Regulation and Optimization Methodology for Smart Grid in Chinese Electric Grid Operators Using Quality Function Deployment, Equilibrium Theory, Fractal Theory and Mathematical Programming

A thesis submitted for the degree of Doctorate of Philosophy

by

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Abstract

As the world is increasingly dependent on energy for the economic and social development and China's Total Net Electricity Generation （TNEG） has remained the highest since 1996 due to its rapid economic growth, it is important to closely examine the operations of China's electric power market, particularly the State Grid Corporation of China (SGCC) since it is the largest Electric Power Grid Operator (EPGO) in both China and the world.

This research has addressed the problem and the urgent needs for the development of a sound framework and methodology for the effective regulation and optimization of the operations and quality management of the SGCC. Based on the critical literature review, the aspects and steps of the solution to the problem have been progressively presented.

Firstly, a Country Wealth (CW) curve has been developed to characterize electricity generation in terms of TNEG, with China's unique position identified. Further, the data has clearly indicated that China's TNEG has also been closely correlated with the economic growth and the carbon emissions during the 30 years period of 1980-2010.

Secondly, compared with the Equilibrium Energy Regulation Model, there are clear deficiencies and problems with the current regulation of China's electric power market. The improvements in the integration of regulation strategies and the formation of one single effective regulator have been identified and proposed.

Thirdly, a uniform regulation structure and framework based on fractal theory and QFD (quality function deployment) has been developed to integrate the existing and future electric power strategies, including smart grid strategy and sustainable development strategy(etc.). Through the use of QFD, the EPGO (SGCC) functions and operations can be prioritized and appropriately designed.

Finally, the QFD methodology has been extended to achieve the optimization of quality and service operations given the target cost of the business processes. The methodology can be applied to both business and technical processes of the EPGOs since quality may be interpreted as a total quality involving the needs and expectations of various customers or stakeholders.

Declaration

The work described in this thesis has not been previously submitted for a degree in this or any other university.

Acknowledgments

I am indebted to all the people who have provided support, guidance and friendship during the course of my research. In particular, I would like to thank my supervisors, Dr QingPing Yang and Prof Kai Cheng for their great knowledge and indispensable guidance throughout my studies.

I also want to express deep-felt appreciation to my family for their loving support and encouragement during the period of my studies.

Abbreviations

CE	Customer expectation
CEPE	China electrical power energy
CEPEC	China Electrical Power Energy Characteristics
CEPM	China’s Electrical Power Market
CES	China energy strategy
CW	Country Wealth
CS	Case study
CSG	China Southern Grid Company
CSR	Customer service representative
EA	Economic analysis
EERM	Equilibrium Energy Regulation Model
EP	Electrical power
EPEC	Electrical Power Energy Characteristics
EPES	Electrical power energy strategy
EPM	Electric Power Market
EP	Electrical Power
EPB	Electric Power Bureau
EPC	Electric Power Company
EPCS	Electric power customer service
EPE	Electric Power Enterprise
EPG	Electrical Power Grid
EPGI	Electrical Power Grid Industry
EPGO	Electric Power Grid Operator
EPGC	Electric Power Grid Company
EPP	Electric power project
EPS	Electric Power System
EPSB	Electric Power Supply Bureau
EPRI	Electric Power Research Institute
EM	Energy Market
LCS	low-carbon sources
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IEPR	Industry Electricity Price Regulation
IPP	Independent Power Producer
PCC	Project Cost Control
PDSM	Power demand side management
SGCC	State Grid Corporation Company
SGPP	Smart Grid Progress Pyramid
SGM	Smart grid modelling
SGS	Smart Grid Strategy
SWP	Step-wise process
SPC	State Power Corporation
SQES	Service quality evaluation system
MEPB	Mudanjiang Electric Power Bureau
MRBD	Marketing research and benchmarking data
NM	Natural Monopoly
NMEU	Natural Monopoly Electric Utility

VoC	Voice of Customer
QFD	Quality Function Deployment
TC	Target cost
TCA	Target costing activity
TMRs	Technical & Managerial Requirements
TMFs	Technical & Managerial Features
TNEC	Total Net Electricity Consumption
TNEG	Total Net Electricity Generation

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CHAPTER 1 Introduction

1.1 Background

1.1.1 Overview of world energy needs

In recent years, the world has become increasingly dependent on energy due to the economic and social development. For example, world energy consumption has been rising and power generation is estimated to account for 81% of the increase in coal use to 2030, boosting its share of total coal demand from 68% in 2004 to 73% (IEA, 2006). According to the International Energy Agency (IEA), the world primary energy demand from 1980 to 2030 may be shown in Fig. 1 (IEA, 2006). The demand growth has been dominated by non OECD (Organization for Economic Cooperation and Development) countries. Therefore, OECD has been working closely with emerging giants like China, India and Brazil regarding their energy demand for their powerful economy, population, industrial and culture change growth (OECD, 2013). The importance of this has been clearly recognized by OECD.

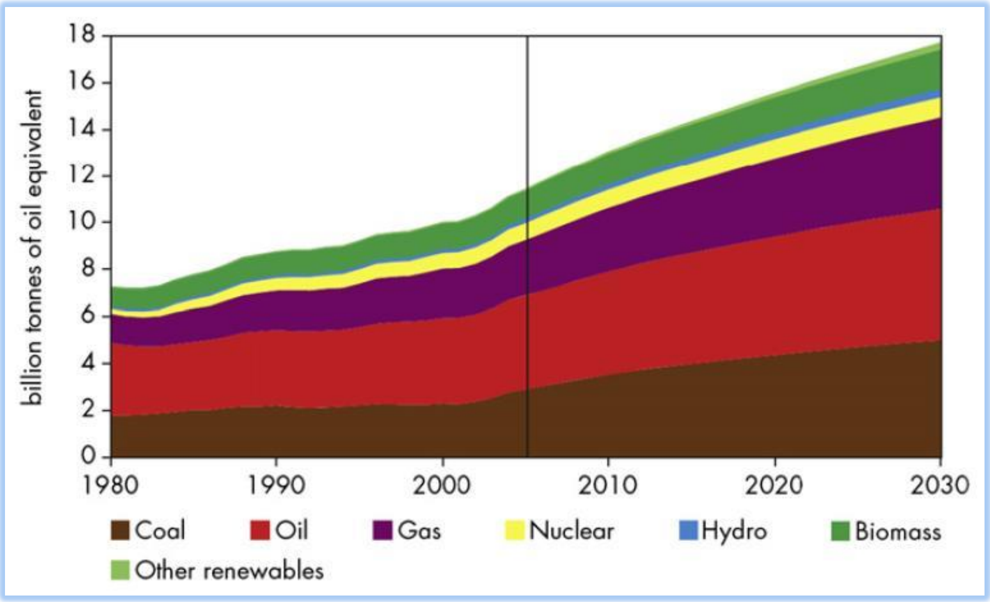


Figure 1 World primary energy demand 1980-2030 (OECD, 2013)

Indeed, electric power energy is important for world economic and social development. All the primary energy can be transformed into electric power energy. Electric power energy can also expediently transform into other forms of energy (e.g. mechanical energy, thermal energy and so on). In general, the total net electricity generation rate (TNEG) is one of the important indices in electrical power market. Table 1 shows the IEA statistical data on the world's top 16 TNEG rates between 1996 and 2006 (EIA, 2013). China has the highest TNEG rate from 1996 to 2006, and its ranking remained unchanged during the period.

Rank	Country	1996 Total Net Electricity Generation	2006 Total Net Electricity Generation	1996-2006 Total Net Electricity Generation Rate (‰)
1	China	1005	2717	17
2	Korea South	210	379	8
3	India	412	703	7
4	Spain	165	283	6
5	Mexico	156	236	5
6	Brazil	287	411	4
7	Australia	168	237	3
8	Italy	225	291	2.8
9	South Africa	186	227	2.6
10	US	3440	4071	1.7
11	Russia	804	940	1.6
12	Germany (East West)	520	594	1.4
13	UK	328	371	1.2
14	France	483	542	1.1
15	Japan	955	1032	0.8
16	Canada	557	594	0.6

Table 1 Total Net Electricity Generation Rate (‰) of 16 Countries during 1996-2006 (EIA, 2013)

1.1.2 Overview of China's energy regulation strategies and EPGO

In 2010, China has exceeded the U.S. to be the world's biggest energy consumer according to IEA. Its energy supplies include coal, electricity, petroleum, natural gas and renewable energy resources. However, its energy consumption and the shortage of traditional energy have increased with the fast economic development. These have caused damage to the eco-environment (Xinhua, 2012). Furthermore, the safe electricity supply has been important for large increase of China's economic development in the last 30 years (EIA, 2013). Besides, the fast increases in economy and energy have large negative impacts on climate change in China. These will in turn have significant negative impacts on the world's sustainable development, according to the experts of IEA (Xinhua, 2012; Luoetal., 2010; Miaoetal., 2009; Miao-1et al., 2009; WEC, 2013).

1.1.2.1 History of China's electrical power market regulation

China passed its Electricity Law in 1995 as the major legal mechanism, according to which every electrical power department, industry and company is controlled by the government (Austin, 2005). In March 1998, Chinese government started the reorganization of regulatory agencies and the restructuring of state owned companies. In this effort, Chinese government aims to streamline, simplify and further centralize the control in the energy industry. The next regulation reforms happened in 2002, with the formation of the State Electricity Regulatory commission (SERC), and extra governmental restructurings were set up during 2003 and 2004 (Austin, 2005; GLOVER et al., 2011; SGN, 2013; Wang et al., 2013; WRI, 2014). Moreover, the Regulations on Electricity Supervision and Control were announced on February 25 2005 (Austin, 2005). The World Resources Institute clearly outlined a situation about the *Regulations on Electricity Supervision and Control*, and it seeks to create a competitive domestic market for energy. The SERC is to supervise and regulate the electric power price and issue electric power permits to businesses (Austin, 2005; GLOVERetal., 2011; SGN, 2013; Wang et al., 2013; WRI, 2014).

1.1.2.2 China's electrical power grids

The purpose of China's electrical power grid in the long run is to build an integrated national electrical power grid. Fig. 2 shows China's current electrical power grids (GENI, 2013). The interconnected grids provide electric power generation, transmission, distribution and power supply in China's electrical power market. Regional electrical power grids are shown in Fig. 3 (U.S.EPA, 2011; Ni, 2006; CSG, 2013; SGCC, 2013a; ICD, 2013):

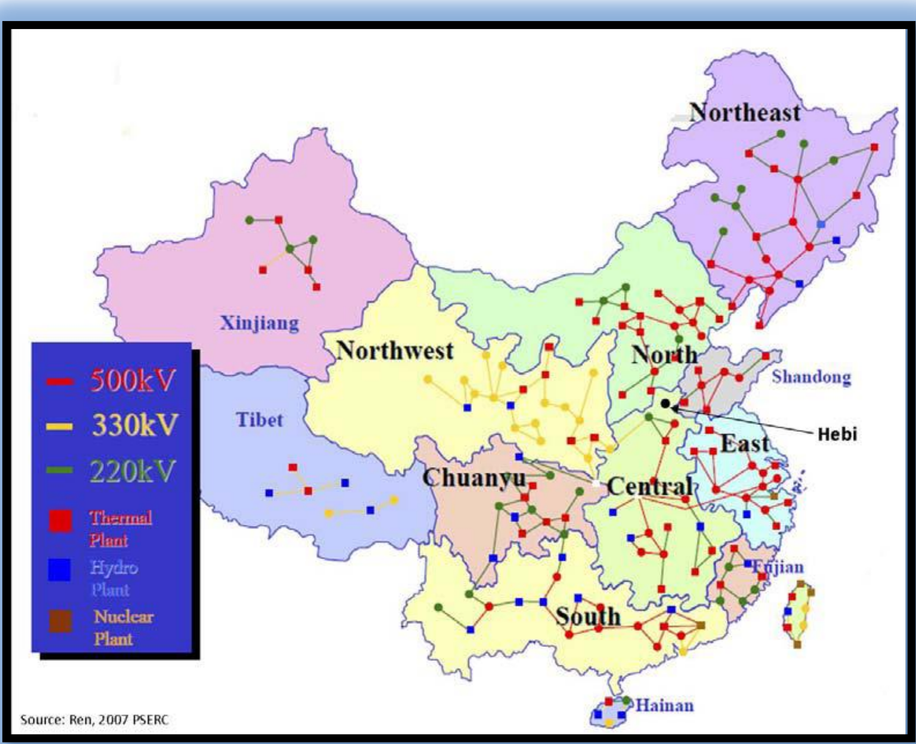


Figure 2 China's Electrical power grids (GENI, 2013)

