Yearbook show that,* the development of Sichuan rural hydropower experiences there stages: 1949-1979, 1980-2000 and 2001 to today.

The period from 1949-1979 is the first stage of Sichuan rural hydropower development which develops rural hydropower from nothing. The local power concentrating on rural hydropower in Sichuan developed from 1356 KW in 1949 (including 735 KW hydropower) to 719,000 KW in 1979 (including 672,000 KW), with an annual increase of 24,000 KW in the 30 years on average.

The period from 1980-2000 is the second stage of Sichuan rural hydropower development which preliminarily develops the scale of rural hydropower from small to large. During this period, Sichuan developed the construction of rural hydropower primary electrified counties to construct 104 rural hydropower primary electrified counties in the whole province, newly added 2.91 million KW of hydropower, eliminated the existence of counties without power and solved the power problem for 15 million of population without power with electrified town ratio up to 97.72%, electrified village ratio up to 97.91% and electrified family ratio up to 97.71%. In 1998, in the 181 counties (municipalities, districts) of Sichuan, 170 counties developed small hydropower, accounting for 93.9% of all; 164 counties developed small grid, accounting for 90.6% of all; 125 counties were supplied power by small grid, accounting for 69% of all; 113 counties were self-management and self-supply counties, accounting for 63% of all; and 3,669 villages (towns) were supplied power by small grid, accounting for 73% of all. In the system of Sichuan power, local power covered 3/2 of the area and 1/3 of the quantity (power quantity). In 2000, local power reached 4.33 million KW, including 3.93 million KW of rural hydropower, with an annual increase of more than 20,000 KW in the 20 years on average.

After entering the millennium, the construction of Sichuan hydropower stepped into the third stage. China carried out the first phase of rural grid construction and reform project during 1998-2001 and the second phase of rural grid construction and reform project during 2002-2003; moreover, in 2003, China started the county grid construction and reform project, which greatly promoted the development of Sichuan rural hydropower. By the end of 2009, the capacity of Sichuan local power reached 9.67 million KW (including 9.36 KW of hydropower) with an annual increase of over 50,000 KW in 9 years on average. Local grid, which is supported with rural water and electricity, has 179 substrates of 110 kv with 8.12

million kva of main transformer capacity and 7,788 km of 110 kv lines, 883 substrates of 35 kv with 6.07 million kva of main transformer capacity and 20,252 km of 35 kv lines, and 146,260 km of 10 kv lines, 134,832 low-voltage distribution districts and 11.89 kva of distribution transformer capacity.

At present, 104 rural hydropower primary electrified counties, 65 hydropower electrified counties and 29 new hydropower rural electrified counties, 7 pilot county project areas of replacing fuel with small hydropower during “2004-2005” and 3 projects of replacing fuel with small hydropower in the “Eleventh Five-Year Plan” have been established. Rural grids of 113 counties (municipalities, districts) and urban grids of 27 counties (municipalities, districts) have been reformed.

In the Sichuan local power system, there are 2 provincial power group corporations, 10 municipal power corporations, 146 county power corporations, 80 independent power generation enterprises and many village small hydropower enterprises. The number of employee reached over 100,000 and five listed companies were established. The development of Sichuan local power and rural hydropower and status thereof in Sichuan power system are shown in Table 4-15 and Table 4-16.

Table 4-15 Power Supply Structure of Sichuan Local Power

	Power generation capacity of Sichuan local power			Proportion of capacity of local power	Power output of Sichuan local power			Proportion of output of local power
	Total	Ratio(%)			Total	Ratio(%)		
	10,000 KW	Hydropower	Thermal power	%	100 million KKWh	Hydropower	Thermal power	%
1980	131.81	45.64	54.36	33.22	42.69	36.24	63.76	27.3
1985	147.63	47.35	52.65	31.91	53.56	45.93	54.07	26.8
1990	218.97	46.92	53.08	29.24	102.15	45.07	54.93	31.24
1995	299.16	39.46	60.54	24.62	172.18	22.96	77.04	32.78
2000	458.84	85.18	14.82	26.84	77.16	86.6	13.4	15.68
2001	461.85	81.44	18.56	25.79	77.38	90.53	9.47	13.91
2002	452.66	87.58	12.42	25.15	147.46	86.38	13.62	23.17
2003	446.92	91.55	8.45	24.27	142.6	91.48	8.52	19.4
2004	516.19	81.61	18.39	25.45	257.78	73.22	26.78	27.56
2005	597.86	75.95	24.05	26.62	274.82	76.39	23.61	26.97
2006	680.13	76.44	23.56	25.03	290.02	74.64	25.36	25.89
2007	755.39	81.37	18.63	23.79	311.48	77.91	22.09	25.4
2008	794.75	81.86	18.14	22.7	313.82	83.87	16.13	25.39
2009	641.84	79.46	20.54	16.87	267.03	81.19	18.81	18.58
2010	808.84	80.04	19.96	19.1	250.79	80.56	19.44	14.73

Source: elaborated by the author according to Sichuan Power Yearbook of Sichuan Power Corporation, Sichuan Hydropower Network, Sichuan Statistics External Network and data provided by Sichuan Power Corporation.

Table 4-16 Status of Sichuan Local Grid in Sichuan Grid

year	Transformer equipment			Transmission line		
	Province	Local power	Proportion of local power	Province	Local power	Proportion of local power
	10,000 kva	10,000 kva	%	km	km	%
1978	681	213	31.28	11576	2300	19.87
1980	815	228	27.98	12991	2891	22.25
1985	1028	259	25.19	16748	3759	22.44
1990	1576	327	20.75	25265	10105	40.00
1995	2297	413	17.98	40251	21474	53.35
2000	3148	700	22.24	45812	22778	49.72
2001	3658	811	22.17	47817	24151	50.51
2002	4072	833	20.46	49081	24155	49.21
2003	4283	865	20.2	53526	27387	51.17
2004	4828	1222	25.31	56102	29424	52.45
2005	5497	1483	26.98	58781	31110	52.93
2006	5949	1485	24.96	54540	25465	46.69
2007	7588	1195	15.75	63320	28988	45.78
2008	8747	1389	15.88	65242	29827	45.72
2009	10250	1687	16.46	69277	31103	44.9
2010	13010	2527	19.42	72634	31689	43.63

Source: elaborated by the author according to Sichuan Power Yearbook of Sichuan Power Corporation, Sichuan Hydropower Network, Sichuan Statistics External Network and data provided by Sichuan Power Corporation.

From Table 4-15, we can see that (1), the proportion of installed capacity and output of Sichuan local power in Sichuan power is constantly decreasing in the new millennium; (2) hydropower accounts for 80% in the power supply structure of Sichuan local power which shows that rural hydropower plays a much important role in Sichuan local power.

From Table 4-16, we can see that Sichuan local grid accounts for a larger proportion in Sichuan grid than power supply, maintaining about 20%. However, as the coverage area is relatively small, the level of transformer equipment and transmission lines of Sichuan local grid is relatively low. Take the transformer equipment for example, the main body of transformer equipment in Sichuan local grid is at the level of 110 kva and 35 kva; by the end of 2010, in the transmission line of Sichuan local grid, 64.5% is at the level of 35 kv, 28.1% is at the level of 110 kv, and only 7.4% is at the level of 220 kv. The low level of Sichuan local grid leads to insufficient competitiveness of Sichuan local grid. From 2011, Chinese government started the third phase of rural grid reform and invested capital up to 500 billion RMB. Along with the implementation of the third phase of rural grid reform, the level of transformer equipment and transmission lines of Sichuan local grid will be improved to further improve and strengthen the grid.

Along with the progress of industrialization and urbanization in Sichuan, the demand on power is increasing rapidly. Compared with the State Grid Corporation of China and subsidiaries—Sichuan Power Corporation, Sichuan local power enterprises is small-scale and weak, so it is hard for them to invest capital intensely into the power supply and grid. As rural hydropower system can not bear the demand on power independently, state grid gradually enters the area of local grid by virtue of powerful strength. However, due to the state grid corporations and local power enterprises stand for interests of different parties, this situation will make the power supply structure in Sichuan more complex. By the end of 2010, in 181 county-level administrative regions in Sichuan, there are 108 county-level power supply enterprises, wherein 70 enterprises are controlled by state grid corporations directly, 32 enterprises are under hosting and 74 counties are under holding management. The market space in Sichuan local power is further compressed, making Sichuan greater challenges.

The same as the frequent change of state power administrative organization of China, power administration in Sichuan also experienced the military control (1949-1950) at the beginning of People's Republic of China, the administration of Chongqing Bureau of Power Management (1950), the administration of Power Management Bureau of Industry Department of Southwestern Military and Political Commission (also called Southwestern Power Management Bureau, 1951-1955), the administration of Chongqing Bureau of Power Management (1956), the administration of Chengdu Bureau of Power Management (1957), the administration of Sichuan Power Bureau (1958, delegated to leadership of Sichuan province), the administration of Sichuanu Department of Water Resources and Power (1958-1965, Power Administration Bureau under Sichuanu Department of Water Resources and Power, delegated to leadership of Sichuan province), the administration of Sichuan Bureau of Power Management of the Ministry of Water Resources and Power (1965), the administration of Southwestern Power Headquarter of the Ministry of Water Resources and

Power (1965-1967), the military control during the cultural revolution (1967-1971), Sichuan Power Bureau (1971-1979, delegated to leadership of Sichuan province), the administration of Sichuan Power Industrial Bureau (1979-1951), the administration of Southwestern Power Management Bureau of the Ministry of Power Industry (1981-1988), the administration of Sichuan Power Industrial Bureau (1988-1993) and the administration of Sichuan Power Corporation (1993 to today). During this period, the administration changes frequently. For example, from 1993-2001, two organizations of Sichuan Power Industrial Bureau and Sichuan Power Corporation existed at the same time, but actually they are the same organization with the same team under dual leadership of Minitery of Power Industry and Sichuan Provincial Government. On February 22nd, 2001, Sichuan Power Industrial Bureau was repealed and Sichuan Power Corporation exists so far. During 1993-1997, it was a governmental corporation. During 1997-2002, it was a power production and supply enterprise integrated power generation, power transmission, power distribution and power sales together for integrated operation. Since 2002, it has become a professional power enterprise.

Sichuan Power Corporation is a provincial subsidiary of the State Grid Corporation, as well as the main force of Sichuan power transmission and distribution.

During the "Eleventh Five-Year Plan", the ratio of power capacity and load of each voltage level of Sichuan grid increases gradually. By the end of 2010, ratios of power capacity and load of the grid at the voltage level of 500 KW, 220 KW and 110 KW reached 1.79, 1.71 and 1.77 respectively, so as to realize the overall development of each level of grid. The grid of 500 kv basically covers each cities of Sichuan and forms a 500 kv ladder-shaped reticulate backbone rack from the north to the south, which have greatly improved the power transmission capacity; the looped network of 220 kv is basically formed in each city to optimize and improve the rack structure and increase the power supply capacity obviously; the distribution network of 110 kv and below in urban and rural areas is constructed and reformed rapidly to increase the capacity of power distribution and further strengthen the resource allocation capacity of the grid.

Therefore, the construction of trans-regional and trans-provincial grids is accelerated, the power exchanging capacity is notably improved and the resource allocation capacity of grids is further enhanced. The 500 kv four-loop connection formed with Chongqing Grid lays a strong foundation for the inter-provincial power exchange. The Deyang-Baoji ± 500kv direct current networking project built ahead of schedule has effectively realized the resource complementation between Sichuan and northwest grids. The Xiangjia Dam-Shanghai ± 800kv extra-high voltage direct current demonstration project will be completed and put into production, on the occasion, Sichuan grid will be connected with the central China grid through four-loop 500kv alternating current lines, connected with the northwest grid through one-loop ± 500kv direct current lines and connected with the east China grid through one-loop ± 800kv extra-high voltage direct current lines so as to form a trans-provincial and trans-regional power transaction platform preliminarily and greatly improve the power exchanging capacity. By the end of 2009, Sichuan grid (including holding and hosting, the same below) has 662 substations of 110kv or above with 88.75 million kva of power transformation capacity and 34,669 km of alternating current lines, and 1 direct current convertor station with 1.50 million KW of direct current converting capacity and 240km of direct current lines, including 20 substations of 500kv with 26 million kva of capacity and 6,400 km of lines and 131 substations of 220kv with 31.56 million kva of capacity and 12,495 km of lines.

Table 4-17 shows the status of Sichuan Power Corporation in Sichuan's power industry.

Table 4-17 Basic Situation of Sichuan Power Corporation

	Sichuan Province		Sichuan Power Corporation				
	Output	Consumption	Sales	Quantity of direct supply	Quantity of bulk sales	Market share	Sales revenue
	100 million KWH	100 million KWH	100 million KWH	100 million KWH	100 million KWH	%	100 million RMB
2001	636.5	589.6	370.6	318.7	51.8	62.85	162.5
2002	735.1	671.8	427.8	370.6	57.2	63.68	189.2
2003	827.8	759.8	495.9	427.1	68.8	65.27	210.7
2004	935.3	857.0	564.5	483.2	81.3	65.87	256.7
2005	1018.8	942.6	638.3	538.7	99.5	67.71	291.1
2006	1120.4	1059.4	725.0	598.3	126.8	68.44	355.3
2007	1226.3	1177.5	832.8	660.8	172.1	70.73	427.2
2008	1235.8	1213.3	871.6	694.4	177.2	71.83	457.0
2009	1468.5	1323.4	969.8	760.6	209.2	73.28	510.2
2010	1683.8	1548.9	1206.2	915.1	291.1	77.87	673.0
2010/2001	2.646	2.627	3.255	2.871	5.616	1.239	4.143

Source: elaborated by the author according to Sichuan Power Yearbook of Sichuan Power Corporation, Sichuan Hydropower Network, Sichuan Statistics External Network and data provided by Sichuan Power Corporation

Table 4-18 Counties Covered by Sichuan Power Corporation

	Unit	2005	2010
Direct-supply power supply bureau	Piece	69	70
Holding local power corporation	Piece	30	74
Hosting local power corporation	10,000 KWh	19	32
Total	Piece	118	176

Source: elaborated by the author according to data provided by Sichuan Power Corporation

Table 4-17 shows that:

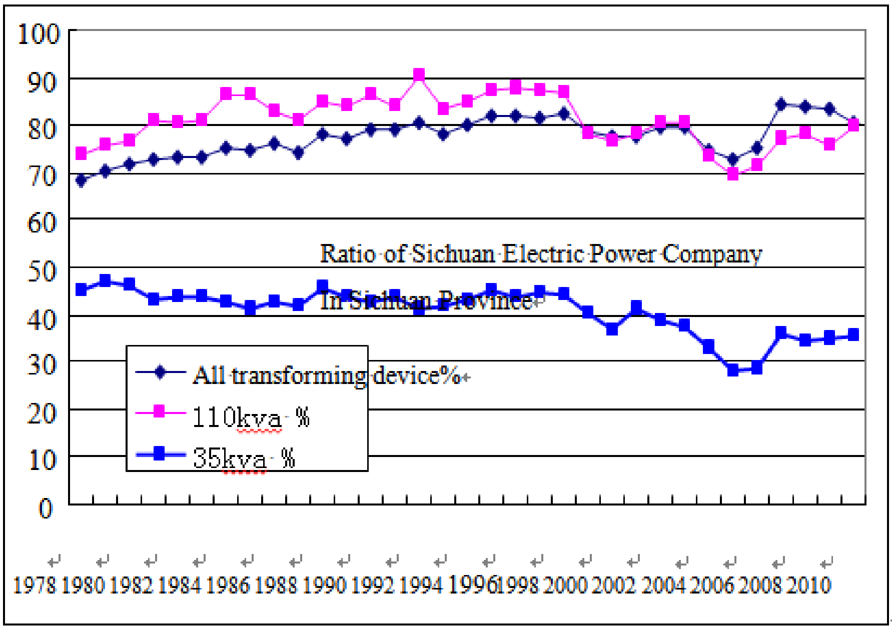
First, during 2001-2010, power supply index of Sichuan Power Corporation increases faster than the index of whole Sichuan Province on the sales volume of power, quantity of direct-supply power and quantity of bulk sales.

Second, during 2001-2010, market share (power sales volume of Sichuan Power Corporation/power consumption in Sichuan Province) increased by nearly 15% and sales revenue of the corporation increased by 4.14 times as compared with the corresponding period.

As for the coverage of power market, in 1990s, the market of Sichuan Power Corporation mainly centred on major cities and economically comparatively developed areas in Sichuan. Along with the power system reform of grids in China, Sichuan Power Corporation strengthens the development of market. As it is shown in Table 4-18, in 2005, in 181 county-level power consuming areas of Sichuan, Sichuan Power Corporation occupied 118 and increased rapidly to 176 in 2010. Sichuan Power Corporation made remarkable achievements in market expansion.

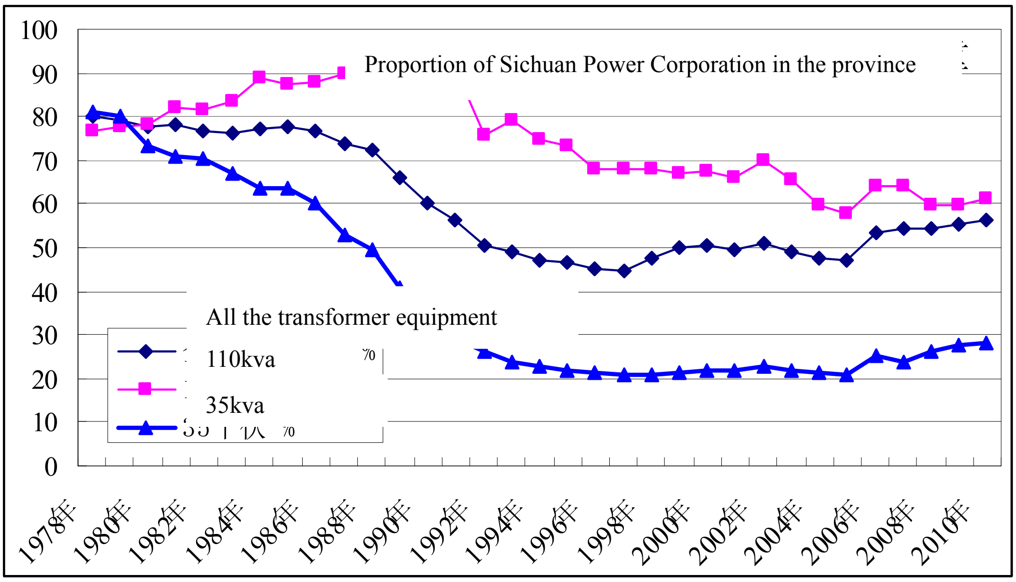
In the power transmission and distribution network, Sichuan Power Corporation has absolute advantages. Figure 4-2 shows the transformer equipments and structure of Sichuan Power Corporation, Figure 4-3 shows the electricity transmition lines and structure of Sichuan Power Corporation.

Figure 4-2 Transformer Equipment and Structure of Sichuan Power Corporation



Source: elaborated by the author according to Sichuan Power Statistics Yearbook

Figure 4-3 Power Transmission Line and Structure of Sichuan Power Corporation



Source: elaborated by the author according to Sichuan Power Statistics Yearbook

From Figure 4-2, we can find that :

First, during 1978-2010, the average ratio of transformer equipment of Sichuan local grids in Sichuan Grids reached 20.55%, but the transformer equipments at the power level of 500 kva and 220 kva were nearly all owned by Sichuan Power Corporation.

Second, the ratio of transformer equipment at the power level of 35 kva is quite low in Sichuan Power Corporation, which shows that the grid of Sichuan Power Corporation has higher level and quality.

From Figure 4-3, we can find that:

First, during 1978-2010, the average ratio of transmission line of Sichuan Power Corporation in Sichuan Grids reached 45.18%, and the power transmission lines at the voltage level of 500 kv and 220 kv were nearly monopolized by Sichuan Power Corporation, the advantages in power grid is obvious. Meanwhile, Sichuan Power Corporation also has 800kv extra-high voltage direct current power transmission lines and is also active in doing early preparation work for the construction of smart grid. Therefore, the coverage area of grids is wider, the grid structure is more reasonable, and the construction of stronger and smarter grid is in progress.

（1）Information of Power Supply Region

1) Division according to county-level administrative region

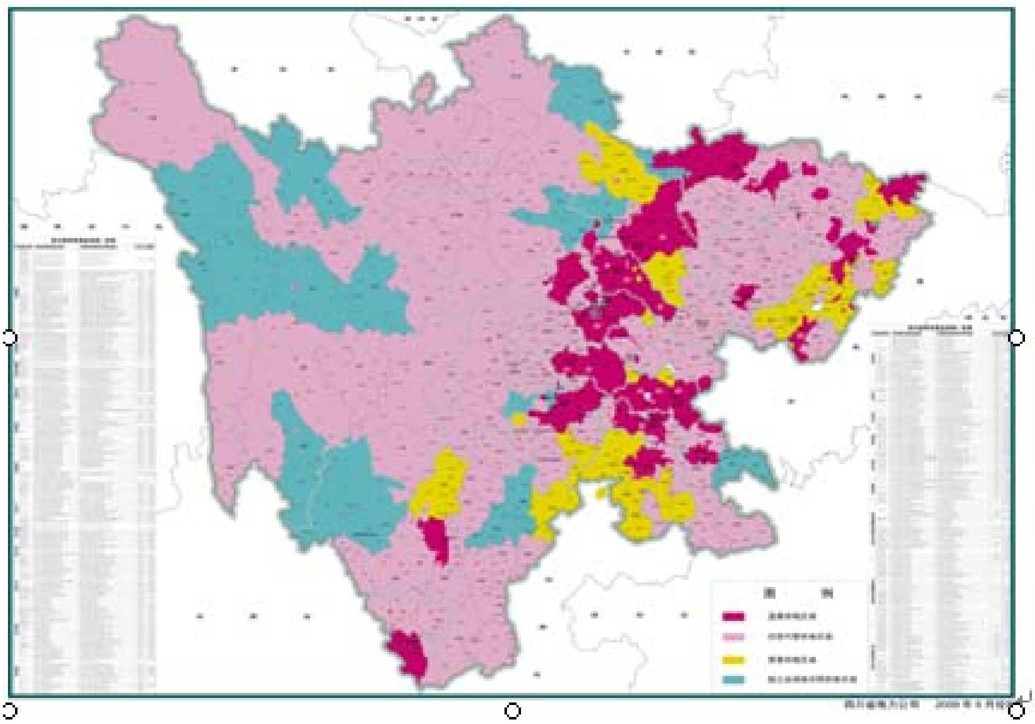
In the 181 counties (municipalities, districts) of 21 prefectures of Sichuan, 37 counties belong to direct-supply and direct-management by the provincial enterprise and 32 counties belong to crossfeed of the provincial enterprise and local power enterprises, while the rest 112 counties have no power supply regions directly under the provincial enterprise, wherein 84 counties establish a bulk sale relationship with the provincial corporation directly and the other 28 counties without direct bulk sale relationship are all distributed in three autonomous prefectures of Ganzhi, Aba and Liangshan. The provincial corporation holds shares of power enterprises in 13 counties and hosts power enterprises in 11 counties (see Table 4-17 and Figure 4-4).

2) Division according to number of county-level power supply enterprises

In the 208 country-level power enterprises, 117 enterprises are under direct-supply and direct-management, or are holding and hosting of provincial enterprises. They include 70 direct-supplies and direct-management power supply bureaus, 74 holding county-level enterprises (53 enterprises have consolidated financial statements) and 32 hosting county-level power enterprises. In the other 32 county-level power enterprises, 15 enterprises established direct bulk sale relationship with provincial enterprises (6 enterprises are holding enterprises of Sichuan Hydropower Group Corporation) and 17 enterprises are independent grid power enterprises (2 enterprises are holding enterprises of Sichuan Hydropower Group Corporation). Besides county-level power enterprises, the provincial enterprise is also holding four prefecture-level listed power companies, namely Mingjiang Hydropower, Leshan Power, Xichan Power and Mingxing Power (see Table 4-18 and Figure 4-5).

According to data provided by Sichuan Power Corporation, power supply area of direct-supply and direct-management, holding and hosting power supply enterprises of the provincial enterprise covers an area of 367,300 sq.km., accounting for 75.15% of total area of Sichuan province and a population of 76,721,200, accounting for 85.71% of the total population, wherein the direct-supply and direct-management power supply region cover an area of 53,700 sq.km., accounting for 11% of total area of Sichuan province, and a population of 34.15 million, accounting for 38.6% of the total population. Market share of the company is 94.3%.

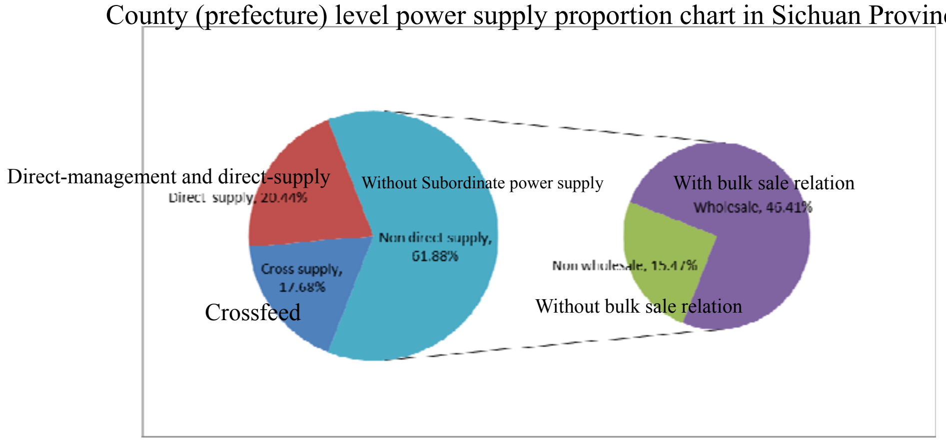
Figure 4-4 Sketch Map of Power Supply Area of Sichuan Power Corporation

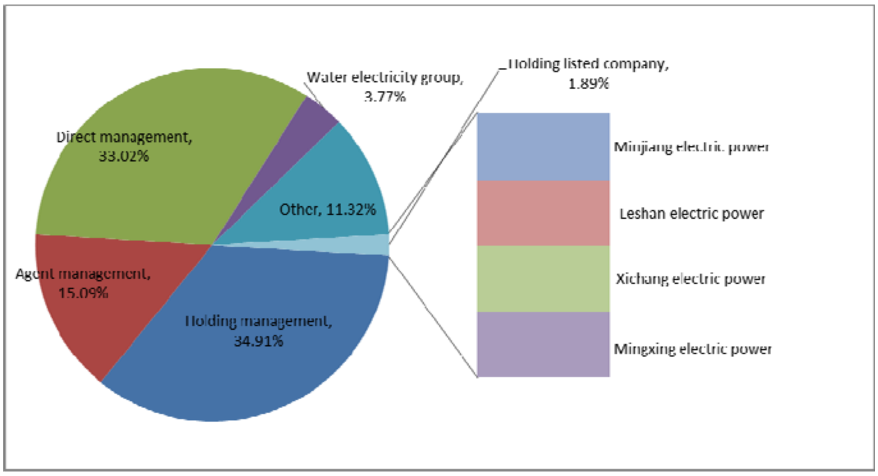


Source: Sichuan Power Corporation

Figure 4-5 Sketch Map of Regional Power Supply Relationship of Sichuan

County (prefecture) level power supply proportion chart in Sichuan Province



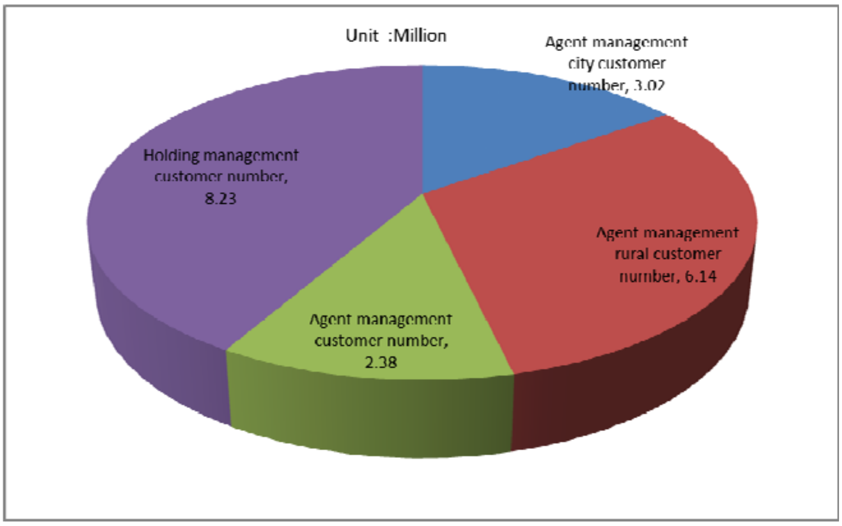


Source: Sichuan Power Corporation

（2）Situation of power users

The number of all the users (including rural power supply stations and holding country-level companies) of the company is 17.394 million, wherein 3.024 million users are direct-supply and direct-management urban business users, including 10,400 users of large industry, 35,600 users of non-industry and common industry, 1,800 users of agriculture, 5.7 users of non-resident lighting, 2,680,500 users of resident lighting, 235,400 commercial users and 3,400 users of bulk sale; 6.14 million users are direct-supply and direct-management rural power supply station users; about 8.23 million users are holding power company users; and about 238 users are hosting power company users.

Figure 4-6 Sketch Map of User Structure



Source: Sichuan Power Corporation

4.4 Power Reform

No one would doubt about the great promotion of electric power on the civilization and progress of human society, but the management of power industry only attracts theoretical attention all the time. Power industry is always considered as a monopoly industry. But along with the progress of power production technology, people are trying to introduce competition into the power industry for reducing power price and improving service quality. At the end of 1980s, many countries in the world tried to carry out reform on the power system according to specific conditions of each country. By entering 1990s, the concept of natural monopoly of power industry was relatively removed to certain extend and the trend of power industry system reform swept across the globe. The pioneer of power reform was Britain oriented in new liberalism economic theory. Later, the trend of reform swept to Europe, North America, South America, Australia and some countries and regions in Asia. After considering the frame mode of power industry reform, each country has two starting points: the first one is that it is necessary to re-recognize the monopoly of public utilities and re-define the scope of natural monopoly of power industry, that is to say the integration of power generation, power transmission, power distribution and power sale should not have an automatic organization form of the power industry and power industry can have different organization forms; the second is that technical progress also brings in, more possibilities to the reform of power system. The trend of industrial reorganization and reform of global power industry is to introduce competition and transparency.

The reform of monopoly power system provides institutional guarantee for the modern society in facing resource and energy crisis and the sustainable development of power industry. However, due to the fact that different countries have different types of control, different degrees of maturity and different historical development, the reform and direction of power industry in each country are also different. This section mainly aims at briefly introducing the American model and British model of power industry and discussing the main measures for power system reform in China.

4.4.1 American Model

Before reform, the power industry in America is of a double-layer management model under joint management of federal government and state government and the control of government is quite strict. In the investment system, the government only permits companies with grids to invest power plants and other investors excluding power companies are forbidden. On the management level, public power companies implement management directly, grids are not open for outside, and market competition pricing is not encouraged in the power price system.

In 1980s, American government carried out power reform and introduced competition mechanism. The model of American power reform is the mode of marketing, namely “plants are independent from grids, price bidding for transaction, and government (parliament pricing)”. The *Energy Sources Policy* modified in 1992 regulated that each power enterprise shared the right of entering power transmission network equally and openly. Starting from America, it becomes the main purpose of global power system reform to break the monopoly through marketization.