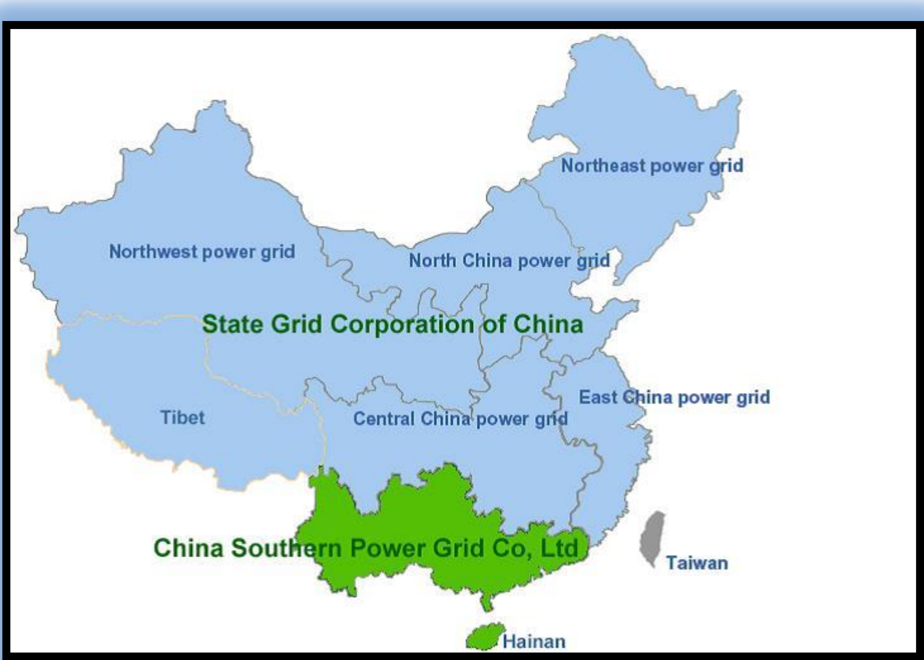


Figure 3 China's regional electrical power grids (U.S.EPA, 2011; Ni, 2006; CSG, 2013; SGCC, 2013a; ICD, 2013)

1.1.2.3 Chinese core energy strategies

A book of Electric Power and Energy in China has explained China has a number of interrelated energy strategies, such as business reengineering of energy development processes; development of a modern comprehensive energy system; Strong and Smart Grid strategy; exploitation of hydro-power, nuclear power, oil and gas resources; substitution of electric energy in Terminal Energy consumption; the electricity-centred energy strategy; exploitation of overseas energy resources; and rural electrification. China has been following the world energy strategies as well (Liu, 2013).

The book of Electric Power and Energy in China has outlined the electricity-centred energy strategy. It concluded that electricity development is the important part in energy development. Electrical power energy is very important for security, energy structure, energy conservation, emission reduction, and building of a harmonious society in China's sustainable energy developments (Liu, 2013).

1.1.2.4 China's Electric Power Grid Operator (EPGO)

To end the State Power Corporation's (SPC) monopoly of the power industry, China's State Council dismantled the corporation in December 2002 and has set up 11 smaller companies (Austin, 2005; U.S.EPA, 2011; Ni, 2006; CSG, 2013; SGCC, 2013a). The smaller companies include two electric power grid operators (EPGOs), five electric power generation companies and four relevant business companies (Austin, 2005; U.S.EPA, 2011; Ni, 2006; CSG, 2013; SGCC, 2013a). One of the two EPGOs is the State Grid Corporation of China (SGCC) and it is the largest state owned electric power operator in China as well as in the world, headquartered in Beijing. The other is the China Southern Power Grid Company (CSG). In the SGCC, the regional level EPGO is called Power Grid Company (PGC), and the provincial level EPGO is called Electric Power Company (EPC). In the CSG, the provincial level EPGO is called PGC too, but it does similar jobs to the SGCC'S provincial level EPGO in south China. As for the City level EPGO, most of them are called Electric Power Bureau (EPB) or Electric Power Supply Bureau (EPSB) both in SGCC and CSG. Therefore, EPGOs may have different names at different regulation levels, but they are all doing similar jobs for their customers and working with electrical power generation, transmission, distribution, electrical power supply and subsidiary companies. Furthermore, they all have similar regulation framework, especially in the SGCC. Therefore, the EPGO in this thesis can refer to any of these EPGOs at different levels in different Corporations. (Austin, 2005; U.S.EPA, 2011; Ni, 2006; CSG, 2013; SGCC, 2013a)

In this thesis, we will focus on the SGCC, because it is the largest EPGO in China and also in the world. The SGCC's power network operations cover 26 provinces and autonomous regions or municipalities with subsidiaries of North China, East China, Central China, Northeast China and Northwest China (Xu, 2012). The SGCC has served more than 1 billion domestic customers in 88 percent of the country's territory. The SGCC has over 618 thousand kilometers length of Transmission Lines. In overseas markets, the SGCC also operates the National Grid Corporation of the Philippines and seven transmission companies in Brazil (SGCC, 2011a). Therefore, the SGCC plays an important role in China's energy security, economy, society and their sustainable developments. Table 2 and 3 list the key performance indicators of China's economy and the SGCC in 2005 and 2010, as the background information for the research on China's EPGO (SGCC, 2005-2010). The current status of smart grid construction is given in Table 4 (SGCC, 2005-2010):

Key Performance Indicators	2005	2010	Average annual growth rate
National GDP (Trillion Yuan)	18.49	39.80	11.20%
SGCC maximum load within State Grid's service area (MW)	297,990	525,080	12.00%
SGCC Electricity sales (TWh)	1,500	2,689.1	12.92%
SGCC installed capacity within State Grid's service area (MW)	394,880	759,760	14.00%
Transmission lines at 110 (66) kV and above (km)	381,764	618,837	10.14%
SGCC transformation capacity of 110 (66) kV and above Transformation Equipment(MVA)	983,380	2,131,930	16.74%
SGCC Revenue (Trillion Yuan)		1.5427	116%
SGCC Total assets (Trillion Yuan)		2.1192	81.2%
SGCC Total Profit (Billion Yuan)	144	450.9	213%
SGCC Fortune Global 500 ranking	40	8	

Table 2 Key Performance Indicators of China's Economy and SGCC in 2005 and 2010 (SGCC, 2005-2010)

Key Performance Indicators	2005	2010	Average annual growth rate
Total productivity Yuan / (person year)	403,000		91%
Average annual blackout time of city power(Hours)	21.5	8.234	
Comprehensive voltage qualification rate of city	99.136%	99.498%	
New enabled power for households(million)		1.34 (2006-2010)	
Employees' volunteer (Million man-times)		2.97	
Brand Value (Billion Yuan)	39.6	126	
Cross-regional resource allocation ability (MW)		4020	25000

Table 3 Key Performance Indicators of SGCC in 2005 and 2010 (SGCC, 2005-2010)

Current Status of the Smart Grid Construction	
Planning reports	"Intensify the Smart Grid Construction" in the Government Work Report; General Report of State Smart Grid Planning (2009~2020); State Grid General Outline for Preparation of State Smart Grid of the "12th Five-Year Plan"
Systems	'Smart Grid Technical Standard System' 'the Critical Equipment (System) for Smart Grid'
Pilot projects	228 smart grid pilot projects
Breakthrough projects	Six fields include: smart transformation substation, electric vehicle charging facilities, and FTTH (fiber to the home)
Technical standards	Release 92 technical standards for smart grid enterprises
Show project	Construct and operate the Shanghai Expo Smart Grid Comprehensive Demonstration Project. More than 1.6 million people visited the State Grid Pavilion.
Established research and testing centers	Three national smart grid research and testing centers.

Table 4 Current Status of the Smart Grid Construction (SGCC, 2005-2010)

1.2 Research problem

Given that the world is becoming more and more dependent on energy due to economic and social development, and that the electric power company SGCC is the largest EPGO in both China and the world, any improvement in the operation and management of the SGCC is important significance with wide impacts in technical, financial, social and environmental. In 2010 the SGCC outlined plans for a pilot smart grid programme to map out deployment to 2030. It is estimated that investments in smart grid will reach at least $96 billion by 2020 (IEAa, 2011). Meanwhile, the EPGO's regulations of electrical power transmission and distribution as the natural monopoly in electric power market are being reviewed for deeper reform. Against such a background it is clear that the China's current energy strategies are seriously fragmented and there is lack of an integrated framework for the effective regulation and management of the Chinese electric power grid operators to optimize their operations in terms of customer satisfaction, operational cost and environmental impacts and so on.

This research project will strive to investigate the wide issues associated with this central problem and provide a sound methodology to solve the problem and answer the questions related to the effective regulation model and structure, optimum operation and satisfaction of customers including various stakeholders.

1.3 Research proposal

The project has proposed a methodology based on the customer expectation (CE) to develop an effective regulation of EPGOs in China's electrical power market. Although QFD has been previously applied in China's electrical power market, they have not been used for the optimization of EPGOs' operations. It seems that the combination of three key features (QFD and mathematical optimization, together with fractal theory) will offer great prospects.

Moreover, this thesis has proposed a novel regulation structure for SGCC based on fractal theory, further integrated with QFD methodology and mathematical optimization.

1.4 Aims and objectives

The aim of this research is to develop a sound methodology for the optimization of Smart Grid Strategy quality, with increasing safety of supply, sustainable development and safeguard environment (3S Strategy) through effective regulation in the China's Electric Power Market.

The distinct objectives for this research are as follows:

1) To characterize the current and future developments of China's electricity generation in comparison with other economies.

2) To provide a longitudinal perspective about the growth of China's electrical power industrial in relation to economical growth and environment impacts.

3) To develop a sound regulation model for China's electric power market and EPGOs.

4) To develop a sound framework to integrate the various existing electric power strategies (mainly smart grid strategy) for the effective regulation and management of EPGOs in terms of structure, quality and operations.

5) To develop a sound methodology for evaluation and optimization of quality and operation management.

1.5 Scope of the research

Firstly, whist the research has addressed problems and issues associated with China's electric power market, the focus has been on the SGCC to simplify the data collection and discussions.

Secondly, the framework and methodology have been presented largely for business processes and operations, particularly quality management, but they can also be applicable to technical processes or other regulation strategies, which are not discussed in detail in this thesis.

1.6 Structure of the thesis

This thesis comprises of six chapters as follows:

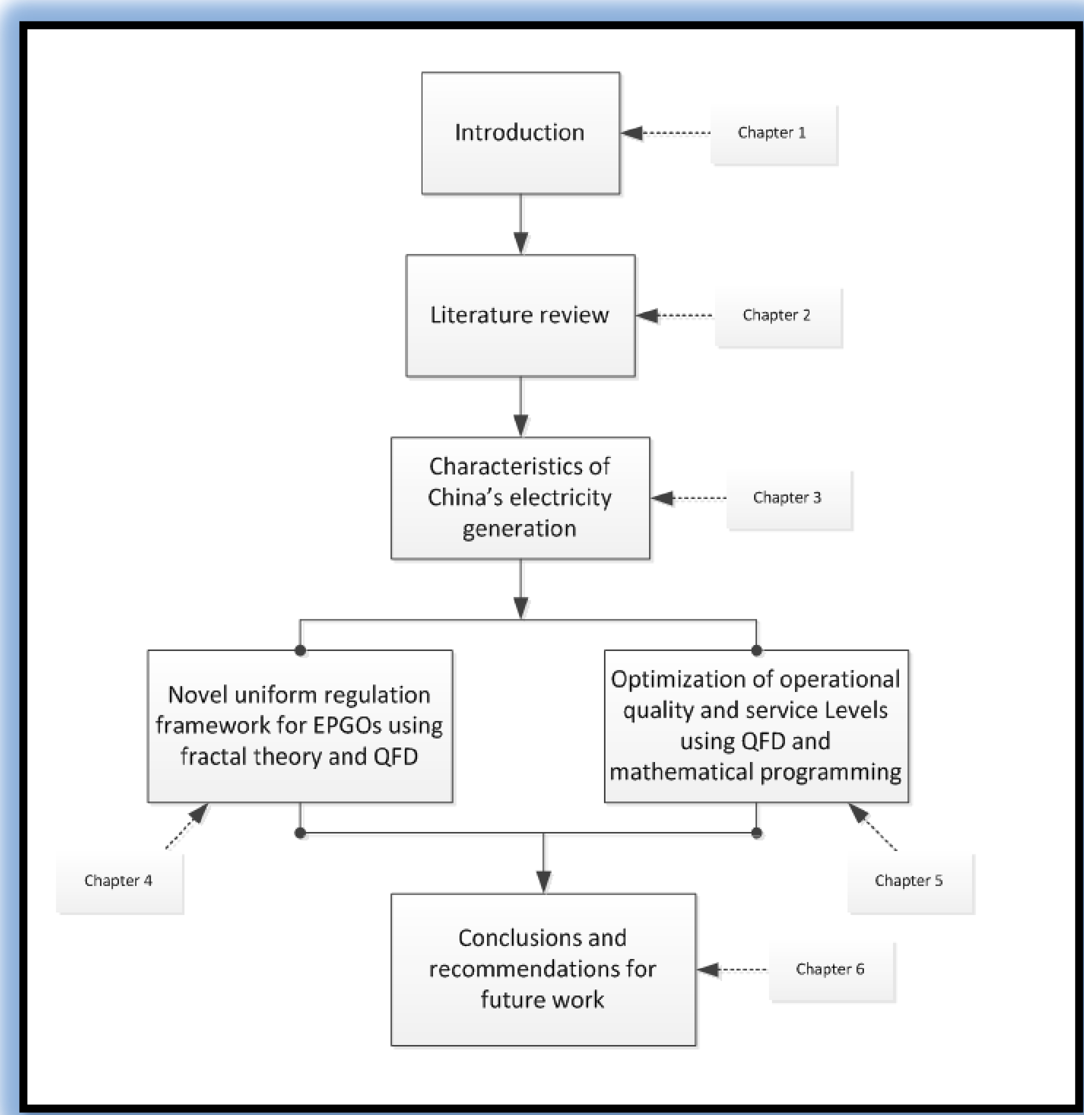


Figure 4 Structure of the thesis

Chapter 1 introduces the background, problem and research aims/objectives.

Chapter 2 reviews the state of the China's Electric Power Market and its regulation; SGCC and EPGOs; Smart Grid Strategy; equilibrium theory; equilibrium energy regulation model; fractal theory; the 3S energy regulation strategy; sustainable development strategy; QFD and Excel Solver tools.

Chapter 3 analyses for China's electricity generation characteristics by means of CW Curve. It also presents some historical data on China's electrical power growth (TNEG), together with GDP, CO2 emissions and distribution losses data.

Chapter 4 analyses the problems associated with China's current electric power market and proposes the required reform for China's electric power market based on the Equilibrium Energy Regulation Model. It further proposes a framework to integrate various China's electric power strategies using fractal theory and QFD.

Chapter 5 presents the proposed methodology for optimization of quality using QFD and mathematical programming, based on a case study of a city level EPGO's 95598 customer service center in the SGCC.

Chapter 6 draws conclusions from this research. Recommendations are also made for the future work.

CHAPTER 2 Literature review

2.1 Introduction

In this chapter, the state of the China's Electric Power Market and its regulation, SGCC (State Grid Corporation Company), EPGO (Electric Power Grid Operators), SGS (Smart Grid Strategy) and its regulation, are reviewed. The concepts, characteristics and design methodology of equilibrium theory, Equilibrium Energy Regulation Model, fractal theory, 3S energy regulation strategy, QFD and Excel Solver tools are discussed. This chapter also discusses the needs, approaches and trends of SGS since they are importantly related to the research approach and the aim to achieve increased safety of supply, sustainable development and safeguard environment in China's Electric Power Market.

The sustainable development strategy and SGCC's common responsibilities are also briefly reviewed.

2.2 China's electrical power market and its regulation

China's electrical power market includes electrical power generation, transmission, distribution and power supply. All of them were regulated by State Power Corporation (SPC) in China before December 2002 (Keping, 2008). And SPC has been restructured since 2002 to ensure that it has the safety of electrical power supply and sustained economic growth. Market restructuring was designed to increase investment and efficiency within the China's electrical power market. However, as the Chinese economy and its electricity demand continue to grow, the Electrical Power Industry (EPI) faces a number of major challenges over the next decade. Some of the key challenges involve developing a secure and differentiated energy mix that is less dependent upon highly polluting energy (e.g. Coal). There are also big challenges for safety and stability of Electrical Power Grid (EPG). These will require suitable strategy (e.g. smart grids) and efficiency investment to fully integrate into the Electrical Power Grid Industry (EPGI) (e.g. SGCC) of China's electrical power market (JohnLoffman, 2011).

2.3 Overview of SGCC's EPGOs

2.3.1 Overview of SGCC

SGCC was established on December 29, 2002. It is the largest Electric Power Enterprise (EPE) in the world. SGCC ranked the 8th in the Fortune Global 500 in 2010. As a state-owned company, the mission of the company is to provide safe, economical, clean and sustainable electrical power through electrical power generation, transmission, distribution, and power supply for social and economic development. Its Electrical Power Grid (EPG) services 88% of the national territory. It has employed more than 1,500,000 employees to serve a population of over one billion (SGCC, 2013b; CNNMoney, 2013; GLOVER et al., 2011). The SPC restructuring and asset allocation in December 2002 is shown below: (JohnLoffman, 2011)

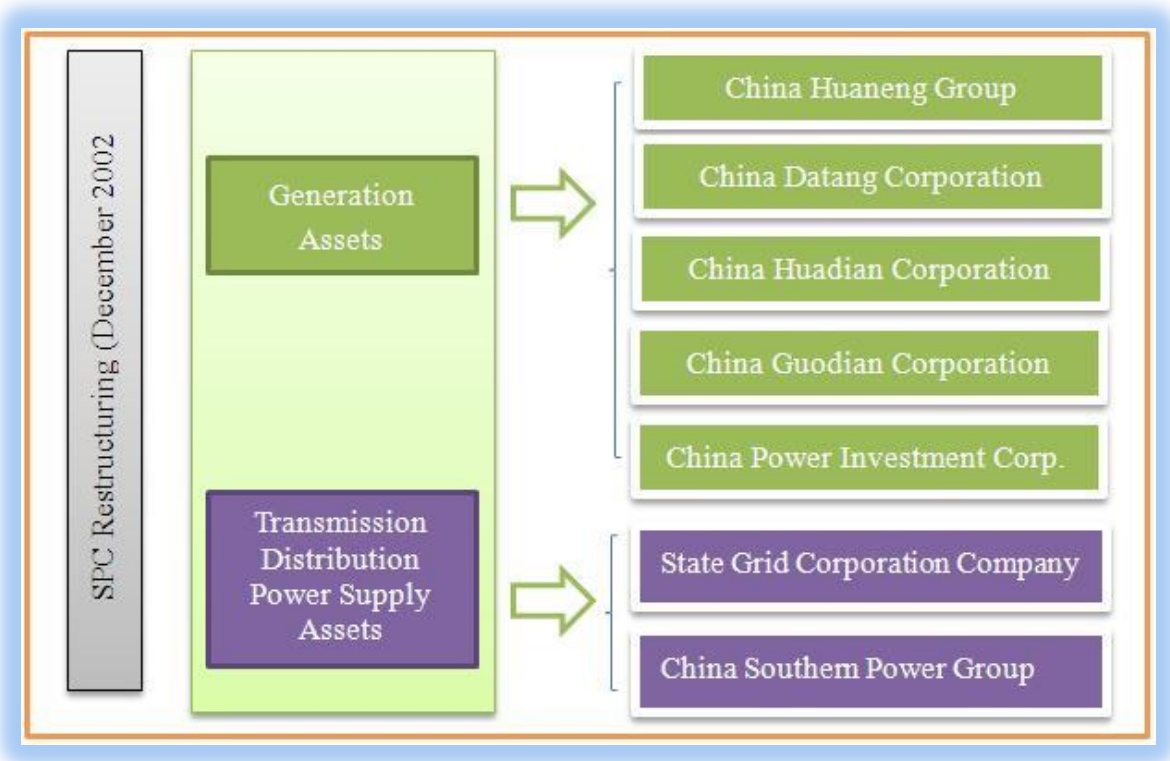


Figure 5 SPC Restructuring and Asset Allocation in December 2002 (JohnLoffman, 2011)

2.3.2 Framework of SGCC

SGCC has 5 regional level Electric Power Grid Operators (EPGOs) (north, north-east,

east, central and north-west) and 27 provincial electrical power companies in China, shown as below (SGCC, 2011a; Sarlos, 2012).

North China Power Grid Company, Ltd	East China Power Grid Company, Ltd	Central China Power Grid Company, Ltd
Beijing Electric Power Company Tianjin Electric Power Company Hebei Electric Power Company Shanxi Electric Power Company Shandong Electric Power Company	Shanghai Electric Power Company Zhejiang Electric Power Company Jiangsu Electric Power Company Anhui Electric Power Company Fujian Electric Power Company	Hubei Electric Power Company Hunan Electric Power Company Henan Electric Power Company Jiangxi Electric Power Company Sichuan Electric Power Company Chongqing Electric Power Company
Northeast China Power Grid Company, Ltd	**Northwest China Power Grid Company, Ltd**	
Liaoning Electric Power Company Jilin Electric Power Company Heilongjiang Electric Power Company East Inner Mongolia Electric Power Company	Shaanxi Electric Power Company Gansu Electric Power Company Qinghai Electric Power Ningxia Electric Power Xinjiang Electric Power Tibet Electric Power Company	

*Note: The SGCC also holds a 100% stake in State Grid Brazil Holding, which consists of seven transmission companies in Brazil, and a stake in the National Grid Corp of Philippines.