Basic measures of American power reform are as follows: putting the power transmission field out as a natural monopoly link, opening the power generation field and power distribution and supply retail field to enable the selling party and purchasing party to enjoy equal power transmission services, and establishing a power wholesale market to realize competition at the power generation side and marketing side. In 1996, American Federal Energy Regulatory Commission (FERC，Federal Energy Regulatory Commission) issued No. 888 and No. 889 laws, requiring functional separation of the power generation and power transmission fields, fairness and opening of grids, and equal treatment of all the power generation enterprises. In 1999, FERC proposed a suggestion of establishing a regional transmit organization (RTO，Regional Transmit Organization) and took RTO as an independent regional dispatching organization which is responsible for the dispatching operation and market supervision of power transmission grids so as to create maximal regional benefits for the operation of power transmission network.

American power system reform is considered as an example of power reform for other countries. However, at the beginning of 2001, California power crisis broke out. Due to severe shortage of power supply and sharp increase of power price, power enterprises were heavily in debt and the government of California has to proclaim a state of emergency. In order to prevent the power transmission network from paralysing, California carried out power control, which was also the first time of power control carried out in California since the Second World War.

California power crisis arouses global attentions, not only because California is the location of Silicon Valley which will influence the economic trend of America, but also because California was once known as the most representative place in the world where the earliest power system reform was carried out. Through California power crisis, people realized that the power reform must be under a comprehensive balance in market mechanism and government guiding, interests of each party in the power market, and long-term contracts and spot transaction, then the sustainable stable development of power can be realized.

4.4.2 Britain

The maketization reform of power in Britain started from the age of Margaret Thatcher. At the beginning, British government divided and reorganized the power industry according to functions. With such guiding concept, more competition mechanisms can be introduced to the generation and sales of power industry, while the power transmission and distribution link of power industry is considered to have the feature of “natural monopoly” in the future. Therefore, limitation on power generation and sales can be removed gradually and the control of power transmission and distribution will be reserved. The reform of Britain power industry is a way of business division which makes the power generation, transmission, distribution and sales to operate independently. In the three links of power generation, power transmission and power distribution, except the link of power transmission that is still monopolized by the State Power Corporation of Britain, other links are all open for the market. Operators in the power production can enter the power market and take part into competition under the condition of having the license issued by Britain Power Management Bureau.

The reform of power marketization in Britain is divided into three stages: the first stage is the pool (POOL) time from 1990 to 2001; in this stage, it is regulated that all power transaction should proceed through POOL, power generators are subject to auction regulations, and power purchasers must purchase most power from POOL; the second stage is the time of New Electricity Trading Agreement (NETA); in order to overcome faults that the power price is too high and users cannot take part into the decision of power price, Britain entered into the time New Electricity Trading Agreement in 2001; the New Electricity Trading Agreement sets up a bilateral contract market that user side and power generation side can meet directly; over 90% of power transactions are realized by signing a bilateral contract in the power exchange; after the application of NETA, power prices in England and Wales decrease about 30-40%; in 2005, Britain entered the stage marked by Britain Electricity Trade and Transmission Agree (BETTA); a totally independent Great Britain system operator (GBSO，Great Britain System Operator) covering Scotland, England and Wales separating from power generation and power supply services was set up.

4.4.3 Reform of China Power

In recent 60 years, China power industry develops rapidly, but still cannot meet the demand of social and economic development effectively. One of the most important reason is the management system. Since the power industry is critical to the stability of the whole society, any measure is quite cautious.

In China, as a special industry, power industry is monopolized by the state for a long time after the foundation of the country. As the channel is single and the investment is woefully inadequate, China power is in shortage for a long time and power shortage is ordinary.

In the middle of 1980s, power shortage in China became quite serious, even heavily hindered the development of national economy and the increase of people's living standard. In order to solve this problem, Chinese government adopted the suggestion of "raising money to develop power" and also increased the investment in power. In 1997, the problem of power shortage in China is greatly relieved. However, the situation of power monopoly in China has not been solved radically, thus China was plunged into severe power shortage from the latter halt of the year 2002.

Along with the shortage of power in China, the power management system has experienced nine changes since the foundation of People's Republic of China in 1949 on the national level, including military control, ministry of fuel industry, ministry of power industry, ministry of energy sources, ministry of water resources and power, ministry of power industry, energy sources bureau and state power corporation, wherein there are 2 times of applying military control, 3 times of establishing energy sources bureau, 2 times of establishing ministry of water resources and power and 3 times of establishing ministry of power industry. The change of national management organization is quite frequent. Chinese power system has experienced 4 historic stages as follows:

(1) The power management system of integration of government and enterprise and vertical monopoly (1949-1978).

This stage of Chinese power system experienced the military control at the beginning of the founding of the new China, ministry of fuel industry during 1950-1955, ministry of power industry during 1955-1958, ministry of water resources and power during 1958-1967, military control again during the Great Cultural Revolution from 1967-1970 and ministry of water resources and power, during 1970-1978. This stage is remarkably characterized by the integration of government and enterprise[10]. Due to national exclusive monopoly, the

[10]After established a national regime in mainland, the Communist Party imeplements highly centralized and integrated

prominent contradiction is the heavy shortage of power supply caused by systematic problems.

(2) Probing into “raising money to develop power” in Chinese power investment system (1979-1997).

During this stage, Chinese power management system experienced changes of establishing ministry of power industry for the second time (1979-1982), establishing Ministry of Water Resources and Power for the second time (1982-1988), establishing energy sources bureau (1988-1993) and establishing Ministry of Power Industry for the third time (1993-1997). During 1985-1997, in order to solve the problem of heavy power shortage, China probed into the stage of “raising money to develop power” and encouraged social investment so as to relieve the power shortage in around 1997 in short-term in a certain degree. Prominent contradiction of this stage is high integration of government and enterprise.

(3) Reform probing into “separating government from enterprise” in Chinese power investment system (1997-2002).

The reform of Chinese power system took the action of solving the integration of government and enterprise as a breach. In May of 1997, the State Power Corporation was set up. In 1998, the ministry of power industry is repealed and the management function of power industry is transferred to the Ministry of National Economy-State Economic and Trade Commission set up the Department of Electric Power to be responsible for the administrative management function of power industry. The State Power Corporation is a power production operator without any government function of administrative management, which integrates power generation, transmission, distribution and sales together, carries out vertical integrated operation and owns all the grids and half of power plants. Prominent contradiction of this stage is the problem of vertical integration monopoly.

---

planned economy in long-term. The central government not only centralizes nearly all the economic policy-making right, excepting individual and very few fields, and enterprises are almost stat-owned enterprises. Moreover, the government not only owns enterprises and operates enterprises, but also confuses administrative functions and economic functions of the government with operation functions of enterprises. In China, this phenomenon is called integration of government administration with enterprise or integration of government and enterprise. To break the management system of integration of government administration with enterprise has become one of the objectives of Chinese economic system reform since 1980s. However, the situation of integration of government administration with enterprise in fileds of telecommunication, power and finance isn’t change until latter 1990s. China Railway is still under the situation of integration of government administration with enterprise up to now.

(4) Reform probing into “separating plant from grid” in Chinese power investment system (2002-2010).

On April 12th, 2002, Chinese State Council released the *Power System Reform Program* which contains three core parts: separating plants from grids and price bidding for transaction; re-organizing power and grid enterprises; dividing the State Power Corporation transversely and longitudinally to preliminarily establish a competitive and open regional power market. Therefore, the former State Power Corporation was divided into 11 enterprises according to the principle of separating plants from grids, including five power generation groups, two grid enterprises and 4 power auxiliary groups. Furthermore, Chinese State Electricity Regulatory Commission was established. On December 29th, 2002, twelve enterprises and institutions of Chinese State Electricity Regulatory Commission related to power reform were formally founded, thus the reform proposal of “separating plants from grids " in Chinese power investment system was put into practice.

The power reform accelerates the development of Chinese power industry. In 1949, installed capacity of Chinese power was 1,848,600 KW and the annual power output was 4.310 billion KWh; in 1997, the installed capacity of Chinese power was 254.14 million KW and the annual power output was 1,119.8 billion KWh. After 48 years of development, the installed capacity of Chinese power has witnessed an increase of 252.3 million KW and output has seen an increase of 1,115.5 billion KWh. After the power reforms of “separating government from enterprise” and "separating plant from grid" were carried out in 1997 and 2002, the installed capacity of Chinese power reached 962.19 million KW and the annual output reached 4,141.3 billion KWh in 2010. During the 12 years, the installed capacity of Chinese powers increased by 708.05 million KW and the output increased by 3,021.5 billion KWh. During the 12 years after power reform, the increase of installed capacity and output of Chinese power is near 3 times as much as the increase during the 48 years before substantial reform.

However, although the reform of separating government from enterprise and separating plant from grid in power management system is carried out, the problem of “monopoly and centralization” in Chinese power management system has not been solved radically. To implement separation of generation, transmission and distribution, the establishment of regional power markets, deepening of rural power reform, reform of power transmission price and power distribution price, reform of government supervision system and diversification of investors and investment channels all become the core content and key task of power system reform in the future. On August 30^{th}, 2008, the National Energy Administration was founded, under which the Department of Coal, Department of Petroleum and Gas, Department of Power, Department of New Energy and Department of Renewable Energy were set up. On November 29^{th}, 2011, two auxiliary groups of Chinese Energy Construction Group Corporation (Chinese Energy Construction) and Chinese Power Construction Group Corporation (Chinese Power Construction) of Chinese power industry were founded, which shows that the reform of Chinese power system is under progress and the task of Chinese power reform is quite hard.

Beside systematic challenges, the development of grid enterprises faces more challenges. We will discuss them hereafter.

Chapter 5: Grid development: Challenges and Countermeasures

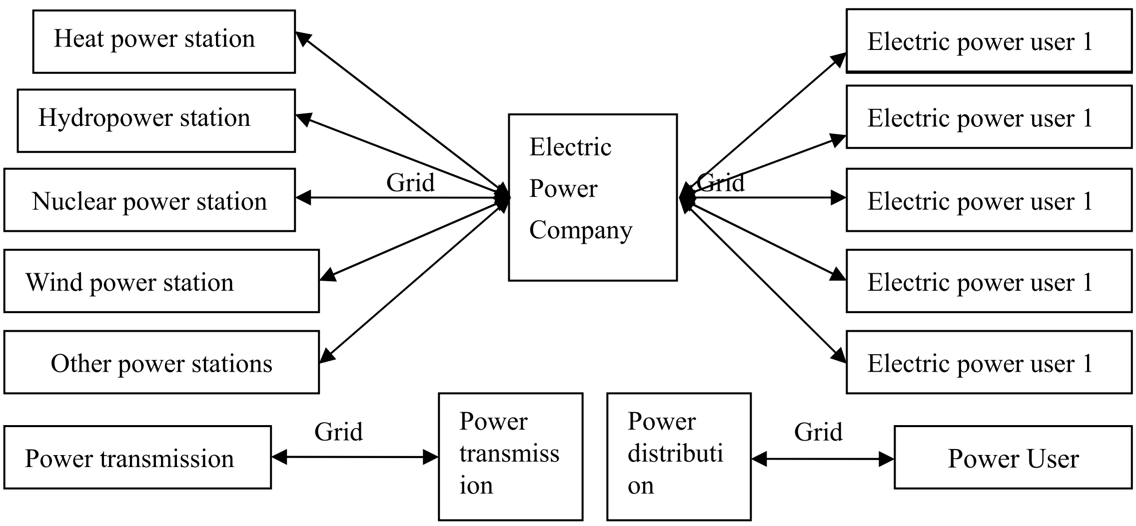
5.1 Network and Grid

5.1.1 Power Industry Chain

Electric power is notably featured with network system. Electric power industry chain is an important part of the power network and it is based on grid. The development of grid has a direct impact on the progress of the national economy; however, its development is significantly influenced by the environment due to its strong external characteristics.

In general, a complete chain of the electric power integrates power generation, power transmission, power distribution and power utilization together (shown in Figure 5-1)

Figure 5-1 Electric Power Industry Chain



From Figure 5-1 we can see that:

(1) Currently the power generation is mainly achieved by the way of thermal (combustible materials such as coal) power generation, solar power generation, large capacity wind power technology, nuclear power generation, hydrogen power generation, hydropower generation, fuel cells (fuel cells is class I electrical energy by directly converting the chemical

energy of fuels such as hydrogen, natural gas, gas, methanol, hydrazine into electrical power) and bio-energy power generation. Power station construction is implemented according to the energy distribution. In addition, power generation is in cyclical fluctuation mainly affected by the characteristics of the power generation energy, thus it is very instable (China Electricity Council, 2010).

(2) As for electric power utilization, electric power users can be divided into the primary industry electric power user, secondary industry electric power user, the tertiary industry electric power user and residential electric power user. Electric power users are located in different geographic positions; the demand for electric power is fluctuated according to the specific circumstances of production and life (China Electricity Council, 2010).

(3) It contains two processes of electric power transmission and distribution for the successful transmission of electric power from the power station to the final user. It is connected mainly through the grid which acts as a power transmission medium. The grid structure is a huge and complex system because the geographical span between the station and the user is very large (up to thousands of kilometers) and the power station and users are scattered in point-style. The power company must manage the transmission and distribution in the course of power transmission.

(4) The grid plays an important part in the electric power industry. It directly affects the entire process from the electric power generation, transmission to the final use and fundamentally affects the entire national economic development. It is clear that the power industry is notably featured as a network system, thus it is particularly important for research on the network-industry-based grid development strategy.

5.1.2 Challenges of Network Industry and Grid Enterprises

(1) Network industry

Water network, river network and road network are traditional “network industries” and we are very familiar with them. The network industry is pushed to the extreme by networks such as telecommunications, electric power, computers, internet, and the internet of things.

(2) Network effect

The network economy produces significant network effect which is also called positive feedback effect, or demand scale effect, or Metcalfe's Law[11]. Network effect largely depends on the number of external network users. It is featured with network externalities, the greater the network size, the greater is the value of networks and network users, and the more the internet users can be attracted to join the network; if nobody use the network products, its value will be reduced, the less will be its network users, and the network effect can not be reflected. Network industries such as communication network, internet and grid have significant network effects.

The network has a locking effect in addition to a positive feedback effect. The so-called locking effect means that economic agents are limited to original technical networks or locked in the original operating platform due to their bounded rationality or their inefficiency in foreseeing the future. Network locking effect is often associated with switching costs or conversion sunk costs in addition to thought and behavior set, for example, the conversion from an old solution to another new solution needs to pay a huge cost and it is difficult to convert and is locked due to asset specificity (including specificity of human capital, skills). People in the network industry are often faced with the difficult situation where you are free in choosing but locked after making a choice.

(3) Power network

Power network or electric power system is the energy production and consumption system composed of power generation, power transmission, power substation, power distribution and power utilization. Comparing with traditional network industry, power network is very unique.

Fisrt, the production and consumption of electric power system is different from that of general commodities. In the production and consumption system of general goods, commodities can be reserved during production, consumption and distribution or even reserved by other systems such as national reserves, strategic reserves, international and domestic futures markets and trading in order to achieve the supply and regulation of

[11] Matcalfe Law：refers to the value of network increase at the squre speed of number of users.

production and consumption. However, the electric power system can not realize mass storage of power due to the current level of technology and equipment, so the production, transmission, distribution and consumption are completed at the same time. The requirements for the security and stability of electric power transmission have been greatly increased due to the simultaneousness of power supply and demand, power production and consumption.

Second, it is strictly required for dynamic matching and transient response in the electric power system considering the simultaneousness of power supply and demand, power production and consumption, especially the characteristics of electric power production and consumption in order to maintain the security, stability and continuous operation of the electric power system.

There are different power supplies in the electric power system especially in the power supply side of a large electric power system, including big and small heat (coal) power stations, big and small hydropower stations, nuclear power stations, wind power stations, solar power stations, etc. power supplies of different sizes, grades and types have different power production characteristics (consuming different power resources and resulting in difference in the power resources conversion efficiency, supply uncertainty and fluctuation, power supply cost and the electric power supply elasticity).