Figure 6 SGCC Regional power companies and provincial electric power companies (SGCC, 2011a;2013c; Sarlos, 2012)

2.3.3 Regulation structure and model of SGCC's EPGOs

Since SPC started its restructure in 2002, SPC has organized its electrical transmission, distribution, substation, dispatching, and power supply assets into two major EPGOs, SGCC and CSG (Sarlos, 2012). And it is also composed of many other EPGOs. Therefore, through a study of China's EPGOs, a regulation framework of SGCC's EPGOs is proposed as below (SGCC, 2011a; 2013a; 2013b):

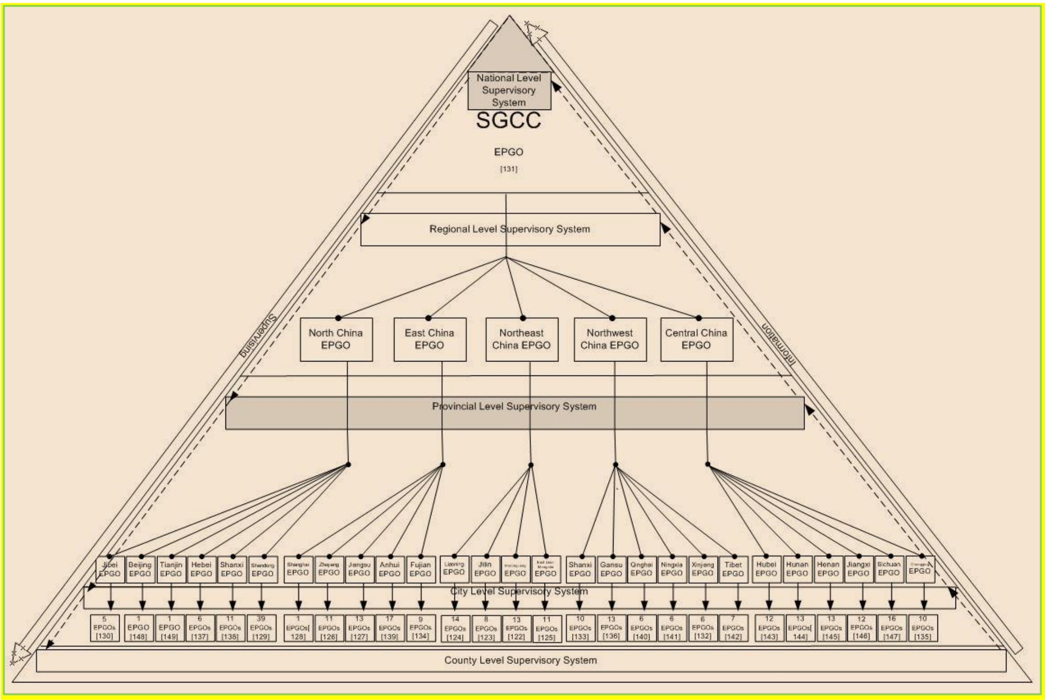


Figure 7 Regulation structure of SGCC's EPGO

The regulation form of each EPGO is similar in China, especially in SGCC. The uniform regulation framework of each EPGO in China was explained in the report of *Corporate Social Responsibility Report* in 2011 (SGCC, 2011a) .

SGCC's common responsibilities are to guarantee safer, more economical, cleaner and sustainable energy supply (SGCC, 2005-2010).

2.3.4 Natural monopoly of EPGO's transmission and distribution

EPGO's transmission and distribution have a natural monopoly in electric power market (Wang et al., 2010; Kim & Horn, 1999; Jones, 1993; Paddon, 1998). The significance of this has clearly been accepted by the well-known 'British Power Market Model'. The electricity industry competition was introduced, and some related reasons for the competition include:

1) Retail competition for final electricity customers;

2) The electricity industry was separated into four sectors, i.e. generation, transmission, distribution and retail supply;

3) An independent regulatory body, Ofgem, was set up to regulate natural monopoly sectors (transmission and distribution) by using incentive regulation;

4) Publicly owned companies were privatized.

To ensure the safety of energy and electrical power supply, the transmission and distribution are regulated by government (Ofgem) in the UK. They were not introduced to the competition market. They are called natural monopoly parts in the electrical market. This should also benefit the EPGO in China's electric power market (Jamison, 1997).

2.4 Smart Grid Strategy

Smart Grid Strategy is an important strategy for enhanced safety grid operations, customer services and environmental benefits in all aspects of the electrical power market. The importance of this has been clearly recognized by the U.S. Department of Energy.

2.4.1 Definition of smart grid

While a variety of definitions of the term Smart grid have been suggested, the definition proposed by National Institute of Standards and Technology (NIST) will be used in this project. NIST defines it as a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications. According to NIST, a smart grid involves the standard coordination process including five aspects, i.e. utility companies; appliance and consumer electronics providers; consumers — residential, commercial, and industrial; renewable power producers; and state and local regulators (SGCC, 2011d).

2.4.2 A brief history of smart grid

The first use of Smart Grid was for an Italian system installed by Enel S.p.A. of Italy in 2005 for a Telegestore project. The meters, system software and integration are done by the company in the project. It was highly remarkable in the utility world (NETL, 2008). The Telegestore project is widely regarded as the first commercial use of smart grid technology to the home, and delivers annual savings of 500 million euro at a project cost of 2.1 billion euro (NETL, 2008).

2.4.3 Current Smart Grid Development

2.4.3.1 Overview of IEEE Smart Grid

In order to standardize and guide Smart Grid development, IEEE, NIST and IEEE Smart Grid have developed the roadmap for the Smart Grid (Erol-Kantarci & Mouftah, 2011; Saber & Venayagamoorthy, 2011; Lu et al., 2011; Palensky & Dietrich, 2011; Calderaro et al., 2011; Cecati et al., 2011).

Figure 8 Current Smart Grid Standards in development by IEEE (IEEE-SG-1, 2011)

IEEE Smart Grid

IEEE Smart Grid was launched by IEEE in January 2010. It has been focusing on both individuals and organizations included in the modernization and optimization of Smart Grid with regard to power transmission and distribution, renewable energy, communications and electric vehicles through development of new smart grid-related standards, best projects, publications, and conferences and educational opportunities (IEEE-SG-1, 2011).

2.4.3.2 Domains and actors in the Smart Grid application

The Smart Grid will enable the electric power grid operation to be more flexible and stronger in the future, according to the definitions of Smart Grid (NIST, 2009; EPRI, 2009).

The smart grid application models can support the plan and organization of the diverse and expanding collection of interconnected networks which will be involved in the

Smart Grid (NIST, 2009). The approach adopted by NIST divides the Smart Grid into seven domains, as described in Table 5 (NIST, 2009). The description of domain and actors in the Smart Grid application models has been contributed by the Office of the National Coordinator for Smart Grid Interoperability. It is shown as below:

Domain	**Actors in the Domain**
Customers	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.
Markets	The operators and participants in electricity markets.
Service Providers	The organizations providing services to electrical customers and utilities.
Operations	The managers of the movement of electricity.
Bulk Generation	The generators of electricity in bulk quantities. May also store energy for later distribution.
Transmission	The carriers of bulk electricity over long distances. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity.

Table 5 Domains and actors in the Smart Grid conceptual model (NIST, 2009)

2.4.3.3 Smart Grid applications

The situation of Smart Grid application model has grown in importance in light of recent IEEE Smart Grid, as shown below in Fig. 9 (S.G., 2014; Gaoa, 2012):

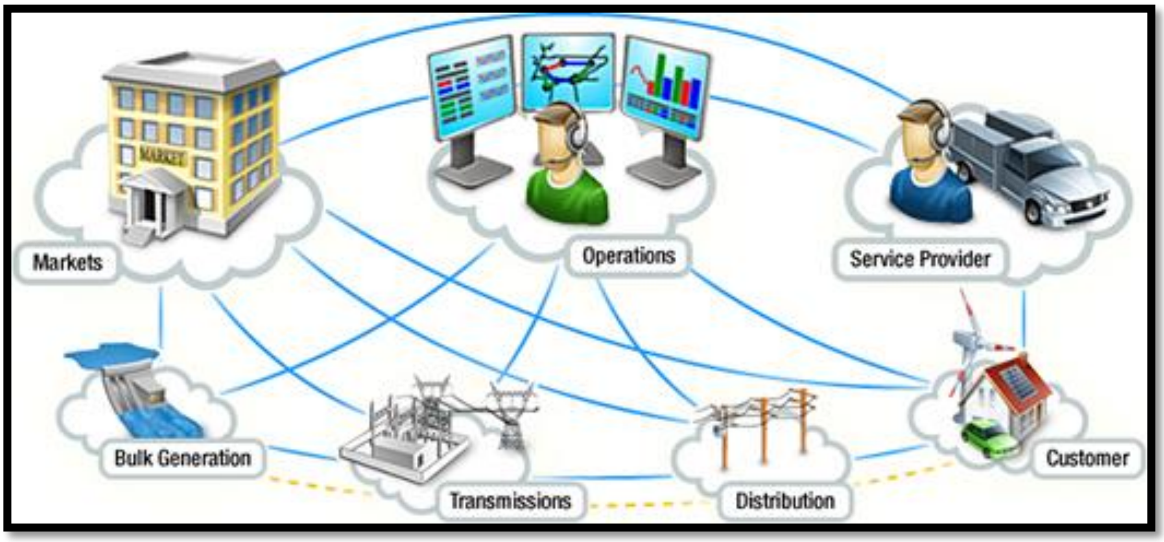


Figure 9 Smart Grid application model (S.G., 2014; Gaoaetal., 2012)

The main physical parts of the electrical power grid are generation, transmission, distribution, and end-user (load). Generation is the collection of power plants electrically connected to the grid (Milligan et al., 2012). The bulk (or wholesale) generation of the Smart Grid application focuses on generating electrical power by using both of renewable and non-renewable energy sources in generation part of electrical power grid (S.G., 2014). These sources can be based on the technologies explored in clean energy solutions such as nuclear, efficient natural gas, clean coal, and energy efficiency, and renewable energy sources including biomass, geothermal, hydropower, solar, pump storage and wind (S.G., 2014; Milligan, 2012). Energy storage may also be included in this area (S.G., 2014).

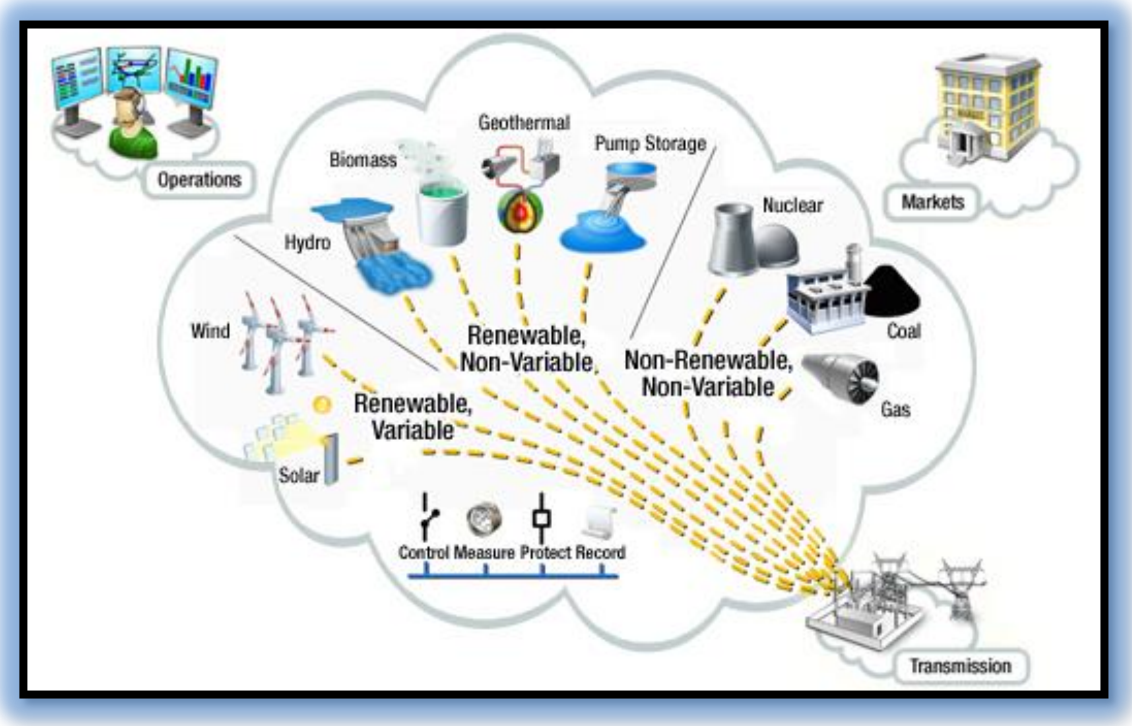


Figure 10 Bulk Generation of Smart Grid application model (S.G., 2014; Milligan, 2012)