Different power loads or power users have different power consumption characteristics (including amount of consumption, consumption time and elasticity of electricity consumption demand). Electric loads include asynchronous motors, synchronous motors, various types of electric arc furnaces, rectifiers, electrolytic devices, refrigeration and heating equipments, electronic equipments and lighting facilities, especially a large number of non-linear impact load, such as scale power electronic devices (energy-saving devices, frequency conversion equipments), high-power electric drive equipments, the DC output devices, electrochemical industry equipments (rectifier of the chemical and metallurgical enterprises), electrified railways, steel making electric arc furnaces (AC, DC), mills, elevator, calcium carbide machines, induction heating furnaces and other nonlinear loads. In controlling and handling of power by nonlinear impact load of new electrical equipments, it is inevitable to produce non-sine wave current and to inject harmonic current into the grid resulting in a variety of power quality disturbance like voltage fluctuation and transient pulse or even leading to a major accident in the electric power system operation.

Third, as the power points and the load centers are mostly located in different regions, there is not only difference in the characteristics of the power supply and user load in the electric power system, moreover, it is inevitable to have temporal and spatial dislocation in electricity and electrical energy structure and uncertainty and fluctuation in supply and demand on the power generation side and demand side. The grid should be dispatched in order to optimize and coordinate the electric power consumption structure, balance and optimize the electricity demand and improve the efficiency of electricity consumption. Therefore, it requires a unified dispatching system.

Fourth, the electric power system itself especially the power transmission network externality has turned the power transmission network into the weak link in the system.

(1) The modern electric power system is regional and even transnational and it is getting bulkier and more complicated. Hundreds of interwoven network nodes in the power network may transport a lot of power and create great wealth, but they are also possible to cause major catastrophic accidents in an instant. All kinds of automatic control devices and communications systems must be equipped in all links and on different levels of the power network as the information and control subsystem in order to ensure the safe, stabile and economic operation of the system. The information and control system in electric power system consists of a variety of testing equipments, communication equipments, security devices, automatic control devices and automotive monitoring and scheduling systems in order to measure, regulate, control, protect, communicate and schedule the electricity production and transport processes and to ensure users to get safe, economic and qualified electric power.

(2) In the internet era, the internet has become the most important basic industry. Development of networks and the network industry has greatly promoted the development of social and industrial departments, showing a good externality. On the other hand, the network has become increasingly regionalized, nationalized and internationalized and it is getting bulkier and network structure is more and more complicated in order to obtain greater

network effects. However, the network is not therefore stronger; on the contrary it is getting more and more “vulnerable”. The loss brought about by network destruction is far beyond the network itself and it is enlarged rapidly because of the “network effects”. The destructed network turns to be the “Achilles heel” of the socio-economic system which is most vulnerable to natural disasters, war and the terrorist attack. For example, the blizzards in early 2008 south of Chinese mainland resulted in shutdown of 36740 power lines of 10 kV and above and 1743 substations of the China Southern Grid and State Grid Corporation, resulting in blackout of more than 100 million populations in 33.48 million households. Another example is the America and Canada blackout on August 14, 2003. In only 9 minutes, dozens of transmission lines, one hundred power plants, including 22 nuclear power plants, and large generating units of installed capacity up to 61 800 MW were cut-off. All of these accidents have shown that it is more difficult to protect the security and stability of power system operation.

As the research objective of this thesis, Sichuan has a complex power management system and grid structure, which has greatly increased the difficulty for network security, stability and economic operation. Therefore, the modern grid should become stronger and more flexible and intelligent. The basic measure to achieve the above objectives is to upgrade the existing grid and build a modern smart grid.

5.2 Challenges Faced by the Grid

The modern grid is getting bulkier, but the flip side is that it is increasingly vulnerable. The security and stability, which are the two basic indicators of grid operation, are faced with stronger challenges. It is a very important task for the grid and the grid enterprises to meet these challenges for sustainable development.

5.2.1 Power Plants and Transmission Power Consumption

Energy saving and emission reduction (energy conservation, reduce emission of waste gas waste liquor and waste residues that damage the environment and ecology) is the urgent task for the whole society and power enterprises, including grid enterprises.

Electric power is the energy or the "motive power" for social development and the electric power enterprises are the economies to provide the energy or the development. However, the power industry and power enterprises are at the same time the power guzzlers and bring most of environmental and ecological problems. The problem is analyzed in the following part by taking two of the consuming countries in global power production and consumption (the U.S. and China) as example. Table 5-1 shows the power consumption and sulfur dioxide emissions in the U.S. power industry. Table 5-2 is the statistics of power consumption of China power industry.

Table 5-1 The consumption and emission in the U.S. electric power industry

Index	Unit	1990	1995	1996	1997	1998
Sales of electric power	Million KWh	2683976	3007469	3093984	3138603	3264231
The proportion of domestic consumption	%	34.06	33.24	33.60	32.88	33.43
Service power rate	%	5.86	5.83	5.79	5.83	5.90
Loss of power in transmission and distribution	Million KWh	276800	248800	252400	217700	228500
loss rate of power in transmission and distribution	%	9.26	7.35	7.27	6.24	6.34
U.S. SO2 emissions	Kiloton	20925	16881	16666	17085	17181
Among them: the power plant emissions	Kiloton	14433	10959	11582	11970	12171
The proportion of power plant emissions	%	69.0	64.9	69.5	70.1	70.8
Index	Unit	1999	2000	2001	2002	Accumulation
Sales of electric power	Million KWh	3312087	3421414	3369781	3462521	28754066
The proportion of domestic consumption	%	33.1	33.22	33.84	35.63	33.68
Service power rate	%	5.38	5.82	3.32	4.75	5.36
Loss of power in transmission and distribution	Million KWh	297200	229100	219200	288600	2258300
loss rate of power in transmission and distribution	%	7.97	6.00	5.89	7.50	7.85
U.S. SO2 emissions	Kiloton	15856	14767	14413	13847	147621
Among them: the power plant emissions	Kiloton	11416	10339	9843	9338	102051
The proportion of power plant emissions	%	72.0	70.0	68.3	67.4	69.1

Source: prepared according to the data in "China Statistical Yearbook" and "International Statistical Yearbook".

It can be seen from Table 5-1 that from 1990 to 2002, the U.S. power plant power consumption makes up 5.36% of the total consumption (it had always been close to 6% in the 1990s), accounting for almost 1/6 of the total consumption in the U.S. people's lives. The grid is the first consumption industry in the U.S. The loss of power on grid during transmission is as high as 7.85% of total social consumption. The U.S. power plant emissions of sulfur dioxide accounts for 69.1% of the country's total sulfur dioxide emissions, consuming a lot of power. Thus, it is a genuine power guzzler and primary pollution emitter.

It can be seen from Table 5-2 that China power plant power consumption makes up 6.1% of the total comsumption of the country during the 20 years from 1990 to 2010. The power loss on transmission line is 7.3% and the power industry consumption is up to 13.4%.

Table 5-2 China power industry power consumption

		1990	1995	1996	1997	1998	1999	2000	2001	2002
Installed power generating capacity	10000 kilowatts	13789	21512	23444	25214	27495	29640	31689	33849	35300
Generating capacity	100 GWh	6213	9942	10650	11198	11431	12176	13510	14839	16541
Power plant power consumption rate	%	6.9	6.8	6.9	6.8	6.7	6.5	6.3	6.2	6.3
Line loss rate	%	8.1	8.8	8.5	8.2	8.1	8.1	7.7	7.6	7.5
Power industry loss	%	15.0	15.6	15.4	15.0	14.8	14.6	14.0	13.8	13.7
		2003	2004	2005	2006	2007	2008	2009	2010	Average
Installed power generating capacity	10000 kilowatts	38212	44070	50841	62210	71329	79250	87407	96219	---
Generating capacity	100 GWh	19110	21943	24747	28344	32559	34334	35965	42880	---
Power plant power consumption rate	%	6.5	6.3	6.1	6.0	5.9	5.9	5.7	5.7	6.1
Line loss rate	%	7.9	7.6	7.2	7.0	6.9	6.8	6.6	6.5	7.3
Power industry loss	%	14.4	13.8	13.2	13.0	12.8	12.6	12.3	12.1	13.4

Souce: prepared according to the data in "China Power Statistical Yearbook" and "China Statistical Yearbook".

Let us look at China power industry pollution emissions. Table 5-3 shows that during the 15 years from 1995 to 2009, the power industry is the largest emission source or pollution source for the five pollutant emissions, especially the emission of industrial waste gas, industrial dust, sulfur dioxide and other gaseous pollutants. The sulfur dioxide emission is more than 55% of the country.

Table 5-3 Proportion of pollution emissions in China power industry

The proportion of the power industry	1995	1996	1997	1998	1999	2000	2001	2002
Industrial added value	7.91	7.31	8.20	9.66	10.02	9.17	9.52	9.59
Solid waste emission	18.82	19.94	21.57	14.87	15.44	16.27	18.19	19.29
Industrial toxic emission	35.52	38.49	34.77	34.6	34.33	35.12	33.27	33.32
Sulfur dioxide emission	51.09	56.43	56.55	43.67	44.17	42.41	53.89	55.01
Industrial dust emissions	53.03	59.24	49.81	28.63	31.67	31.21	43.67	45.32
Industrial wastewater discharge	9.32	12.51	10.55	10.62	10.68	9.73	11	10.21
	2003	2004	2005	2006	2007	2008	2009	Average
Industrial added value	8.59	8.96	7.92	7.59	7.54	7.26	6.93	7.90
Solid waste emission	22.11	21.01	20.62	20.51	22.88	23.48	23.67	19.91
Industrial toxic emission	34.17	33.62	32.96	33.51	31.25	30.08	30.95	33.73
Sulfur dioxide emission	57.97	56.97	58.93	58.14	56.6	56.48	56.01	53.62
Industrial dust emissions	46.89	43.8	47.4	44.74	42.65	41.42	40.79	43.35
Industrial wastewater discharge	13.66	12.72	11.63	10.44	7.92	8.36	7.13	10.43

Source: prepared according to the data in “China Environment Yearbook”, “China Power Statistical Yearbook” and “China Statistical Yearbook”.

In comparing Table 5-1 and Table 5-3, we can see from the data alone that if we take sulfur dioxide emission as an example, the proportion of China power industry emission to the whole country emission is not as large as that of U.S. power plants. This does not mean that China power plant emission is smaller than U.S.; instead, it may because that the emission amount over China (including the amount of sulfur dioxide) is very big and the proportion of sulfur dioxide emissions of the power industry is dragged down. Therefore, it is a very urgent task for power countries like China and U.S., especially for the large developing country–China, to carry out energy conservation all over the country, including the power industry.

Table 5-4 is made in order to further compare the power consumption of economic development and sulfur dioxide emissions of power industry in China and U.S.

It can be seen from Table 5-4 that the economic gap between China and the U.S. Chinese has been sharply narrowed by China’s rapid economic development. In 1990, Chinese GDP accounted for only 6.73% of U.S. GDP; this ratio rose to 9.82 percent in 1995 and it has been continuously improved throughout the 1990s. Entering the new millennium, especially after 2004, the proportion of Chinese GDP in the U.S. GDP was increased rapidly, reaching

16.56%. From 2008 to 2010, it rose from 29.45%, 35.85% to 41.50%, and the Sino-US gap was narrowed rapidly.

People have a strong feeling of the electricity consumption and waste of high-emission in addition to Chinese rapid economic development: the proportion of Chinese power to the U.S. power is generally 2 to 3 times of the proportion of Chinese GDP to the U.S. GDP. The proportion of sulfur dioxide emissions of Chinese power industry to the sulfur dioxide emissions of the U.S. electric power industry is 5 to 8 times of the proportion of Chinese GDP to the U.S. GDP, 2 times the proportion of Chinese power to the U.S. power. High resource-consuming and high pollution emissions in Chinese economic development are further displayed.

Table 5-4 Comparison between China and the U.S

China / the U.S.	1990	1995	1996	1997	1998	1999	2000	2001	2002
GDP	6.73	9.82	10.92	11.43	11.59	11.58	11	11.39	11.91
Generating capacity	19.43	27.75	28.96	30.28	29.84	31.11	33.56	38.66	41.08
Sulfur dioxide	70.5	83.23	77.78	81.71	92.87	91.02	96.23	93.42	98.47
	2003	2004	2005	2006	2007	2008	2009	2010	2011
GDP	12.65	16.56	17.88	20.31	21.65	29.45	35.85	41.5	48.5
Generating capacity	47.13	53.19	58.13	66.44	74.59	81.07	86.73	95.73	105.2
Sulfur dioxide	108.93	129.35	148.37	172	226.72	223.92	236.82	248.31	265.2

Source: the table is prepared according to relevant data.

5.2.2 The Challenges of Using New Energy

The fossil-energy-based energy and power structure faces huge challenges due to the duel unsustainability of natural resources and environmental ecology. The basic measure to address this challenge is energy conservation. Pollutants are discharged to the environment by saving or reducing the energy and power consumption, thereby mitigating the environmental and ecological crisis.

However, in the “electrification” world of today, the power industry provides the most fundamental and important impetus for the modern society. Meanwhile, social development is still of overriding importance for most countries in the world especially for the developing countries. Therefore, the demand for energy, including the electric power, is rigid to a considerable degree, and it is a continuous and strong driving force for the development of the electric power industry. Moreover, the power industry is not only the producer and provider of power but also the largest consumer of power and the most primary source of environmental and ecological crisis. Therefore, the development of clean energy, renewable energy and green energy is not only an important part for the implementation of energy saving over the whole society but also the most important safeguards to achieve the sustainable development of power industry and energy conservation. New energy is the most important energy which is clean, green and renewable.

New energy, also known as non-conventional energy, refers to the energy that is at the beginning of development and utilization or under active study and needed to be promoted, such as solar energy, geothermal energy, wind energy, ocean energy, biomass energy and fusion energy. As we have mentioned earlier, due to the constraints in development and utilization of technology and resource, the proportion of power generated by new energy like biomass, tidal and geothermal energy is small at present and for a quite long time in the future, and it is still difficult to become the main power source. At present, the clean energy with a certain capacity mainly includes hydropower, nuclear power, wind power and solar power. There has already been lot of discussion on hydropower and it will not be discussed in detail here. The security of nuclear power development is under considerations and questioned due to the leakage of the Fukushima Nuclear Power Plant in Japan, and its development is impaired. Therefore, the new energy in this thesis mainly refers to wind power and solar photovoltaic energy system (generally speaking, wind power and solar photovoltaic energy system are of fluctuation and uncertainty due to the constraints of the geography, climate and other factors. The impact of new energy to grid is investigated by taking wind power as an example).

Wind energy is an energy resource and is rich in reserve. The global wind energy is about 2.74 × 109MW, among which the exploitable energy is 2 × 107MW, being 10 times more than the total exploitable hydropower on Earth. Wind energy has been used for a long time. As early as 8000 years ago, the ancient Egyptians created a simple sailing to sail in the Nile by wind. Chinese people used sailing to transport goods on the river in the Shang

Dynasty over 5,000 years ago. The use of wind energy is later extended to flour and rice grinding, pumping and irrigation through windmills. In the 16th century, the Dutch established a large number of windmills in the coastal areas for land expansion. 1/4 of the country was finally reclaimed from the shallow sea and low-lying beach in the western and northern parts by using windmill for drainage.

Human use of wind power began in the second half of the 19th century. In 1888, Danes F. Bloushi invented the first direct current wind generator. It is of great significance though it is just experimental, as it marked the possibility of transformation of natural wind energy into secondary energy – electric power. In 1891, the Danish professor Lakuer built the world's first wind power plant with a power generating capacity of 9 kilowatts. Wind power makes the first appearance on the world energy stage. In the early 20th century, Netherlands, France and other European countries also joined in wind power development. In the 1930s, countries like Denmark, Sweden, the Soviet Union and the U.S. successfully developed the small-scale wind power generation equipment for use in the windy islands and remote villages. The power generation cost is much less by small wind turbine than by small internal combustion engine. However, the generating capacity is small and mostly less than 5 kilowatts.

In general, gentle breeze is valuable for use. However, only when the wind is at a speed greater than 4 meters per second can it be suitable for power generation from the economically reasonable point of view. The output power of a 55 KW wind turbine at the wind speed of 9.5 meters per second is 55 KW, 38 KW at the wind speed of 8 meters per second; only 16 KW at the wind speed of 6 meters per second and it is only 9.5 KW at the wind speed of 5 meters per second. It is clear that the greater the wind, the greater are the economic benefits.

As a clean renewable energy, wind power attracts more and more world attention with the continuous depletion of fossil energy resources and the resultant environmental and ecological crisis. The power of the wind power installations is continuously increasing. Foreign countries have already manufactured 15 KW, 40 KW, 45 KW, 100 KW, 225 KW wind turbine in the 1980s. Currently, the power of commercialized and industrialized wind turbine has been improved to 1.5 ~ 2.0 MW. The power for the wind turbine for mass production is up to 5 MW, 6 MW 7 MW and even 8 MW.

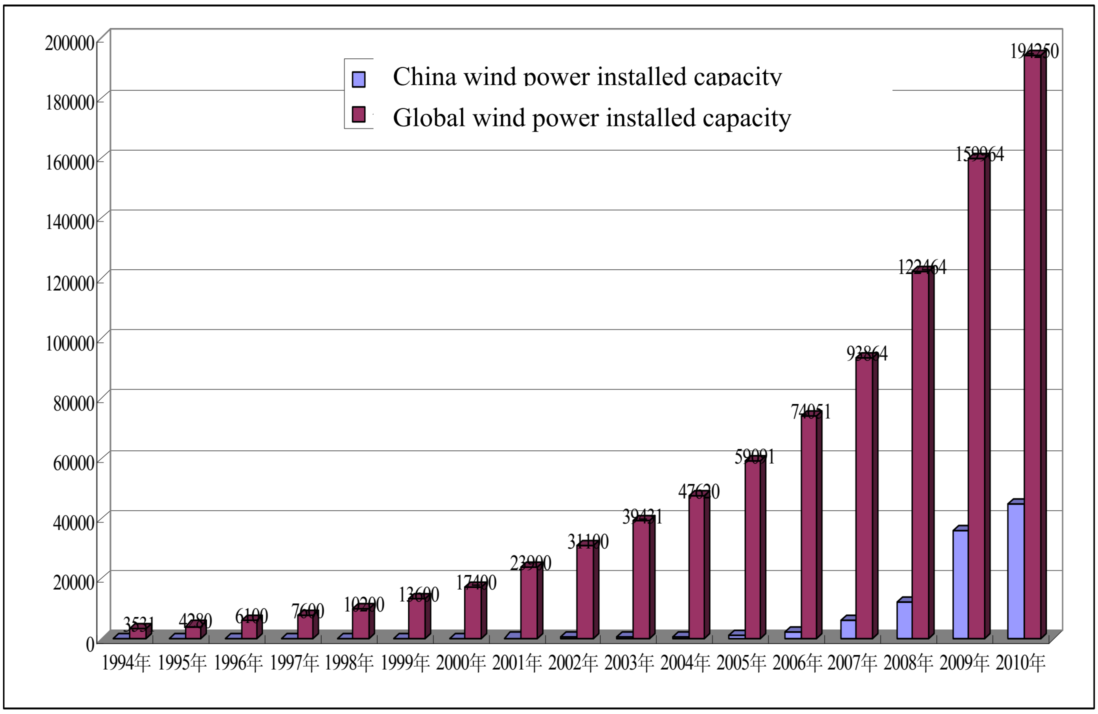
In January, 1978, the U.S. built a 200 KWwind power generator in the town of Clayton, New Mexico. The rotor diameter is 38 meters. In the summer of early 1978, the wind power installation was put into operation in the west coast of Jutland in Denmark. It has a generating capacity of 2,000 KW and a windmill height of 57 meters; at the first half of 1979, the U.S. built the world's largest power generation windmill in the Blue Ridge Mountains of North Carolina. The windmill is as tall as a 10-storey building and the windmill steel blades are 60 meters in diameter. The windmill can rotate freely to receive power from any one direction because the blades are mounted on a tower-shape structure. The generating capacity is up to 2,000 KW at the wind speed of more than 38 km. In 2004, Germany built the world's largest wind turbine. The wind turbines is 120 meters high, the diameter of blades on the rotor is 126 meters. Its rotor area is 126 m in diameter and equals to two football pitches. The total weight of generator tower and generator is 1,100 tons. The generator is driven by three rotors, each of which is as long as 61.5 m. The distance from the highest point to the ground is 183 meters. The generator output power is 5 MW. In 2008, the power of the world's largest wind power generator was up to 7 MW. In the 21st century, the global wind power has been developed more rapidly. Figure 5-2 shows the Global and Chinese wind power installed capacity from 1994 to 2010. Table 5-5 show 10 countries with the largest installed wind power capacity all over the world.

Table 5-5 The 10 countries with the largest installed wind power capacity all over the world

MW	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Global	24390	31228	39431	47317	59084	74223	94,122	120791	159213	199520
The U.S.	4275	4685	6374	6725	9149	11603	16818	25170	35159	40274
Germany	8754	11994	14609	16629	18428	20621	22247	23903	25777	27364
Spain	3337	4825	6203	8263	10027	11615	15145	16754	19149	20300
China	400	468	567	764	1260	2604	6050	12210	36010	44781
India	1502	1702	2125	3000	4430	6270	8000	9645	10925	12900
Italy	682	788	905	1,265	1717	2123	2726	3736	4850	5793
France	85	148	253	386	757	1567	2454	3404	4521	5961
Britain	474	552	667	907	1353	1963	2389	3241	4092	5862
Denmark	2489	2889	3116	3118	3122	3136	3125	3180	3497	3805
Portugal	127	195	296	522	1022	1716	2150	2862	3535	3837

Source: same as Figure 4-6.

Figure 5-2 Schematic diagram of Global and Chinese wind power installed capacity



Source: “China wind power research report” by Corporate Research Center at University of Electronic Science and Technology of China

However, wind power is directly affected by the change of season, topography, and geography and climate. The wind power changes significantly within a few minutes from year to year, from quarter to quarter, from month to month, from one period to another period of the 12 two-hour periods of the day, and even from one hour to another hour in a single day. This may lead to fluctuation in wind power generation. This will bring adverse or even catastrophic consequence to the stability and safe operation of the grid.

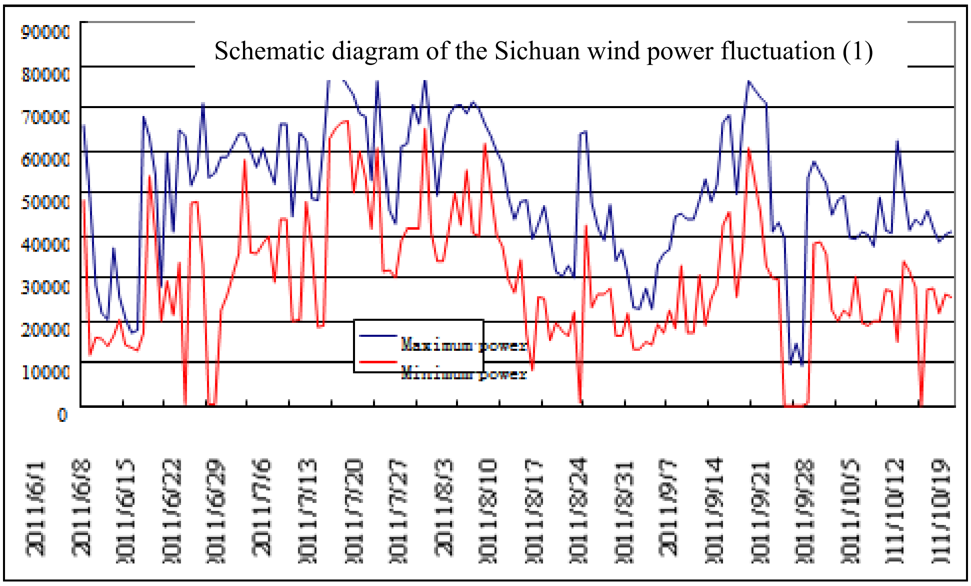
Theoretical reserves of wind energy resources in Sichuan Province are 88.35 million KW and they are mainly distributed in the three ethnic minority areas in western Sichuan plateau. The provincial centers of the maximum wind speed are mainly distributed in three regions of western Sichuan plateau and mountain regions: 1. the Anning Valley centered on Dechang County; 2, the Minjiang Valley centered on Mao County; 3.the Dadu River Valley centered on Danba County. Among them, the wind resources in the Anning Valley are the most valuable for development. A brief analysis of the fluctuation of the wind energy in Sichuan is given with the wind resources on Dechang wind farm at Anning Valley in order to get an intuitive understanding of the wind power fluctuation.

We have conducted a simple analysis on the data of wind power generation at Dechang wind farm from June 1, 2011 to October 24, 2011 (hourly data and data every 15 minutes). The maximum power output, the minimum power output, average power output and power output range(between the maximum power output and the minimum power output) are analyzed respectively on a day sharing basis, resulting in Figure 5-3 and Figure 5-4: the schematic diagram of the wind power fluctuation in Sichuan province.

It can be seen from Figure 5-3 and Figure 5-4 that fluctuation in wind farms in Sichuan is very frequent and severe. We can make a more detailed analysis in addition to the overall understanding of the wind power fluctuation.

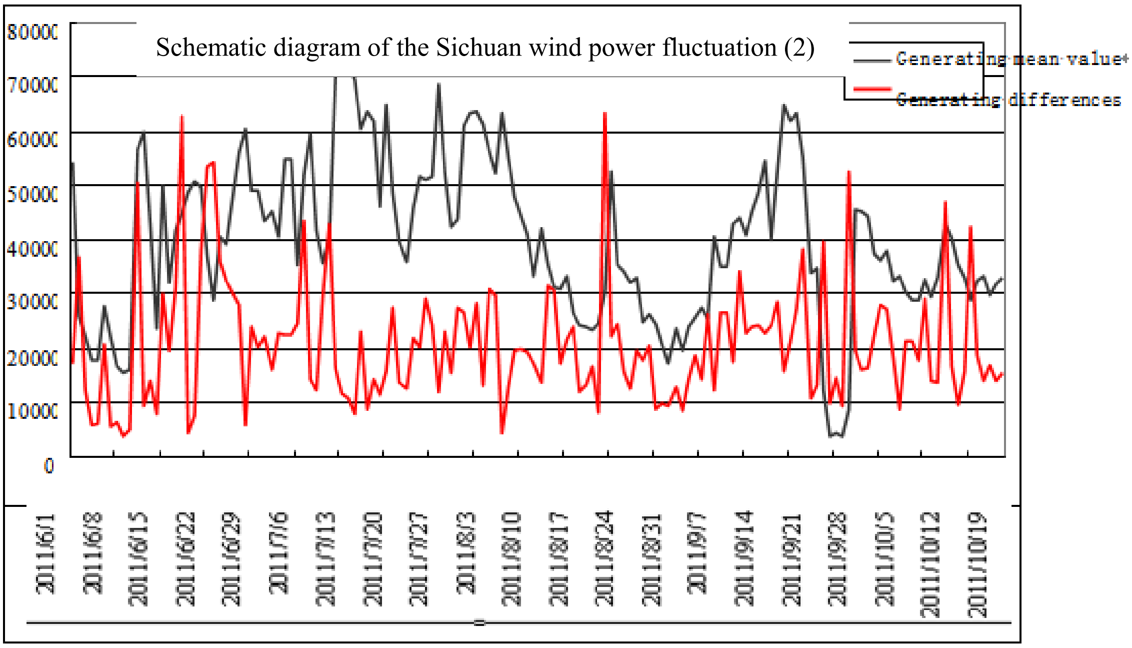
During the period from June 1, 2011 to October 24, 2011, a total of 144 dates, excluding the individual date with seriously missing data, were taken into calculation, and we take the limit degree (refers to the power output range / average power output, indicating the fluctuation) as an indicator to examine Sichuan wind power fluctuation. The data processing results show that the limit degree of 70 dates is more than 50%, accounting for nearly 50% of the dates; the limit degree of 14 dates is more than 100%, accounting for nearly 10 % of the dates. The largest limit degree is 604.87%, which is six times the average value; the fluctuation is extremely large (see Table 5-6).

Figure 5-3 Schematic diagram of fluctuation in the power output of wind energy resources in Sichuan



Source: prepared according to data of Dechang wind farm in Sichuan.

Figure 5-4 Schematic diagram of fluctuation in the power output of wind energy resources in Sichuan



Source: prepared according to data of Dechang wind farm in Sichuan.

Table 5-6 Typical inspection of the day sharing fluctuation of wind farm in Sichuan

Date	Average power output	Standard deviation	Range	Coefficient of variation	Limit degree
2011-6-2	26056	8058.8	36876	0.3093	141.53
2011-6-18	44832.9	21861.9	62816	0.4876	140.11
2011-6-22	37063.6	17787.6	53423.1	0.4799	144.14
2011-6-23	28865.8	19069	54185.9	0.6606	187.72
2011-7-11	40636.4	8594.7	42824.7	0.2115	105.38
2011-8-23	30501.4	20450.9	63216.6	0.6705	207.26
2011-9-8	25339.3	6525.3	26233.4	0.2575	103.53
2011-9-26	12146.5	15935.4	39568.9	1.3119	325.76
2011-9-27	3840	2770.9	9831.6	0.7216	256.03
2011-9-28	4285.9	4772.7	14719.5	1.1136	343.44
2011-9-29	3893.5	3677.1	9317.9	0.9444	239.32
2011-9-30	8706.9	10313.9	52665.7	1.1846	604.87
2011-10-15	42817.8	12496.6	47139.4	0.2919	110.09
2011-10-19	28975.4	11994.3	42250.4	0.4139	145.81

Source: prepared according to the data of Dechang wind farm in Sichuan

It can be seen from Table 5-6 that the fluctuation of wind power in Sichuan is embodied in the frequent occurrence of limit degree and the great value of limit degree. It is also reflected in the table that the coefficient of variation is much higher than the index of the general system, thus the risk is very high. Such a huge fluctuation has posed a serious challenge to the stable and safe operation of the grid.

The fluctuation analysis of wind power in Sichuan mentioned above is just on a day sharing basis. The day sharing fluctuation is prepared from the data of time points during 24 hours a day. In fact, the actual fluctuation has already been "ironed" during the analysis of the 24 hours time-point data. Therefore, the "actual" fluctuation may be much beyond the situation under investigation. The situation will be explained through a simple analysis in the following part.

Some typical data of the wind power in Dechang wind farm are selected from the day sharing and timesharing data to reveal the micro (instantaneous) fluctuation of Sichuan wind power, including the timesharing data between 5:00 and 11:00, from June 18, 2011 to June 19, 2011, the timesharing data between 0:00 and 6:00, from June 22, 2011 to June 23, 2011, the timesharing data between 7:00 and 13:00, from September 25, 2011 to September 26, 2011. They are shown in Table 5-7.

It can be seen from Table 5-7 that the power fluctuation at the same time point of 6:00 on June 18, 2011 and June 19, 2011 is up to 118.7 times, while the power fluctuation between 5:00 and 6:00 on the same day of June 18, 2011 is 151.3 times; Similarly, you can see from table 5-7 that the fluctuation between 0:00 to 6:00 on June 22, 2011 and June 23, 2011 is between 14 and 152.7 and the maximum fluctuation is 152.7 times at 5:00; the fluctuation between 8:00 to 13:00 on September 25, 2011 and September 26, 2011 is between 45 and 130.3, and the maximum power fluctuation is 130.3 times at 8:00; the fluctuation between 7:00 and 8:00 on the same day of September 26, 2011 is 110.3 times. These fluctuations are much larger than those shown in Figure 5-3 and 5-4 and Table 5-6. Thus we can roughly see the real fluctuation ratio of the wind power in Sichuan.