The distribution part of the electrical power grid is to distribute the electrical power from transmission to the customers (end-users). The smart meters and all intelligent field equipment are connected to the distribution, and are managed and controlled through a two-way wireless or wire line communication networks. The distribution part may also connect to energy storage equipment and alternative resources in electrical power grid (S.G., 2014; Milligan et al., 2012). The distribution of Smart Grid application model is shown as below (S.G., 2014; NIST, 2009):

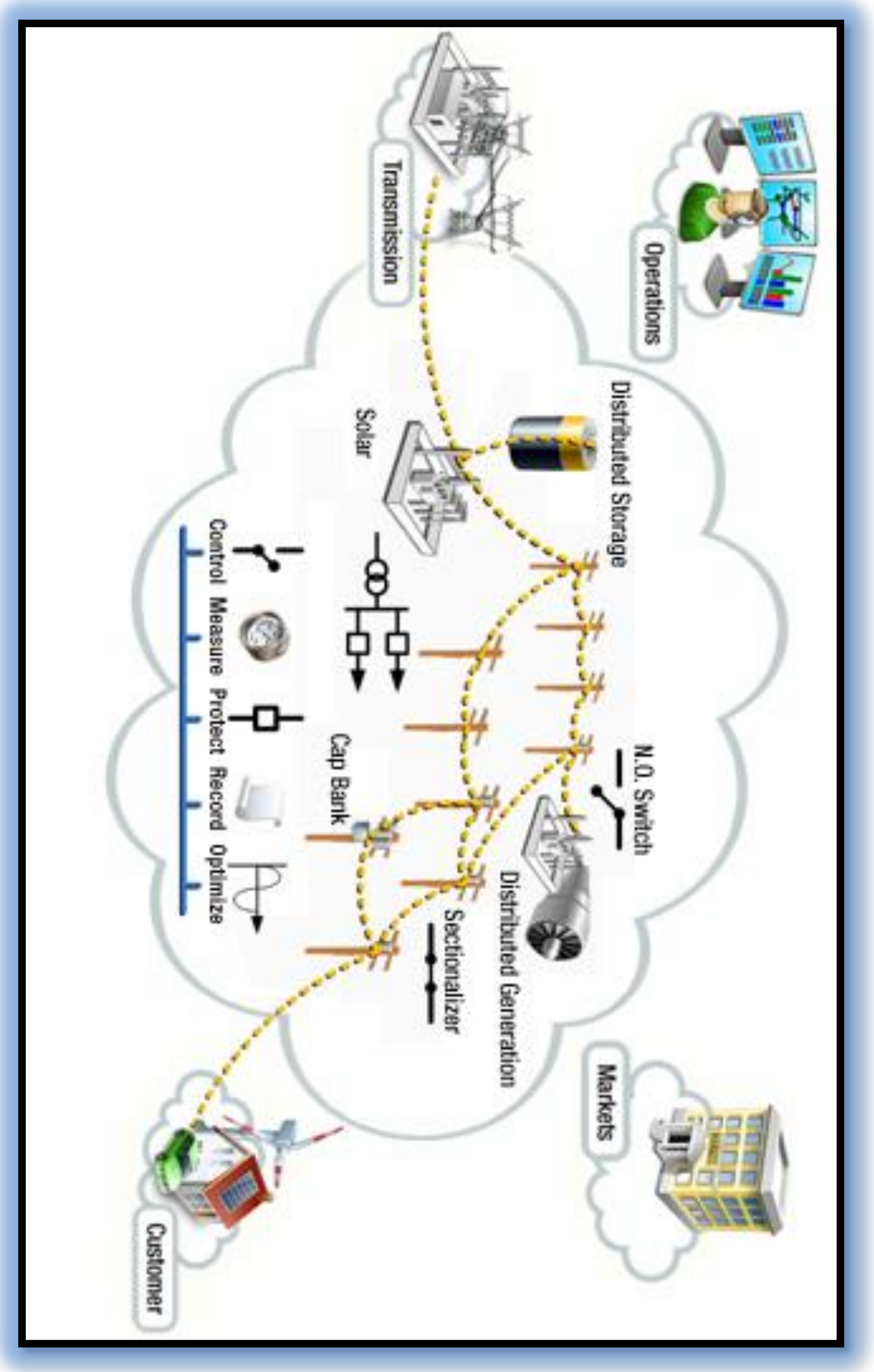


Figure 11 Distribution of Smart Grid application model (S.G., 2014; NIST, 2009)

The customer (end-users of electricity) part of the electrical power grid is the home and commercial/ industrial buildings connected to the electric distribution network. The electrical power energy is transported to customers from the distribution network via the smart meters which control and manage the electricity flow and show the information on energy usage and patterns (S.G., 2014). Energy generation, energy storage and the management of energy use and connectivity with plug-in vehicles may be also included in a customer part (S.G., 2014; Milliganetal., 2012). The customer part of Smart Grid application model is shown as below (S.G., 2014; NIST, 2009):

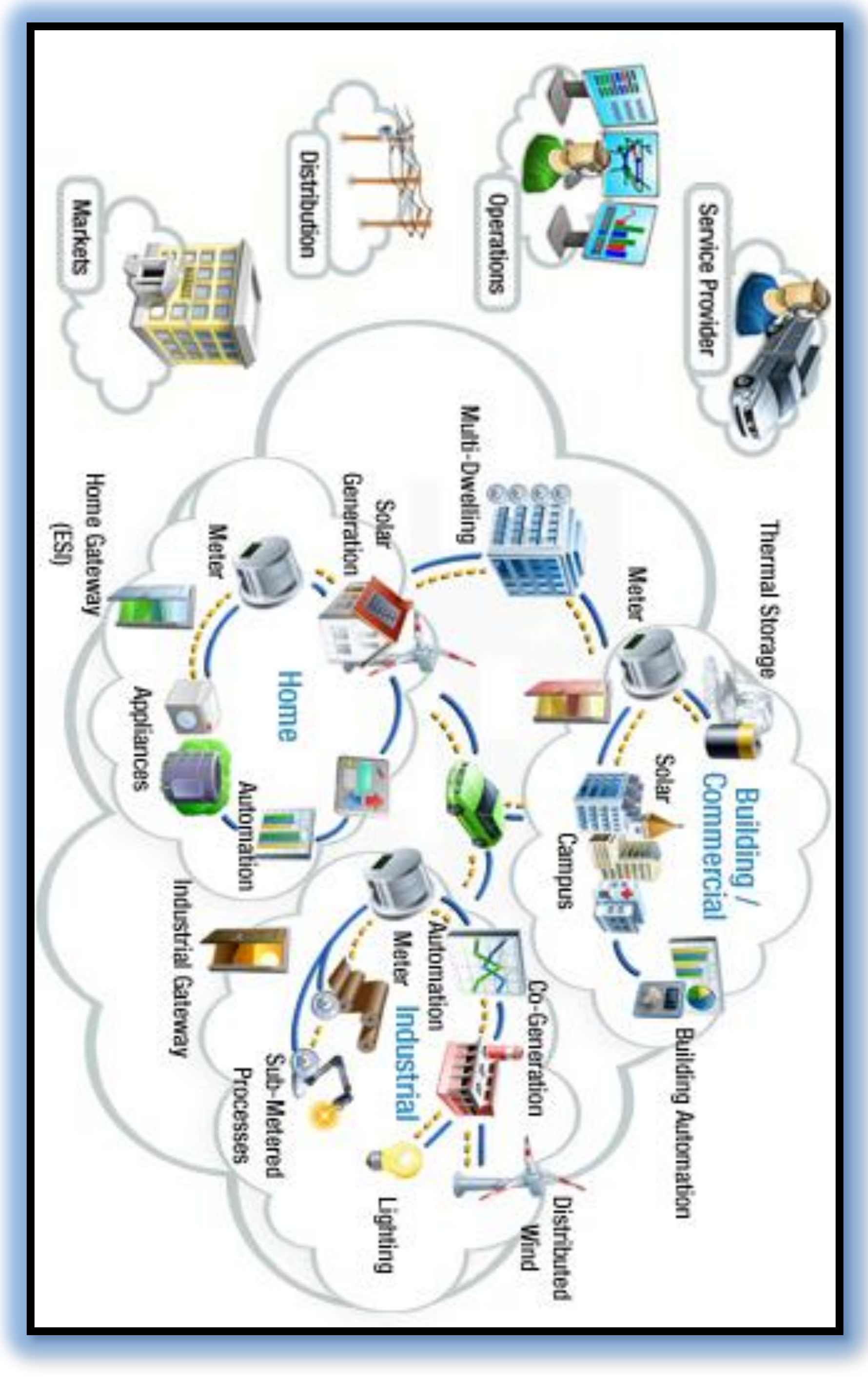


Figure 12 Customers of Smart Grid application model (S.G., 2014; NIST, 2009)

Furthermore, the operation manages and controls all electricity flow in the electrical power grid. Substations, customer premises networks and other intelligent field equipment are connected to the operation using a two-way communications network (S.G., 2014). It also gives monitoring, reporting, controlling and supervision status and important process information and decisions to the whole electrical power grid. Business intelligence processes gather data from the customer and network, and provide intelligence to support the decision-making (S.G., 2014; Milliganetal., 2012). The figure below gives the operation of a Smart Grid application model (S.G., 2014; NIST, 2009; Ancillottietal., 2013):

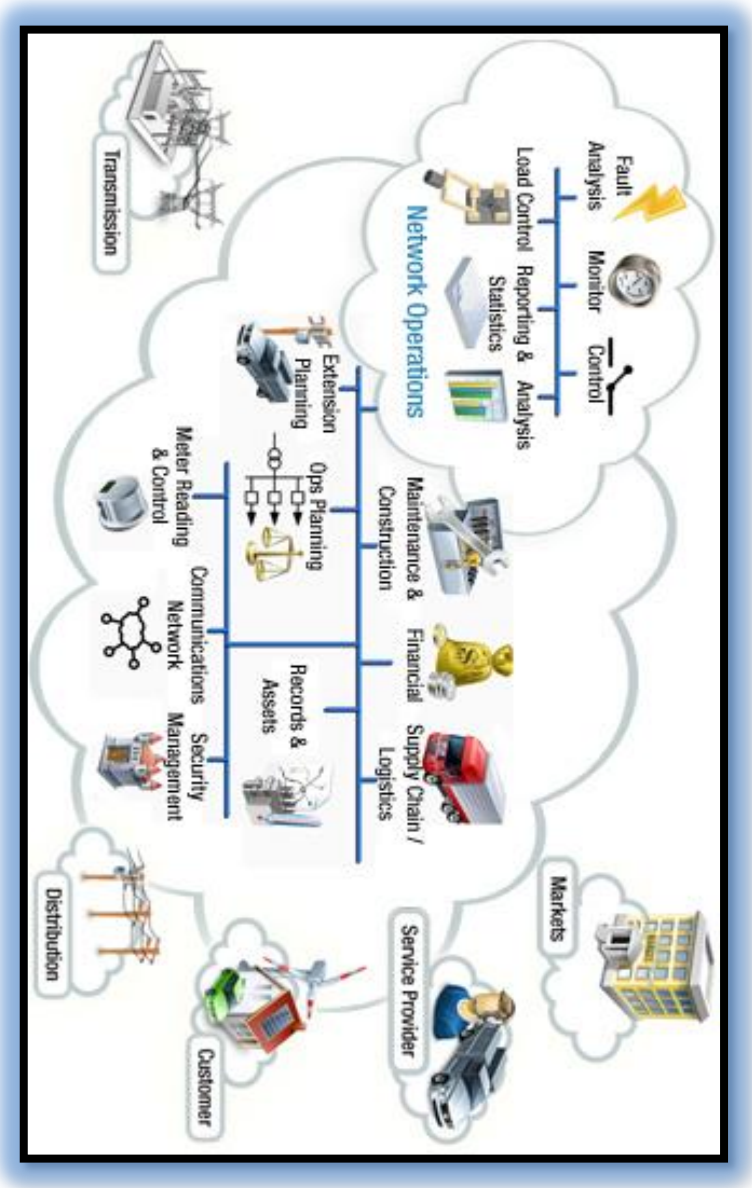


Figure 13 Operations of Smart Grid application model (S.G., 2014; NIST, 2009; Ancillotti, 2013)