Table 5-7 Comparison of typical time-point fluctuation of wind farm in Sichuan

Date	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**
2011/6/18	**61272.5**	**404.9**	1060.6	742.4	497.1	34040.6	33977
2011/6/19	47479.5	48068.1	47913	50012.9	49484	48716.4	49034.5
A	0.775	118.703	45.177	67.367	99.537	1.431	1.443
Date	**0:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
2011/6/22	52000.5	50693	51599.8	53644.1	53107.2	51544.1	50983.4
2011/6/23	**3722.6**	**879.3**	1495.4	454.5	497.1	337.5	447.4
B	13.969	57.652	34.505	118.018	106.825	152.744	113.945
Date	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**
2011/9/25	34424.6	35834.3	36220.4	37381.0	33586.8	34002.8	31714.0
2011/9/26	**30330.1**	**275.0**	795.4	469.4	307.9	515.9	430.0
C	1.135	130.307	45.536	79.629	109.082	65.904	73.758

Note: A, B, C respectively refers to the ratio of the wind farm wind power at the same time point.

In addition, the region, where is rich in wind resource, is often in very bad natural conditions and it is difficult to become a power load center, thus wind power generation often requires long-distance transmission. High fluctuation and long-distance transmission of wind power poses a severe challenge for the safe and stable operation of grid.

5.3 Development of Smart Grid: Basic Countermeasures in Response to Challenges

5.3.1 Construction of China Smart Grid

In the “Eleventh Five-Year Plan” (2006-2010), electric power construction in China developed in leaps and bounds, with notable improvement of electric equipment and significant achievements in energy saving and consumption lowering. By the end of 2010, the total installed generating capacity has reached up to 970 millionKW and annual generating capacity to 4.2 trillion KWh, both ranking the second in the world for 15 consecutive years. Furthermore, the grid scale leaped to the first place all over the world.

In spite of rapid development, China's electric power system still presents high consumption and high emission. Based on the data from BP, in 2010, China has increased by 11.2% in terms of energy consumption against the previous year, surpassing that of America and becoming the largest energy consumer in the world. In the “Eleventh Five-Year Plan”, China’s installed generating capacity has increased over 400 million KW, equivalent to the sum in the past 50 years. In 2010, the coal output toped approximately 3.2 billion tons, which grew by 1.5 times as compared with the output in 2005. In 2010, the coals consumed by the coal-fired generating unit were about 1.73 billion tons, increased by 11.4% against the previous year and accounting for over half of the total coal consumption in China. As is known to all, considerable coal is consumed in the electric power industry, producing plenty of hazardous substances, CO_2, SO_2, industrial smoke and dust, for instance. From the data published by the World Bank, CO_2 emission was about 7.5 billion tons in 2010, accounting for 25% of the global emission (The population in Chinese mainland takes up 19.6% of the world population and China’s GDP 9.65% of the global GDP). Therefore, China’s electric power industry is under enormous pressure in energy saving and emission reduction.

In line with the new energy (wind energy and solar energy in especial) development plan, by 2020, China will invest 1,500-1,800 billion RMB to construct along its coastline 3000-5000 offshore artificial islands which will be individually provided with 12,000-15,000 superconducting wind turbine generators. In this way, the installed wind power capacity may reach up to above 400 million KW. Besides offshore wind power and coastal wind power, China will vigorously develop such renewable energies as solar energy and wind energy in Inner Mongolia, Xinjiang, Ningxia, Gansu, Tibet Plateau and desert areas, for the purpose of an optimized energy structure and scientific and sustainable development of China’s electric power. It is estimated by the experts that by 2020, the installed capacity of China’s renewable energies will achieve 570 million KW, accounting for about 30% of total installed capacity and that an amount of 470 million tons standard coals can be reduced every year, reducing CO_2 emission by 1.38 billion tons.

The construction of smart grid is a significant measure for the scientific development of electric power, as it is beneficial to improve the transmission and service efficiency of power energies and to enhance the safety, reliability and economic efficiency of the grid operation. Also, with the construction of smart grid, advanced generation technologies in high efficiency are possible to be applied to the generation side for improvement of overall service efficiency of power generating equipment, for reduction of pollutant discharge and for energy saving, consumption reducing and environmental protection. Moreover, the construction of smart grid contributes to realization of flexible access and safe & stable transmission of clean energies.

To this end, smart grid adapts to China’s demands for sustainable development of energy in the future. Power generation with smart grid technology not only effectively improves the system's capacity of admitting clean energies, but also makes a great breakthrough in the efficiency of traditional power generation technologies. Viewed from the grid link, this technology is possible to lower the line consumption and improve the power transmission efficiency as well; while in terms of power distribution, it helps users to adjust their power consumption modes, improve the service efficiency and facilitate the access of distributed power sources so that the function of smart interaction and green energy saving can be fulfilled.

Distinguished from smart grids in America and European countries, China’s smart grid contains six links of the power system: power generation, power transmission, power transformation, power distribution, power consumption and power dispatching, featured by informatization, digitization, automation and interactively “smart”. In addition, primary energy and productivity development level are very imbalanced in China and 2/3 coal, wind, hydropower and solar photovoltaic generating resources are concentrated in the north and southwest; while 2/3 energy consumption is placed at the middle and eastern regions. Therefore, a strong EHV grid is required for long-distance transmission and extensive consumption of electric power.

State Grid Corporation of China (SGCC) is the major constructor for China smart grid. State Grid Corporation of China is a large energy supplier whose core businesses are investment, construction and operation of power network that covers 26 provinces, autonomous regions and municipalities. Besides, SGCC posses 675,000 km power transmission lines at 110 kv and above, with the transformation capacity of 2.35 billion kva. Its service area covers 88% of the national territory, serving a population of over one billion. Moreover, SGCC spreads its business over Philippines, Brazil and other countries. In 2010, SGCC’s annual electricity sales was 2.7 trillion KW, with revenues over 230 billion U.S.

dollars, and the company was ranked the 7th in the Fortune Global 500 in 2011. In May 2009, SGCC firstly put forward the strategic objective of constructing a strong smart grid with EHV grid as main grid, in cooperative development of all grids and featured by informatization, automation and interaction. In this aspect, significant achievements have been made through practices in several years. To achieve this objective, the following key points shall be stressed: (i) A completely strategic planning system of a strong smart grid was shaped; (ii) EHV AC and DC demonstration projects were successfully constructed; (iii) The smart grid project was carried out in a systematic way; (iv) A test and research system characterized with sound functions and leading technologies was established; (v) An innovation and breakthrough was made to key technology and equipment.

By 2010, SGCC has, within its business scope, developed in total three batches, 29 categories and 287 smart grid trial projects and established the Smart Grid Research Institute, 4 test bases (EHV AC & DC, high altitude and engineering dynamics), 2 R&D centers (large grid simulation and DC package design) and 3 state-level R&D (test) centers (large wind-power network, solar energy generation and smart power consumption). Besides, the company completely grasped the core technology of EHV DC & AC power transmission and made a successful development on various EHV key equipment and elements including large-capacity transformer and 6-inch thyristor. In terms of the smart grid construction, SGCC was ranked the 1st in construction scale, application field and promotion speed.

In the “Twelfth Five-Year Plan”, the State Grid will invest 500 billion RMB to construct an EHV main grid shaped as “three horizontals and three verticals” connecting large energy bases and main load centers and a 13-loop long-distance AC power transmission project. At that time, a core world-class strong smart grid will be primarily constructed.

The construction of smart grid contributes to the development of China’s new energies, the transmission of electric power by long-distance, large energy and high efficiency as well as the safe and stable operation of the grid. Currently, China is ranked the first all over the world in terms of wind power installed and generating capacity, solar photovoltaic cell & generating equipment capacity and EHV technologies. Furthermore, the proportion of power loss during power transmission and distribution is decreasing, while the enterprise economic benefits are increasing. The two largest grid corporations in China, namely State Grid Corporation of China and China Southern Power Grid are listed in Fortune Global 500, and they become higher and higher in the rankings. SGCC plans to invest 4.5 trillion RMB between 2011 – 2020 to build a Chinese style strong smart grid which is at international level in terms of information and communication platform and 6 application links including power generation, line, power transformation, power distribution, power service and power dispatching.

5.3.2 Construction of Sichuan Smart Grid

（1）Major Issues of Sichuan Power Grid

1）Although the power demands in Sichuan maintain a high growth rate, the power supply can still meet the demands in general. Affected by the structure of the power sources, the power supplied in winter is primarily sourced from coal power and other external power supply, and power supply is easily limited by the coal supply, so the short power supply may still occur in winter.

2）In recent years, Sichuan Electric Power Corporation still endeavors to speed up construction of power grids in spite of such difficulties as serious natural disasters, poor construction conditions and insufficient funds. However, the bacKWard development of the power grid constriction has not been improved fundamentally, the underdeveloped main transmission grid and the power distribution network are still rather serious, the capacity-load ratios are 1.79 and 1.82 respectively for the 500 kv and 110 kv power grids, the power supply in some areas can still not meet the demands, the supply safety of power grid, the power quality and the service level are required to be further improved. Specifically, the underdeveloped external transmission grid constraints the transmission of power in Sichuan to the east; thermal stability of some transmission and distribution equipment in the load center are still severe; the foundation is shaky for the safe and stable operation of reactive voltage of the power grid, and it results in the inadequate reactive power compensation in some areas and poor stability of the voltage, which affects the supply of power and safe operation of the power grid.

3）The complexity is increasingly grown for controlling the operation of the power grid in Sichuan as the mutual influence and interaction are significantly increased between the power grids within Sichuan and the outside grids and between the AC grids and the DC grids, and low-frequency oscillation of the grid (especially for the power grids in a large region) becomes increasingly prominent after the long-distance external transmission grids of the hydropower of Sichuan Power Grid are put into operation extensively and the large regional power grids are interconnected all over the country, especially the parallel operation of the AC and DC power grids is realized after the Xiangjiaba-Shanghai UHVDC transmission line is erected and put into operation.

（2）Elementary Objective of Sichuan Smart Grid Construction

1）Ensuring power supply

In recent years, Sichuan faces great energy tensions, for instance, coal and water shortage. By 2015, Sichuan's GDP is expected to surpass 3 trillion RMB. At that moment, the power consumption of the whole society will amount to 250 billion KW and the maximum load over 480 billion KW. The power quantity and insufficiency will be separately about 33 billion KW and 140 billion KW. Although Sichuan is abundant in hydroelectric resources and considerable hydropower is available in high water period, power shortage still occurs in draught period due to the hydropower’s nature of “rich in wet season but poor in draught season”. Hence, the construction of multi-provincial EHV grid with large capacity and in long distance shall be speeded up to offset the power insufficiency. On the one hand, redundant hydropower in wet season shall be transmitted from Sichuan’s west to east; on the other hand, the project of “Power from Xinjiang to Sichuan” shall be constructed to deliver rich coal and wind energies from Xinjiang to Sichuan via electric high-speed channels, realizing the purpose of the west-to-east power transmission and for optimizing resources in various regions to a maximum extent.

To ensure the power supply, Sichuan Electric Power Corporation will enlarge its grid investment and invest totally 100.3 billion RMB in the “Twelfth Five-Year Plan” to construct a smart grid with EHV as main grid, “large grid, large hub and large platform” and “western power development highland”. In that period, the largest provincial grid will be built in China.

2）Environmental protection

First of all, the construction of smart grid improves the grid’s capability to be compatible with the development of various clean energies, facilitates the development and consumption of clean energies and provides a platform for developing clean energies in a wide and high-effective way. Also, it plays an important role in the development of green economy. Secondly, the smart grid makes it possible for end users to use power energy in an effective and rational way, leading the transformation of energy consumption concept and mode so as to meet the requirements of green development. The construction of smart grid promotes user services in a friendly way as well as the development of battery charging technology, facilitates and accelerates the large-scale application of such smart equipment as low-consuming equipment and motor-driven autos and intelligent apparatus, effectively changing energy consumption mode of end users, improving the proportion of low carbon power in the end energy consumption, reducing the utilization of fossil fuels, and lowering the energy consumption and emission. Meanwhile, further improvement will be made to the grid operation mode and the users' electric energy application mode through enhancing the information integration and sharing between users and grids, so as to develop low carbon economy as well as energy saving and environmental protection in the long run.

3）Demands of industrial restructuring

Dependent on advantages of smart grid, energy gradient utilization and resource utilization in a high-effective and cycling mode shall be made, using the friendly interactive platform between users and the gird, to such industries as steel, non-ferrous, coal, chemical and building material under the leadership of the government, so as to improve the output of resources.

Advanced information, control and energy storage technologies shall be applied to the construction of a strong smart grid, realizing the interaction of each link in the grid as well as cooperative operation of concentrated energies and distributed power sources. Thus, overall improvement will be made to the grid in terms of its performance and diversified services. In the construction of smart grid, the smart construction at the user side concerns the immediate interests of every family. The reconstruction is mainly composed of smart transformation for electric equipment at the user side. A great promotion will be made to electric construction and rural water consumption mode in Sichuan Province by constructing a batch of smart communities and towns characterized by energy saving. Hence, the people's living standards will be improved and the development of the local economy will be promoted as well.

Besides, new economic growth will be achieved through the construction of a strong smart grid, promotion of the development of the related industries, facilitation of the employment and result of good economic and social benefits. With the construction of a strong smart grid, not only a driving force is made to the related traditional industries including the electric and mechanical and equipment manufacturing industry, metal smelting industry, rolling processing industry and metal product industry, but also quicken the development of new industries and hi-tech industries in relation to smart grid, for instance, new energy, new material, information network technology, energy saving and environmental protection. By changes in the power consumption mode, a huge market is indirectly created in the relevant industries such as intelligent appliances and green transportation, resulting in a significant leapfrog development opportunity of such industries as power, electronics, appliance, information and communication, control and motor-driven auto, as well as tremendous benefits in consumption and economic growth.

4）Demands of new energy access and energy saving and emission reducing

In total, 7 wind power stations are currently planned in Sichuan, with the generating capacity of 2.5 million KW.

Even though Sichuan has harvested substantial achievements in the “Eleventh Five-Year Plan” in terms of new energy development and utilization, wind energy, solar energy and biomass energy still remain a low pace in the development and utilization since some issues maintain unsettled in the aspect of distribution and development of Sichuan’s new energies and there is a relatively large gap in terms of new energy development and utilization as compared to those regions with a high development and utilization of new energy. For instance, wind energy and solar energy are distributed in an imbalance way, and the majority is concentrated in the river valley and mountains areas where road conditions and grid access are comparatively poor, with high constriction costs. In terms of biomass energy, materials cannot be continuously supplied due to weak cognition of the public and uncertain capital collection. Finally, the development of a strong smart grid will improve the access capability of various distributed power generations, promoting the development and utilization of traditional hydropower resources and facilitating the development of clean energies such as wind energy, solar energy and biomass energy. As a result, the purpose of energy saving and emission reduction is achieved, giving a good reply to the global warming.

（3）Phases of Sichuan Strong Smart Grid

The development phases of Sichuan strong smart grid is correspond to the three phases of the strong smart grid under State Grid, including:

1）Planning and Testing (From 2009 to 2010)

Strengthen all-level grid construction and perform research on application of critical, fundamental and general technologies; track the R&D results of applications of technologies for connecting power generated from wind into the grid, initially construct transmission line monitoring center, complete pilot projects of construction and reconstructing of smart substation and the power distribution automation of Chengdu (capital city of Sichuan), promote the practicability of SG186 marketing application system, focus on the construction of trial electricity-consumption information acquisition system required by State Grid, finish the pilot construction for electric vehicle charging station and AC charging station, set up a smart grid dispatching technology supporting system in provincial power dispatching center and complete “SG186”project.

2）Construction and Development (from 2011 to 2015)

Carry out specific research and technological applications related to wind power integration into the grid based on Dechang wind power pilot project, improve the provincial transmission line monitoring center, complete the construction of provincial transmission line monitoring centers in some areas, monitor the conditions of all 500 kv and 220 kv lines, advance the construction and reconstructing of smart substation in an all-round way, thoroughly promote key technologies of smart transmission equipment, update the functions of smart devices, continue to improve the construction of Chengdu distribution automation, and promote the standard distribution automation system in the central urban area of prefecture-level cities as well as the construction of urban grid GIS project.

Basically complete the construction of electricity-consumption information acquisition system for the user of direct-supply straight pipe, the pilot project of distributed supply connection and electric vehicle smart-charging service network, create a mature business operational pattern, set up a smart grid dispatching technology supporting system, built specified, unified and fully-covering transmission network, access network, management network and synchronization network for transmission and distribution telecommunication, and basically complete SG-ERP system.

3） Upgrading (from 2016 to 2020)

Assess constructional performance, improve and enhance the overall strengthen of smart grid on the basis of comprehensive construction. Set up transmission line monitoring system in all cities to monitor the conditions of all lines of more than 110 kv, complete the construction and reconstruction of intelligentizing all substations of 110 kv and above, establish management system for the operation of smart grid and smart equipment; comprehensively finish the construction of strong grid for distribution network, completely establish and improve electricity-consumption information acquisition system with coverage rate of 100%, provide the electric vehicle smart-charging service network for the whole province, set up user electricity-consumption geographic information system in this province, further strengthen and optimize the communications network, and establish SG-ERP system in an all-round way to make information platform reach to international advanced level.

（4）Construction and Performance of Sichuan Smart Grid

Sichuan is rich in hydropower resources, with theoretical reserves of 144 million KW and technical available resources of 120 million KW, both of which account for more than 1/4 of total amount in China, and the hydropower resources mainly are distributed in Dadu River, Chin-sha River and Ya-lung River. Three of thirteen state-planned major hydropower bases are located in Sichuan. By the end of 2010, the installed capacity of Sichuan Grid is 42.35 million KW, wherein the installed hydropower capacity has reached to 29.79 million KW. The power-transmitted surplus amounts of Sichuan in 2010, 2015 and 2020 will reach to 6.5 million KW, 20.8 million KW and 26 million KW. By 2015, the installed capacity of Sichuan Grid will exceed 90 million KW, wherein the hydropower capacity will reach to 76.29 million KW and the power transmission capacity of Sichuan will reach to about 33.3 million KW.

Sichuan Grid is featured with west-to-east power transmission, power transmission from Sichuan and long-distance and large-capacity power transmission. Due to historical reasons, power management system in Sichuan is complex, with great differences among different regions in terms of grid structure and load structure and level, as well as with a complicated relationship with power transmission network. The development of strong smart grid is particularly significant to Sichuan.

With extensive experience in aspects of control strategies, measuring technologies and digital and physical experiments, Sichuan Grid adopts serial compensation technology, SVC and FACTS technologies for high-power transmission lines, providing 500V substations and main power plants with phasor measurement devices, establishing dynamic monitoring system in dispatching center, forming a safe control system playing a great role in ice disaster and earthquake based on Ertan power transmission and power transmission from Sichuan to the east, as well as introducing a series of grid channel designs to the power transmission lines from Sichuan, including macroscopic and microscopic observation, reasonably planned channel, scientific delimitation of the ice, different line design and steel tower with unequal legs. Sichuan is equipped with infrastructure and conditions to construct smart grid.

In 2008, Sichuan electric power system suffered huge casualties and property loess in “5.12” Wenchuan Earthquake, with 755 people killed or missing, bringing about 32 power plants in western Sichuan disconnecte with the main grid, 289 power plants disconnect with local grid, with total outage capacity exceeding 8.43 million KW, including 3.978 million KW in the main grid and 4.46 million KW in the local grid. “5.12” Earthquake made 206 substations of more than 35kv and 1,264 lines of 10kv in Sichuan Grid out of service, directly inflicting economic loss of 60 billion RMB. In the earthquake-stricken areas, especially in worst-hit areas, the electric power system is almost damaged completely, 322 people of Sichuan Electric Power Corporation were killed or missing, bringing about outage of 1 substation of 500 kv, 5 substations of 220 kv, 68 substations of 110kv,123 substations of 35kv, 5 lines of 500kv, 59 lines of 220kv, 113 lines of 110kv, 104 lines of 35kv, and 683 lines of 10kv, with load loss of 4 million KW and direct economic loss exceeding 15 billion RMB, while for Sichuan local power industry, more than 400 people were killed or missing, 470 hydropower stations damaged, with installed capacity of 3.3 million KW, 49 local power enterprises affected by the earthquake in Sichuan Province, 41 county-level grid companies suffered losses, 457 lines of over 10kv out of service, with direct economic loss of 12 billion RMB, and more than 36 billion RMB required for the recovery of water-conservancy and power facilities. Sichuan electric system is under enormous pressure.

As the saying goes that crisis produces commercial opportunity, China has launched tremendous reconstruction projects, taking recovering, optimizing and upgrading the grid as one of critical projects; moreover, in order to cope with development difficulties (such as international economy downturn and sharp drop in world trade) brought by global financial crisis caused by U.S. subprime mortgage crisis, Chinese government has increased investments in the infrastructure including the grid with loose monetary policy and expansionary fiscal policy to stimulate domestic demands, thus speeding up the construction of the smart grid in Sichuan.

On September 29, 2010, 110kv Beichuan Smart Substation in Mianyang was formally put into operation and Mianyang also is the first county-level city with smart substation in China. Smart substation plays an important role in generating, transmitting, transforming, distributing and dispatching the electric power in the smart grid, and is regarded as one core platform for energy conversion and control in the construction of strong smart grid as well as a significant support the connection of wind energy, solar energy and other new energies with the grid. The completion of smart grid's "heart" proves that Sichuan has come out in front of the construction of smart grid in China. As one of first batch of smart substations put into operation, Beichuan Smart Substation, its operation indicates that China has been leading the way in smart substation technologies in the world.

On May 28, 2010, the operation of Chengdu Shiyang Electric Vehicle Charging and Discharging Station was taken as one of "Top Ten Livelihood Projects" of Chengdu in 2010, which indicates that the first electric vehicle charging and discharging station in Chengdu is successfully put into operation and that Chengdu is another city with model management of electric buss running following Beijing, Shanghai, Guangzhou and other metropolis. As an important part of smart grid planning, from 2010 to 2012, Sichuan Electric Power Corporation has invested not less than 4.5 billion RMB in the comprehensive construction of Chengdu electric vehicle charging facility system.

The performance of Sichuan Smart Grid is prominent, with such achievements as constructing domestic first smart substation and creating first-batch model city of electric bus running.

China Smart Grid, taking UHV grid as main grid, is committed to setting up a safe and reliable strong smart grid, low in cost, high in inefficiency, clean and friendly to the environment. In China, the understanding of strong smart grid is that strong is the foundation of the smart grid, as human body, smart is the key to putting the strong grid into operation, as the brain, and they complement and coordinate each other to achieve harmonization. Therefore, featured by west-east electricity transmission, power transmission from Sichuan to the east and long-distance and large-capacity power transmission, Sichuan has became the forerunner of UHV grid construction. In October, 2009, Deyang—Baoji ± 500kv DC transmission line connected Sichuan Grid with Northwest China Grid, in July, 2010, Xiangjiaba – Shanghai ± 800kv UHV DC model transmission project, which was completed in advanced, was put into operation. During "Twelfth Five-Year Plan" (from 2011 to 2015), Sichuan is the main construction site of UHV grid, and the completed, ongoing or proposed UHV transmission projects rank the first in China; starting such projects as Xiangjiaba –

Shanghai ± 800kv UHV DC project, Jinping – Sunan ± 800kv UHV DC project, Ya'an – Nanjing 1,000kv UHV AC project (north-south dual channel), Xiluodu – Zhexi ± 800kv UHV DC project, Qomul in Sinkiang – Chengdu in Sichuan ± 1,100kv UHV project, and "Sinkiang - Sichuan power transmission" project, and "Tibet – Sichuan power transmission" project has been taken into the agenda. A grid composed of "two crossing lines and four straight lines" will be created with the construction of inter-provincial and inter-regional transmission channels, synchronous with "ThreeChina" (Central China, East China and North China) ultra-high voltage, connecting "ThreeChina" grid in the east and linking with Sinkiang and Tibet grids in the west and hooking up to Northwest China Grid and transmission lines for "Sinkiang – Sichuan power transmission", "Tibet – Sichuan power transmission" and "power transmission from Sichuan" in the north, to transmit hydroelectric power of Sichuan and Tibet and electric power generated from coal and wind of Sinkiang to Central China, East China and North China, thus creating a "great grid, hub and platform" for power transmission.

By 2015, Sichuan UHV Grid will be provided with "three loops of east-west channels and south-north bidirectional interchange channels". By 2020, in Sichuan UHV Grid, three loops of Ya'an – Leshan – Chongqing – Hubei 1,000 kv EHV transmission lines will be completed, and 8+3 transmission pattern will be formed at Sichuan – Chongqing cross section, with three loops pf 1,000kv HV lines and eight loops of 500kv lines; Sichuan Grid will be turned from local gird into comprehensive hub grid, becoming an important platform for the national optimization allocation of electric power resources.

（5）Policies and Recommendations for Faster Construction of Sichuan Smart Grid

1) Improve integrated planning, and play the guiding role of government.

- Bring the development of strong smart grid into overall planning of Sichuan new energy development and industrial restructuring.
- Bring smart grid planning into the planning of economic development and industrial restructuring of all industries in municipalities and cities.
- Give full play of the guidance of the government to improve the management over such

industries related to smart grid as new energy and electric vehicles to promote the cooperation with grid companies.

2) Issue relevant incentive policies to support smart grid construction

- Provide policy support and incentive measures in terms of capital and land for the construction of line corridor, channel and smart substation.
- Bring electric vehicle charging facilities into urban planning, give support to land using indicators, land reserve zone and land acquisition for charging station, and provide supporting policies, including capital subsidy, discount loan and tax relief, to the construction originations and operators of electric vehicle charging facilities.

3) Promote relevant supporting industries to develop industrial chain

4) Improve electricity price structure to provide more options for the user

- Improve electricity price forming mechanism to create a reasonable and flexible electricity price structure;
- Implement tiered of pricing for electricity at sale side;
- Widely implement such electricity price system such as peak-valley time-of-use electricity price, seasonal electricity price and reliability electricity price; simplify the classification of retail electricity price, adjust electricity prices for different voltages, and gradually minimize the cross subsidization of electricity price for the user;
- Stand by the research and development of policies for price of new energy integration into grid and charge price of electric vehicles.

Chapter 6: Main Conclusions

Since the electric power was officially available in human society and triggered a power revolution in the 1880s, the modern society has become a “power-driven society”. However, three big challenges are limiting the development of the power network. First, the increasingly sophisticated power technology (be it power generation technology or transmission technology) and the increasingly large and complicated power system are not accompanied by improved safety and stability; second, the power generation dominated by fossil fuels, such as coal, is facing more and more severe challenges from the shortage of natural resources, energy sources and the concern about ecological environment, as a result of which, energy conservation and emission reduction impose constraints on the society at large, either the power sector or the grid enterprises; third, the development of new and clean energy, including wind power and solar PV power, has become the basic measure for human beings to resolve the resource, energy and ecological risks, and it brings challenges to the stable, safe and economical operation of the power network. In response, constructing a smart grid is of primary importance.

First, this thesis sorts out the theoretical research documents on network industry and network economy, and then analyzes the characteristics of power network industry and economy in order to provide the research on power network and smart grid with a theoretical framework.

For this purpose, this thesis makes a review and research on the emergence of electric power and its development in Sichuan, in China and the world by and large. Moreover, it indicates the significance and urgency of smart grid construction through the research on local power development, grid structure, dependency of Chinese (Sichuan) economic development on energy (power) specific to the conditions of Sichuan and China at large.

Then, this thesis analyzes the problems of smart grid development in China (Sichuan) from such perspectives as “network challenge”, energy source challenge, access of new energy and pertinent countermeasures, power development environment, space and time mismatch in power demand and supply (such as distribution of new energy) of China including Sichuan Grid. Research shows that the strategic choice for China (Sichuan) to develop smart grid is to construct a strong smart grid, with EHV grid as its main grid, which covers the whole industrial chain from generation, transmission, transformation, distribution, utilization to dispatching, and it is characterized by informatization, automation and interaction. Specifically, developing smart grid also supports the implementation of new energy strategy of Chinese power industry and the transition into green development mode, helps foster strategic emerging industry, meets diversified demand of consumers, improves grid interaction and value-added service capacity and drives the optimization of Sichuan industrial structure as well as rapid and sustained development of Sichuan economy.

Based on the research above, this thesis describes the research approach to the general objectives, stages, important measures and results of Sichuan smart grid construction as well as the policies of Sichuan on smart grid construction so as to complete the research on the topics listed in this thesis.

Major innovations of this thesis are: 1) research on operating characteristics of the power network from the perspective of **network industry** and **network economy**; 2) research on smart grid development from the perspective of the **“network challenge”**, **energy source challenge**, **access of new energy** and **pertinent countermeasures** particular to Sichuan Grid; and 3) research on development of power sector, grid enterprises and smart grid based on **national and regional development** as well as **sorting and analyzing of large quantities of data**.

Bibliography

Aggarwal A and Kunta, S. Verma P.K. (2010) , *A proposed communications infrastructure for the smart grid* [J] Innovative Smart Grid Technologies,1:1-5

Ahmad F and Ryan H. (2009) *Piloting the Smart Grid* [J] The Electricity Journal, 8(7), 55-69

Brown, R.E. (2008) *Impact of Smart Grid on distribution system design*[C]. Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, IEEE,

Bruce Kogut (1985), *Sloan Management Review* (pre-1986); Fall ; 27, 1

Bruce Kogut (1985), *Sloan Management Review* (pre-1986); Summer; 26, 4

CAO Qun (2009), *Research on Industrial Cluster Innovation Mechanism Based on Industry Chain Integration*, Harbin Institute of Technology, 4

Caron and S.Kesidis (2010), *G.Incentive-Based Energy Consumption Scheduling Algorithms for the Smart Grid*[C] Smart Grid Communications

CARRERAS B A, LYNCH V E, NEWMAN D E, et al(2003). *Blackout Mitigation Assessment in Power Transmission Systems* [C]// Proceedings of the 36th Annual Hawaii International Conference on System Sciences, January 2003, Maui, Hawaii, USA. Washington, DC, USA: IEEE Computer Society, 2: 65−74.

Charles C. Poirier and Stephen E. Reiter(1996). *Supply Chain Optimization: Building the Strongest Total Business*, Network, Pub Group West,

CHARTER D. *Power Supergrid Plan to Protect Europe from Russian Threat to Chokeoffenergy* [N/OL].LondonTimes2008-07-21.[2010-03-18]. http://business.timesonline.co.uk/tol/business/industry_sectors/natural_resources/article 5142622.ece.

CHEN Xiaogang, SUN Ke, CAO Yijia (2007). *Structural Vulnerability Analysis of Large Power Grid Based on Complex Network Theory*. Transactions of China Electrotechnical Society, 22(10): 138-144

China Electricity Council. *2009-2010 Country's Electricity Supply and Demand Situation Analysis and Economic Forecasts Industry and Market*, Market Survey.2010.3:26-31

China Energy Strategy Research Group 1996. *China Energy Strategy Research from Year 2000 to Year 2050*, Beijing: China Electric Power Press

Chuang A.McGranaghan M(2008) *Functions of a local controller to coordinate distributed resources in a smart grid*[C].Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, IEEE

Clements S.Kirkham H(2010).*Cyber-security considerations for the smart grid*[C] Power and Energy Society General Meeting,

DING Mincheng, WANG Jing, ZHU Zhizhong (2008). *Ascendant Smart Grid* [J], State Grid, (5): 86−88.