In addition, the market (commercial operation) conducts the operation and coordination of every element in electrical power market providing the market management, wholesaling, retailing and trading of energy services (S.G., 2014), (Ancillotti, et al., 2013). The market communicates with all other parts of electrical power market making sure they are coordinated in a competitive market (S.G., 2014; Ancillottietal., 2013). Moreover, it handles energy information clearinghouse operations and information exchange with third-party service providers (S.G., 2014; Milliganetal., 2012). Markets of Smart Grid application model is illustrated as below (S.G., 2014; NIST, 2009; Ancillottietal., 2013):

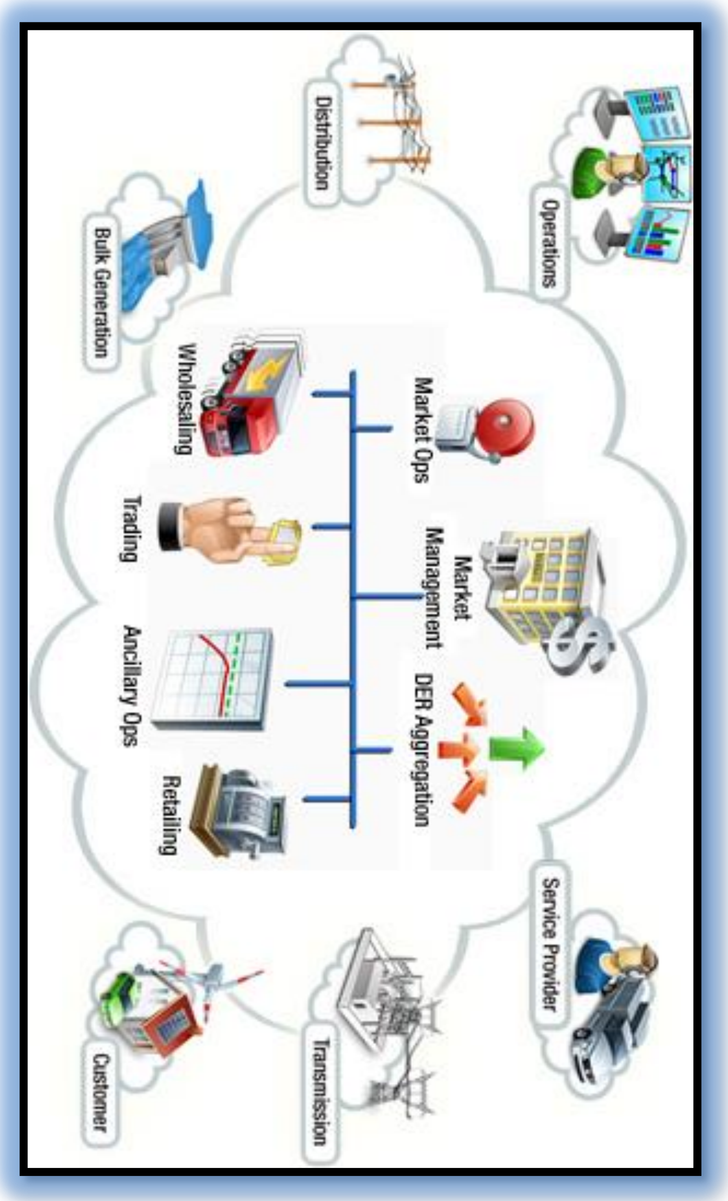


Figure 14 Markets of Smart Grid application model (S.G., 2014; NIST, 2009;Ancillotti, 2013)

The service provider of the electrical power grid handles all third-party operations in electrical power market, e.g. including web portals that provide energy efficiency management services to end-customers, data exchange between the customer and the utilities concerning energy management and electricity supplies to homes and buildings. It also manages other processes for the utilities, e.g. demand response programs, outage management and field services (S.G., 2014; Milliganetal., 2012). Therefore, the service provider in a Smart Grid application has grown in importance in light of recent IEEE Smart Grid, as shown below (S.G., 2014; NIST, 2009; SGCCy, 2013):

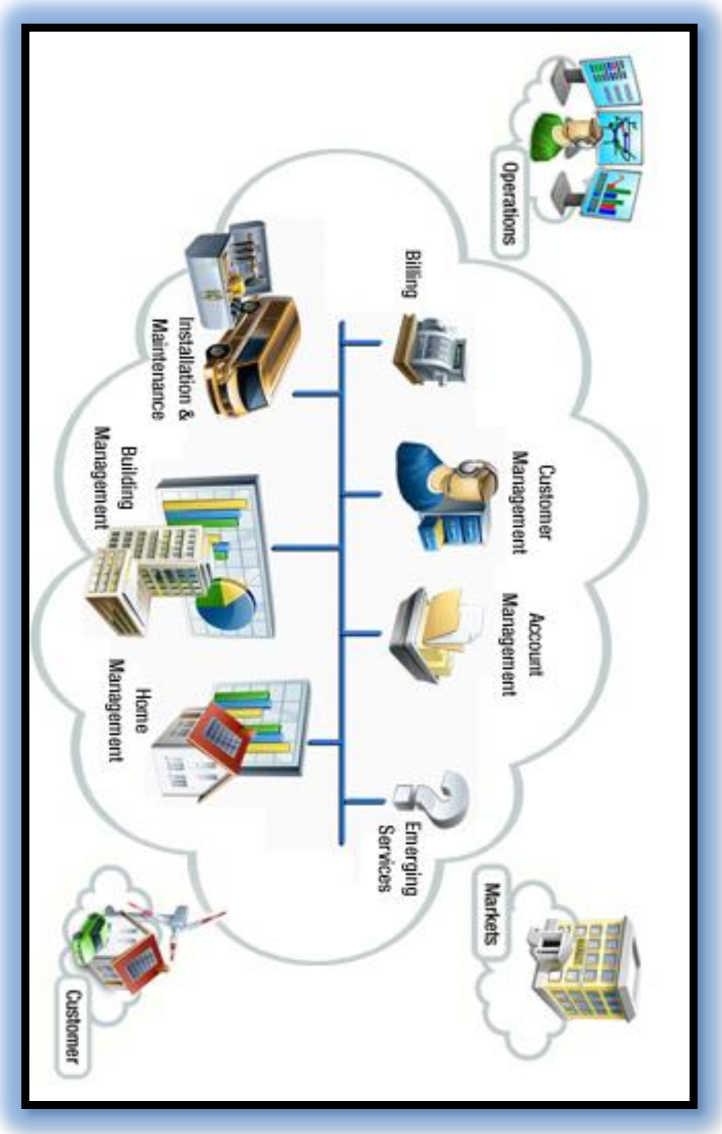


Figure 15 Service provider of Smart Grid application model (S.G., 2014; NIST, 2009; SGCCy, 2013)

The transmission of electrical power grid within Smart Grid is the collection of networked high-voltage lines from generation to load (end-users) in electrical power grid (S.G., 2014; Milliganetal., 2012). The transmission cost can be reduced through sharing of resources, which provides enhanced reliability in case of events such as the loss of a large generator.

The distribution system refers to the lower-voltage generally radial lines that deliver electricity to the load (end-users) (S.G., 2014; Milliganetal., 2012).

2.4.3.4 Smart Grid Networks for information exchange

The Smart Grid is a network of networks consisting of many systems and subsystems which are interconnected to provide end-to-end services between and among stakeholders as well as between and among intelligent devices. The systems and subsystems have various ownership and management boundaries, so information exchange within the smart grid is imperative (NIST, 2009). The Figure 16 below demonstrates the Smart Grid networks for information exchange (NIST, 2009):

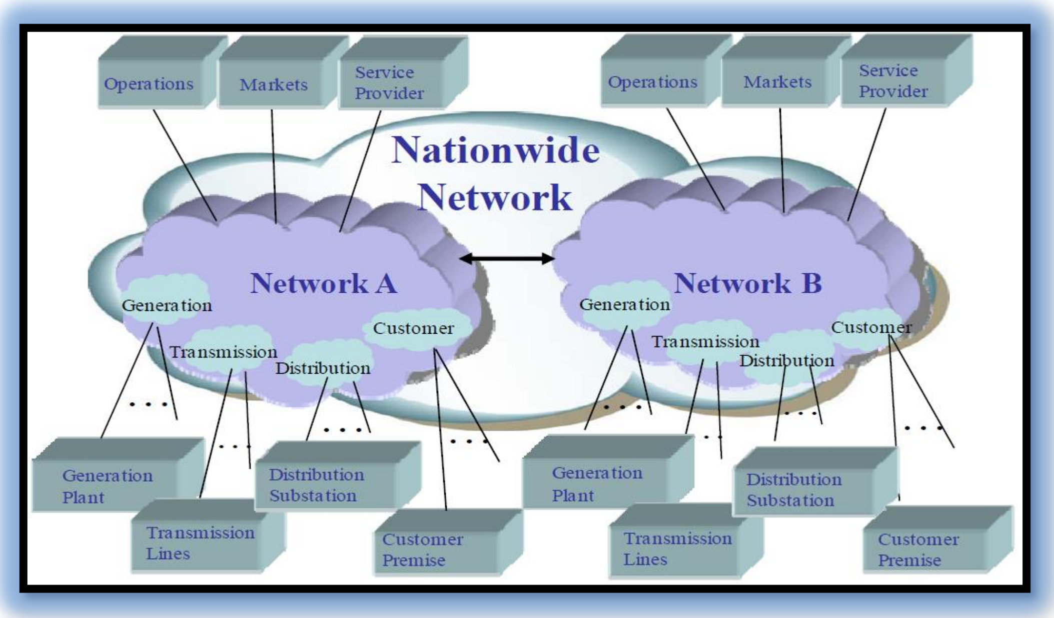


Figure 16 Smart Grid Networks for Information Exchange (NIST, 2009)

2.4.4 Advantages of the Smart Grid

The detailed comparison between smart grid and current grid has been given by Kiyoul Lee and Mooyoung Jung in their conference paper *Fractal-based Control and Monitoring System for Smart Grid*, as shown in table 6 below (Lee & Jung, 2009).

Moreover, the current electrical power grid has been facing some problems such as the lack of automated analysis, equipment failures, energy storage problems, the capacity limitations of electricity generation, one-way communication and increasing electricity demand. Besides, decrease in fossil fuels, the growing population, the global climate change, greenhouse gas emissions also limits the current grid (Gungoretal., 2010; DoE-1, 2011; Erol-Kantarci & Mouftah, 2011; Saber & Venayagamoorthy, 2011). Against this, the demand of the smart grid is emerging, and it is the new development trend in China and the world.

Principal Characteristics	Today's Grid	Smart Grid
Self-heals	Responds to prevent further damage. Focus is on protection of assets following system faults	Automatically detects and responds to actual and emerging transmission and distribution problems. Focus is on prevention. Minimizes consumer impact.
Motivates & includes the consumer	Consumers are uniformed and non-participative with the power system.	Informed, involved and active consumers. Broad penetration of Demand Response
Resists attack	Vulnerable to malicious acts of terror and natural disasters.	Resilient to attack and natural disasters with rapid restoration capabilities.
Provides power quality for 21st century needs	Focused on outages rather than power quality problems. Slow response in resolving PQ issues.	Quality of power meets industry standards and consumer needs. PQ issues identified and resolved prior to manifestation. Various levels of PQ at various prices.
Accommodates all generation and storage options	Relatively small number of large generating plants. Numerous obstacles exist for interconnecting DER.	Very large numbers of diverse distributed generation and storage devices deployed to complement the large generating plants. "Plug-and-play" convenience. Significantly more focus on and access to renewable.
Enables markets	Limited wholesale markets still working to find the best operating models. Not well integrated with each other. Transmission congestion separates buyers and sellers.	Mature wholesale market operations in place; well integrated nationwide and integrated with reliability coordinators. Retail markets flourishing where appropriate. Minimal transmission congestion and constraints.
Optimizes assets and operates efficiently	Minimal integration of limited operational data with Asset Management processes and technologies. Siloed business processes. Time based maintenance.	Greatly expanded sensing and measurement of grid conditions. Grid technologies deeply integrated with asset management processes to most effectively manage assets and costs. Condition based maintenance.

Table 6 A Comparison between Smart Grid and current Grid (Lee & Jung, 2009)

Based on the review of the Smart Grid application, the major advantages of smart grid include (S.G., 2014; Milliganetal., 2012; Gungoretal., 2010):

- improving efficiency, reliability and safety;

- smooth integration of renewable and alternative energy sources;
- using automated control and modern communications technologies.

2.4.5 Smart Grid Opportunities

Because of the importance of smart grid, some countries have started doing research and development in smart grid applications and technologies, such as China, USA, Japan, South Korea, Canada, Australia, Brazil and European countries (IEAa, 2011). For example, the US Government has announced the largest power grid modernization investment in the US history, i.e. '$3.48 billion for the quick integration of proven technologies into existing electric grids, $435 million for regional smart grid demonstrations, and $185 million for energy storage and demonstrations. Also, China will invest at least $96 billion in smart grid development by 2020 (IEAa, 2011). Selected national smart grid demonstration and deployment efforts contributed by IEA are given in Table 7 (IEAa, 2011):

Country	National smart grid initiatives
China	The Chinese government has developed a large, long-term stimulus plan to invest in water systems, rural infrastructures and power grids, including a substantial investment in smart grids. Smart grids are seen as a way to reduce energy consumption, increase the efficiency of the electricity network and manage electricity generation from renewable technologies. China's State Grid Corporation outlined plans in 2010 for a pilot smart grid programme that maps out deployment to 2030. Smart grids investments will reach at least USD 96 billion by 2020.
United States	USD 4.5 billion was allocated to grid modernisation under the American Recovery Reinvestment Act of 2009, including: USD 3.48 billion for the quick integration of proven technologies into existing electric grids, USD 435 million for regional smart grid demonstrations, and USD 185 million for energy storage and demonstrations.
Italy	Building on the success of the Telegestore project, in 2011 the Italian regulator (Autorità per l'Energia Elettrica ed il Gas) has awarded eight tariff-based funded projects on active medium voltage distribution systems, to demonstrate at-scale advanced network management and automation solutions necessary to integrate distributed generation. The Ministry of Economic Development has also granted over EUR 200 million for demonstration of smart grids features and network modernisation in Southern Italian regions.
Japan	The Federation of Electric Power Companies of Japan is developing a smart grid that incorporates solar power generation by 2020 with government investment of over USD 100 million. The Japanese government has announced a national smart metering initiative and large utilities have announced smart grid programmes.
South Korea	The Korean government has launched a USD 65 million pilot programme on Jeju Island in partnership with industry. The pilot consists of a fully integrated smart grid system for 6 000 households, wind farms and four distribution lines. Korea has announced plans to implement smart grids nationwide by 2030.
Spain	In 2008, the government mandated distribution companies to replace existing meters with new smart meters; this must be done at no additional cost to the customer. The utility Endesa aims to deploy automated meter management to more than 13 million customers on the low voltage network from 2010 to 2015, building on past efforts by the Italian utility ENEL. The communication protocol used will be open. The utility Iberdrola will replace 10 million meters.
Germany	The E-Energy funding programme has several projects focusing on ICTs for the energy system.
Australia	The Australian government announced the AUD 100 million "Smart Grid, Smart City" initiative in 2009 to deliver a commercial-scale smart grid demonstration project. Additional efforts in the area of renewable energy deployments are resulting in further study on smart grids.
United Kingdom	The energy regulator OFGEM has an initiative called the Registered Power Zone that will encourage distributors to develop and implement innovative solutions to connect distributed generators to the network. OFGEM has set up a Low Carbon Networks fund that will allow up to GPB 500m support to DSO projects that test new technology, operating and commercial arrangements.
France	The electricity distribution operator ERDF is deploying 300 000 smart meters in a pilot project based on an advanced communication protocol named Linky. If the pilot is deemed a success, ERDF will replace all of its 35 million meters with Linky smart meters from 2012 to 2016.
Brazil	APTEL, a utility association, has been working with the Brazilian government on narrowband power line carrier trials with a social and educational focus. Several utilities are also managing smart grid pilots, including Ampla, a power distributor in Rio de Janeiro State owned by the Spanish utility Endesa, which has been deploying smart meters and secure networks to reduce losses from illegal connections. AES Eletropaulo, a distributor in São Paulo State, has developed a smart grid business plan using the existing fibre-optic backbone. The utility CEMIG has started a smart grid project based on system architecture developed by the IntelliGrid Consortium, an initiative of the California-based Electric Power Research Institute.

Table 7 Selected national smart grid demonstration and deployment efforts (IEAa, 2011)

2.4.6 Aims of SGCC Smart Grid project in China

Development of smart grid aims to support clean energy, raise energy efficiency, tackle climate change and reduce emissions (SGCC, 2011b). Major efforts have been put into grid planning, testing and research systems, demonstration projects, international cooperation and standardization (SGCC, 2011b; UHVC-SGCC, 2013).

Moreover, a main Smart Grid project in SGCC has been an ultra-high-voltage (UHV) grid backbone and coordinated development of subordinate grids at all levels (UHVC-SGCC, 2013). However, the challenges of Smart Grid include regulation and optimization methodology to allow Chinese electric power grid operators to optimize their operations in terms of customer satisfaction, operational cost and environmental impacts and so on (Bari et al., 2004).

2.4.7 Challenges for Smart Grid Strategy in China's EPGO

To address Smart Grid applications in China's electrical power market, China has to reflect and devise a sound design methodology for SGS regarding the customer expectation (CE) to improve an effective regulation of EPGO in China's electrical power market (Liu, 2013). Furthermore, there are three energy problems in China, including the problem of sustained supply, problem of transport and allocation, and the quality problem of development (Liu, 2013). Therefore, the design methodology for SGS has to also focus on sustained supply, problem of transport and allocation, and the quality problem.

2.4.8 Regulation framework of Smart Grid in China

China Smart Grid Regulation Framework

The main Smart Grid and Energy Development Regulation Departments (SGEDRD) in China includes the National Development and Reform Commission, National Energy Administration, State Electricity Regulatory Commission, China Electricity Council and Ministry of Science and Technology as shown in Figure 17 (GLOVER et al., 2011; SGN, 2013; Wang etal., 2013).

National Development and Reform Commission (NDRC) is ministerial agency in

China. The duties of NDRC for Smart Grid include:

1) Organize smart grid development plans within national development plans;
2) Making decisions for Smart Grid project approval process;
3) Controlling electricity price.

National Energy Administration (NEA) sits under the NDRC. It is a vice-ministerial department. The duties of NEA for Smart Grid are:

①Formulating and implementing national energy policy and development plans, which includes smart grid development plans;
②Taking part in the approval process of smart grid projects.

State Electricity Regulatory Commission (SERC) is part of NEA since the reformation in March 2013. The duty for Smart Grid is to enhance the energy supervision and management.

China Electricity Council (CEC) is a non-profit organization composed of all China's power enterprises. It operates under the supervision of the SERC,

①As the think tank for power policies;
②As a lobbyist for the development of smart grid plans.

The duty of **Ministry of Science and Technology (MOST)** for smart grid include:

①Research on new technologies;
②International cooperation.

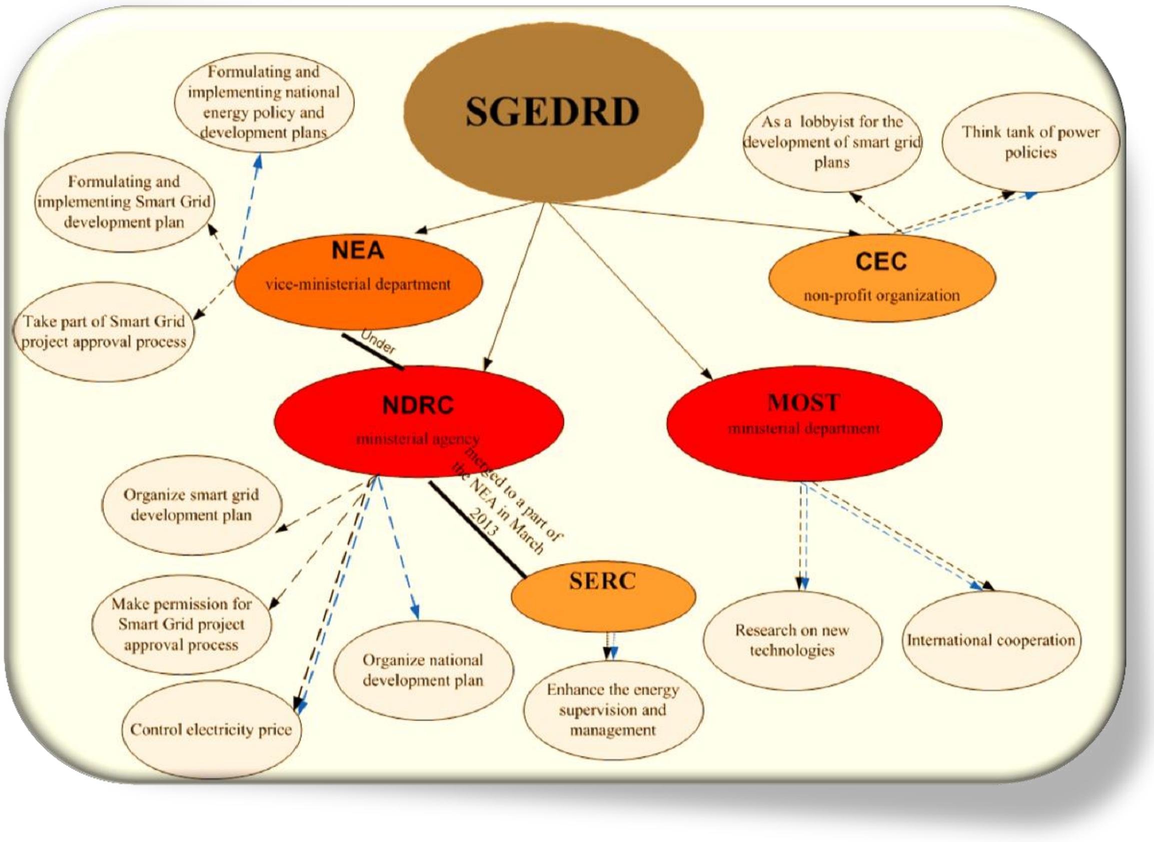


Figure 17 Regulation framework of Smart Grid in China

Blue line:national energy policy
Black line(solid line &dashed line) :Smart Grid policy

2.4.9 Smart Grid development plan in SGCC

A SGCC's Smart Grid development plan has been promoted by the China's Smart Grid Program: One Goal, Two Main Lines, Three Stages and More. SGCC developed the smart grid strategy 'Strong & Smart Grid' in 2009. The goal of this strategy includes: incorporating information into automatic and interactive technology, and integrated operation, consolidated development, standardized construction and streamlined control of management (Wang, 2012). Its applications include electrical power generation, transmission, substation, distribution, dispatching, consumption, etc. (Wang, 2012). As the main construction of Smart Grid in China has taken from 2010-2015, improvements of Smart Grid are planned for 2016-2020 (Wang, 2012).