EPRI (2003) *Power Delivery System and Electricity Markets of the Future* [R], 1009102, Palo Alto, CA, USA: EPRI

EPRI (2004). *Technical and System Requirements of Advanced Distribution Automatio*n [R], Palo Alto, CA, USA: EPRI

European Commission. *European Technology Platform Smart Grids: Vision and Strategy for Europe's Electricity Networks of the Future* [EB/OL]. (2008-02-10) [2010-03-18].

http://ec.europa.eu/research/energy/pdf/smartgrids_en. Pdf.

European smart-grids technology Platform(2006): *Vision and strategy for Europe's electricity networks of the future*[R]. Direetorate-General for Research Sustainable Energy Systems,

FAN Ming-tian1,LIU Si-ge2,ZHANG Zu-ping,ZHOU Xiao-xin1(2007) *A Research and Review on the Emergency Management of Power Supply in Urban Power Network*[J]Power System Technology,10(7):11-16

FAN Yuncui(2009). *Research on Co-opetition Mechanism of the Units in the Telecommunications Industrial Value Chain*, Jilin University, 6

FANG Hong (2006). *Research Review on Global Value Chain Theory [J] Sci-Tech Information Development & Economy,* 26 (23):177-179

Farhangi, H (2010). The path of the smart grid [J].Power and Energy Magazine, 1:18-28

FU Guohua (1996). *Operating Agricultural Industrial Chain to Improve Efficiency of Agricultural System, China Agricultural Economy* [J] (11):24-25

Gall S.Scaglione(2010) *A.Power Line Communications and the Smart Grid[C] Smart Grid Communications*, 10:303-308

Gary Gereffi（1999）. *International trade and industrial upgrading in the apparel commodity chain*, Journal of International Economics 48 (1999) 37–70

Gungor V C.Bin Lu Hancke G P（2010）. *Opportunities and Challenges of Wireless Sensor Networks in Smart Grid* [J].Industrial Electronics, 10（57）：3557-3564

Guo Zhi-zhong（2005）. *Scheme of Self-healing Control Frame of Power Grid* [J] Automation of Electric Power Systems, 10(2):34-39

Hart D G（2008. *Using AMI to realize the Smart Grid*[C] Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, IEEE

HE Shuzhen and WANG Riyuan(1994). *Network Economy and Investment*, Computer World News, Nov.8

HE Zhao (2004). *A Discussion on Scheme of Improving Structure of East China Power Grid to Reduce Short Circuit Capability*, Power System Technology, 28(2):28-31.

Hommelberg M P F. Warmer C J.Kamphuis I G. Kok J.K.Schaeffer, G.J(2007). *Distributed Control Concepts using Multi-Agent technology and Automatic Markets: An indispensable feature of smart power grids*[C]Power Engineering Society General Meeting, 2007. IEEE, 1-7

HOROWITZ S H and PHADKE A G(2003). *Boosting Immunity to Blackouts* [J]. IEEE Power and Energy Magazine, 1 (5): 47−53.

HU Guoping (2009). Re*search on Stability of Industrial Chain*, Southwestern University of Finance and Economics, 5

HU Xuehao (2009). *Smart Grid-A Development Trend of Future Power Grid* [J]. Power System Technology, 33(l4):1.5.

JIANG Chunhai (2005). *The Research Method on ECPR about Access Pricing of Networks Industry*, Industrial Economics Research, 6(19):63-72

Jun Wang Huang, A.Woongje Sung Yu LiuBaliga, B.J.(2009), *Smart grid technologies*[J] Industrial Electronics Magazine,6(2):16-23

Jya W．(1969), *Forrester Urban dynamics*. M．I．T．Perss, 1969.

Kempton W. (2005), *Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy*[J]Journal of Power Sources, 4(6):54-60

Khurana H. Hadley M. Ning Lu;Frincke D A.(2010), *Smart-Grid Security Issues*[J] Security & Privacy,1(8),81-85

King, R.L.(2008), *Information services for smart grids*[C]Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, IEEE

KOIZAWA K. Smart Grid Related R&D in NEDO, New Energy and Industrial Technology Development Organization [EB/OL]. (2009-05-06)[2010-03-18].http://www.bids.cz/files/20090506-254-07%20II_2_2_NEDO%20 Kazuaki%20KOIZAWA.pdf.

Kulshrestha, P.Lei Wang Mo-Yuen Chow; Lukic S.(2009), *Intelligent energy management system simulator for PHEVs at municipal parking deck in a smart grid environment*[C]Power & Energy Society General Meeting, PES '09. IEEE

LI Xinqin, LI Shiming, et al.(2004), *Structure and Types Analysis on Industrial Chain*, Journal of Electronic Science and Technology (Social Science Edition).(4): 60-63.

LI Zaihua, BAI Xiaoming, DING Jian, et al.(2007), *Analysis of the Western Europe Blackout* [J]. Automation of Electric Power Systems, 31 (1): 1-3.

LL Zaihua, BAI Xiaoming, DING Jiang, et al(2007),. *Analysis for the Blackout of Europe* [J]. Power System Automation, 2007, 31 (1): 1−3.

Lin F R and Shaw M J(1998). *Reengineering the order fulfillment process in supply chain networks*[J]. International Journal of Flexible Manufacturing Systems, 10 (2): 197-239.

LIU Guifu and ZHAO Yingcai(2006). *Content, Characteristics and Formats of Industrial Chains* The Theory and Practice of Finance and Economics, (141): 114-117.

LIU Jiejiao(2001),*Competition and Regulatory Reform in Network Industries,* China Industrial Economics 9:30-37

LIU Jiejiao(2001), *Deregulation and Regulatory Reform in Network Industries-International Experience and Chinese Practice*, Chinese Academy of Social Sciences, 5

LIU Zhonghua, ZHOU Jieru(2005). *Network Externality and Competition in Network Industry*, Modernization of management, (5):52-54

Massoud Amin, S.Wollenberg, B.F.(2005), *Toward a smart grid: power delivery for the 21st century*[J]Power and Energy Magazine,10(3):34-41

Massoud Amin, Wllenberg BF(2005), *Toward a smart grid: Power delivery for 21 century* [J]. IEEE Power and Energy Magazine, 3 (5):34-41.

Mcdaniel P;P.McLaughlin S.(2003), *Security and Privacy Challenges in the Smart Grid*[J].IEEE Security & Privacy, 5:75−77.

MENG Fanchao, GAO Zhiqiang and WANG Chunpu(2009), *Smart Grid Key Technologies and Comparing with Traditional Grid* [J], Hebei Electric Power Vol . 28 S:5.

Metering International, South Korea is proposed to build Smart Grid [EB/OL]. [2010-03-18].

http://www.smartgridnews.com/artman/publish/news/Senate_takes_ on_energy_bills_ Utilities_miffed_at_NERC_red_tape_Duke_Energy_partners_with_Cisco-599.html.

Metering International. Kepco will adopt Smart Grid Technology for Renewable Energy Project in Philippines [EB/OL]. (2009-08-21) [2010-03-18],

http://www.metering china.com/cn/html/xingyexinwen/21-339.html

Metke A R.Ekl R L(2010), *Security Technology for Smart Grid Networks*[J] .Smart Grid, 6（1）：1949-3053

Metke A.R.Ekl, R.L（2010）,*Smart Grid security technology*[J] Innovative Smart Grid Technologies,1:1-7

Mohd, A.Ortjohann, E.Schmelter, A.Hamsic, N.Morton, D(2008),*Challenges in integrating distributed Energy storage systems into future smart grid*[C]: Industrial Electronics, ISIE

Mohsenian-Rad A.-H.Wong V.W.S.(2010), *Optimal and autonomous incentive-based energy consumption scheduling algorithm for smart grid*[J]: Innovative Smart Grid Technologies,1:1-6

MOMOH J A.(2009), *Smart Grid Design for Efficient and Flexible Power Networks Operation and Control Power Systems Conference and Exposition*[C]// IEEE/PES, 1-8.

Momoh J A.(2010), *Smart grid design for efficient and flexible power networks operation and control*[C]Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES[8]Moslehi K., Kumar R.A Reliability Perspective of the Smart Grid [J].IEEE Smart Grid,6(1):57-64

Moslehi, K. Kumar, R.(2010), *Smart Grid - a reliability perspective[*J]Innovative Smart Grid Technologies, 1:1-8

Novosel D.(2008), *Emerging technologies in support of smart grids*[C].Werand Energy Soeiety General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century Pittsburgh, Pennsylvania, USA

Pipattanasomporn M., Feroze H., Rahman S.(2009), *Multi-agent systems in a distributed smart grid: Design and implementation*[C] Power Systems Conference and Exposition, PSCE '09. IEEE/PES

Potter, C.W.Archambault, A.Westrick K.(2009), *Building a smarter smart grid through better renewable energy information*[C] Power Systems Conference and Exposition, PSCE '09. IEEE/PES,1-5

Rahimi F.Ipakchi A.(2010), *Demand Response as a Market Resource Under the Smart Grid Paradigm*[J]Smart Grid,6(2):82-88

RAHMANA.(2009), *Smart grid expectations: What will make it reality* [J].IEEE Power and Energy Magazine, 7(5):84-88.

Shang-Wen Luan Jen-Hao Teng Shun-Yu Chan.(2009), *Development of a smart power meter for AMI based on ZigBee communication*[C]: Power Electronics and Drive Systems, 11:661-665

SHENG Da-kai, QI Li-zhong,YAN Fu-zhang(2009), *Improve the Survey Capability and Serve for the Unified Strong Smart Power Grid*[J]Electric Power Construction,12(27)

SHI Jie,AI Qian(2009), *Research on several key technical problems in realization of smart grid*[J]Power System Protection and Control, 19

SHUAI Junqing (2009). *Speed up Construction of China style Smart Grid* [J]. Shanghai Electric Power, 2009, (4): 341 - 344.

Srinivasa Prasanna G.N.Lakshm A.(2009), *Data communication over the smart grid* [C] Power Line Communications and Its Applications, ISPLC 2009:273-279

TAO Aiping(2009), *Study on Network Industries Structure, Behavior and Performance,* Shanghai Academy of Social Sciences. 5

The national standard terms on logistics of the People's Republic of China. http: //www.moc.gov.cn/05zhishi/wuliugl/ t20050316_17342.htm.

United States of America] Robert H. Reid(1998), Utima Onine [M. Lanzhou: Lanzhou University Press, 140-143

United States of America(2009), Written by (Hopp, W. J.), Translated by XU Hie and WU Qiong. *The Supply Chain Management: Scientific Method of Obtaining Competitive Advantage*, B Beijing: China Machine Press. 9

Venayagamoorthy G.K.(2009), *Potentials and promises of computational intelligence for smart grids*[C]: Power & Energy Society General Meeting

WANG Chengshan, GAO Fei, LI Peng, et al.(2008), *Review on the EU Research Projects of Integration of Renewable Energy Sources and Distributed Generation* [J]. Southern Power System Technology, 2 (6): 1−6.

WANG Meiyi,WU Jingchang and MENG Dingzhong(1991). *Large Power System Technology,* Beijing: China Electric Power Press.

WANG Zhi-dong, LI Hui, LI Jun, HAN Feng.(2009), *Assessment Index System for Smart Grids*[J]Power System Technology,17

WEI Zhaolian(2009), *Research on the Development and Experience of Overseas Network Economy*, Jilin University: 3

Written by Michael Porter.(1997), Translated by CHEN Xiaoyue. *Competitive Strategy* [M] Beijing: Hua Xia Press, 1997

WU Jingru and CHEN Jianbo (2005), *Problems of development planning for electric power industry in China*, China Electric Power, 38(9):11-14.

Xiao Shijie(2009), *Consideration of Technology for Constructing Chinese Smart Grid*[J]Automation of Electric Power Systems, 9（2）, 23-27

XIAO Xingzhi and CHEN Yanli(2003), *A Study on Access Pricing in Vertical Integration Network*, China Industrial Economics, 10:50-54

XIE Kai, LIU Yongqi, ZHU Zhizhong, et al(2008), *Smart Grid towards Future* [J], China Power, 41 (6): 19−22.

YANG Gongpu and XIA Dawei(2002), *Modern Industrial Economic*. Shanghai: Shanghai University of Finance and Economics Press, 2002.

YAO Jianguo and LAI Yaning(2010). *The Essential Cause and Technical Requirements of the Smart Grid* [J], Automation of Electric Power Systems, 2010, 34(2): l-4.

YAO Jianguo and LAI Yening(2010), *The Essential Cause and Technical Requirements of the Smart Grid*[J]Automation of Electric Power Systems,2(2):21-27

YU Yihong (2005), T*ype of Industrial Chain and the Benchmark of Industrial Chain Efficiency*, China Industrial Economics, (11): 35-42.

YU Yixin and LUAN Wenpeng(2009). *Smart Grid* [J], Power System and Clean Energy, 25(1), : 7−11.

YU Yixin(2009), *Intelligent Distribution Network in the New Situation* [J], Power System and Clean Energy, 2009, 25 (7): 1-3.

YUAN Jixiu(1999), *Planning and Study of Power System Security and Stability Control*, China Electric Power 32(5):29-32.

Yvonne Chan in Hong Kong, Business Green, South Korea Plans Smart Grid by 2030[EB/OL]. (2009-01-08) [2010-03-18].

http://www.businessgreen.com/business-green/news/2243674/south-korea-plans-smart-grid.

ZHANG Boming, SUN Hongbin, WU Wenchuan(2009), *Future Development of Control Center Technologies for Smart Grid*[J]Automation of Electric Power Systems:,17

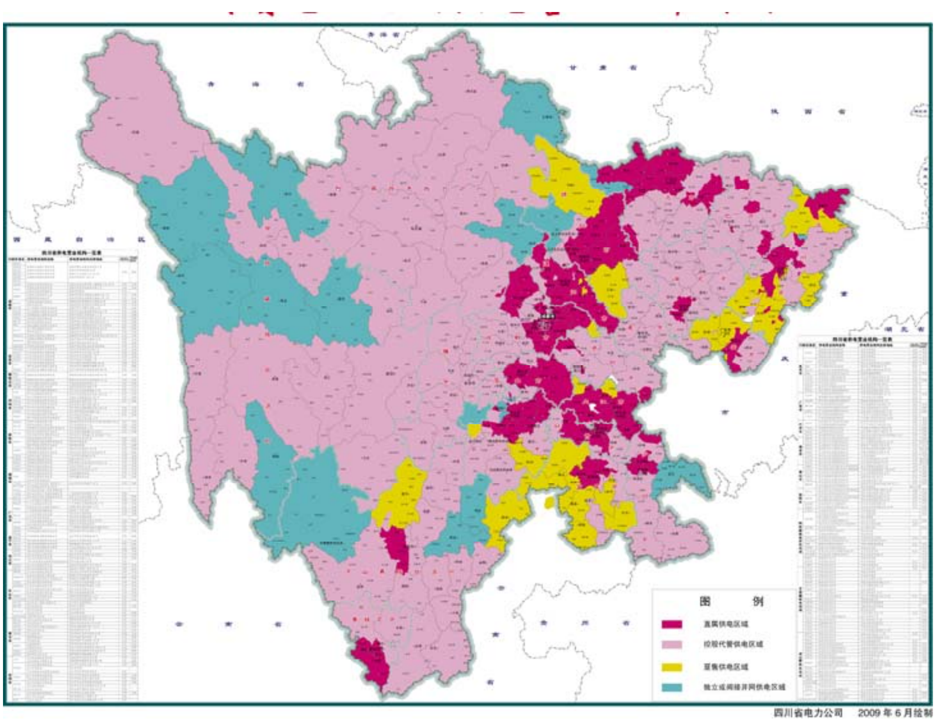
ZHANG Wenxuan (2008), *Global Value Chain Theory and Its Application* Northwestern University 6

ZHANG Yunzhou(2003), *Specific Problems in the Planning and Development of Power Network in China*, China Electric Power, 36(9):50-53.

Appendix

Attached Map 1 Service Areas of Power Supply Enterprises throughout China

Attached Map 2 Sichuan Electric Power Corporation Service Area Plan



Attached Map 3 Sichuan Electric Power Corporation Grid Connection