2.5 Energy strategies

In recent years, climate change, the shortage of the traditional energy and many other problems have emerged in the world (Xinhua, 2012; (Luo et al., 2010; Miao et al., 2009; Miao-1et al., 2009; WEC, 2013). So smart grid strategy, sustainable development strategy, energy Trilemma Strategy and many other energy strategies have been launched to ensure energy security and improve energy efficiency for the economic development (Luo et al., 2010; Miao et al., 2009; Miao-1et al., 2009). Therefore, Smart Grid Strategy, Energy Trilemma Strategy and the Sustainable Development Strategy are briefly studied in this section.

2.5.1 3S energy regulation strategy

3S energy regulation strategy is to ensure safety of energy supply, sustainable development, and to safeguard the environment (3S). The 3S Strategy is given in the figure below (Wang et al., 2010):

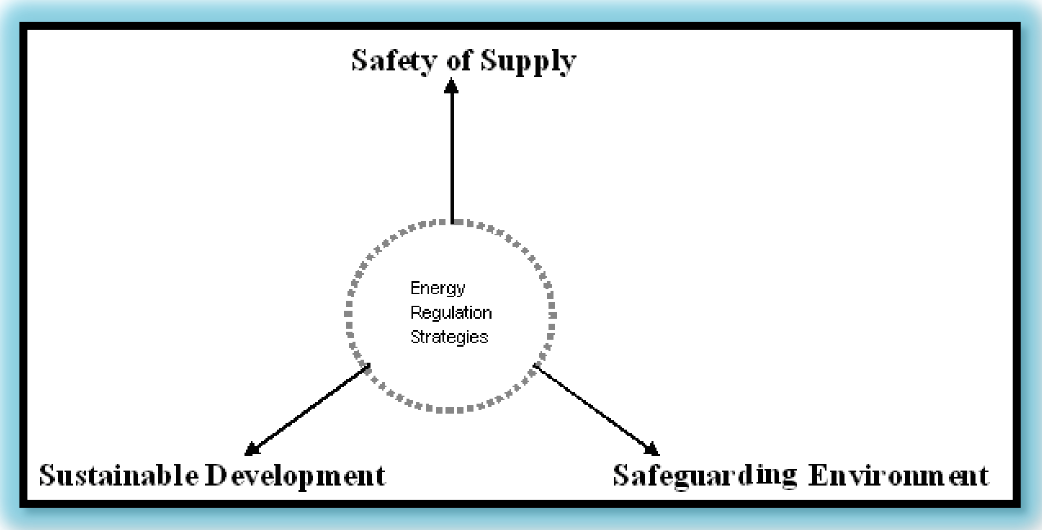


Figure 18 3S energy regulation strategy

2.5.2 Sustainable development strategy

The sustainable development scheme includes social, economic and environmental development. A scheme of sustainable development is shown in Figure 19. The Venn diagram of sustainable development has many versions, but was first used by economist

Edward Barbier (1987) (Wikipedia, 2014).

The concept of sustainable development was recognized for the first time at the UN Conference on the Human Environment held in Stockholm in 1972 (SDC, 2013). Sustainable development aims to achieve economic prosperity, environmental quality and social equity simultaneously. Sustainable development is characterized by the bearable, equitable and viable components. The components of the sustainable development is shown in Fig.19 below: (Lavigne & Wotherspoon, 2008)

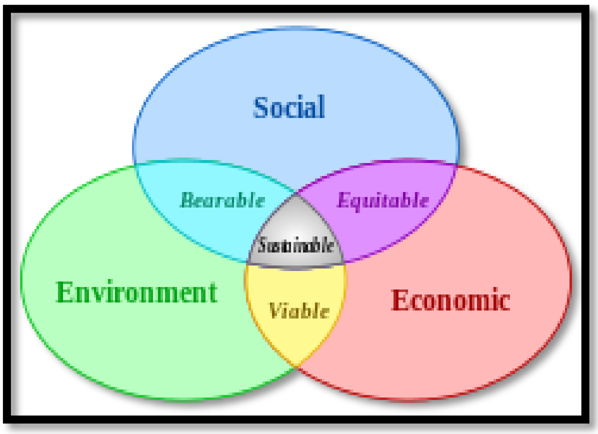


Figure 19 The components of the sustainable development (Lavigne & Wotherspoon, 2008)

Most EPGOs have been owned by the government in the world, and EPGO is a natural monopoly part of the China's electrical power market (Wang et al., 2010). So it is challenging to get the balance among the country's economic development, social equity and safeguard environment, with the bearable electric price (bearable), quality service (equitable), efficiency investment (sustainable) and sustainable safety supply for EPGOs in the world.

2.5.3 Energy Trilemma

Smart grid strategy is an important strategy for the safety and quality of grid operation, customer services and safeguard environment for EPGO in the world. However, what is the exact relationship among the energy security, social equity and environment impact mitigation?

The answer can be get from the Energy Trilemma proposed by the World Energy Council (WEC 2012) in terms of Energy Security, Social Equity and Environmental Impact, as shown below:

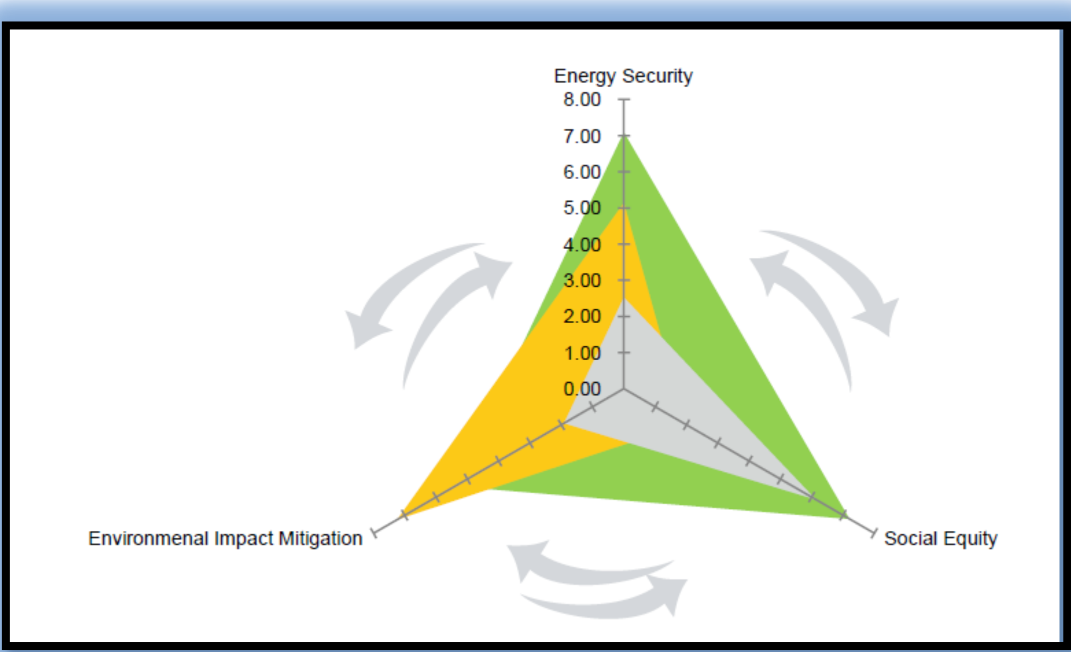


Figure 20 The meaning of energy trilemma (WEC, 2014)

The Energy Trilemma has three main dimensions – energy security, social equity, and environmental impact, involving complex links between public and private actors, governments and regulators, economic and social factors, national resources, environmental concerns, and individual behaviors (WEC, 2014; EP, 2003). The Energy Trilemma provides a clear framework for the energy transformation making sustainable energy systems a reality (WEC, 2014; EP, 2003). Government and industry are faced with the challenge to address energy security, universal access to affordable energy services, and environmentally sensitive production and use of energy (WEC, 2014). Therefore, the Energy Trilemma will value for the regulation and optimization of EPGOs.

2.6 Equilibrium theory and energy market regulations

Equilibrium theory is important to economic analysis. It is the theoretical foundation of the classical economic models and their relevance to the understanding of socioeconomic phenomena (Arrow & Debreu, 1954).

There is an important revelation from the UK energy regulation model. Based on the equilibrium theory, the Equilibrium Energy Regulation Model can be demonstrated in Figure 21 (Wang et al., 2010).

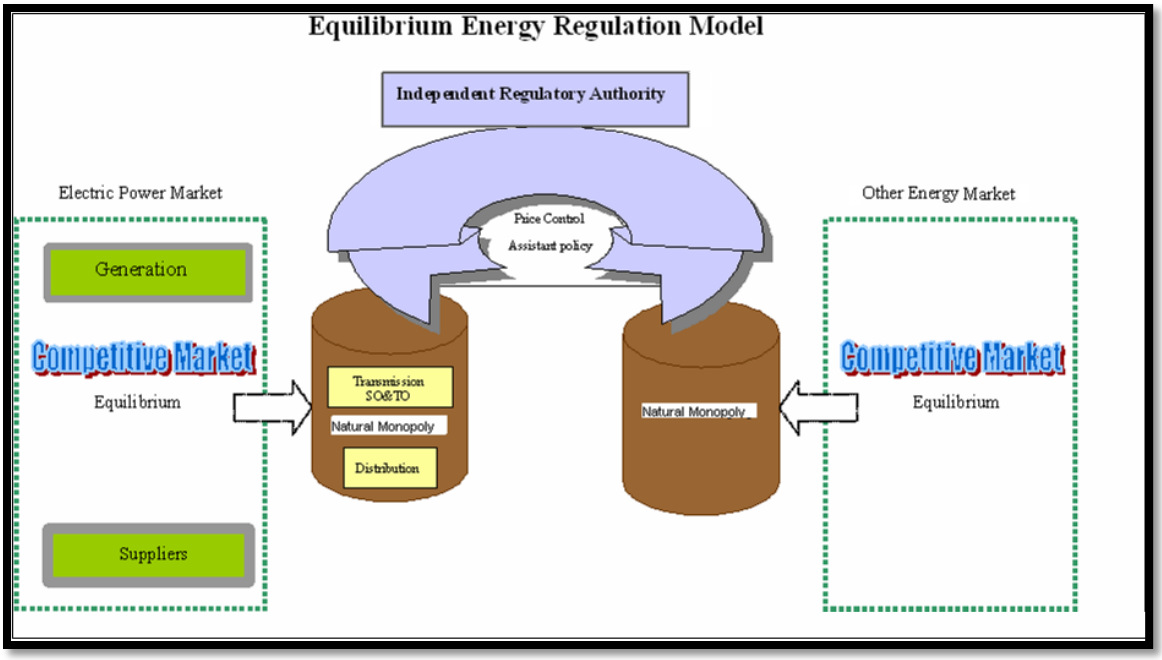


Figure 21 Equilibrium Energy Regulation Model

2.7 Quality function deployment (QFD)

2.7.1 Definition of QFD

QFD is a quality management approach that provides a means of translating customer requirements into the appropriate technical requirements for each stage of product development and production (i.e. marketing strategies, planning, product design and engineering, prototype evaluation, production process development, production, sales) (Sullivan, 1986; Suhardi, 2013).

2.7.2 A brief history of QFD

QFD was developed in Japan in the late 1960s and early 1970s, and then it has been used and developed very well in US in the 1980s and later, also it has been applied in many industries in many countries (Chan & Wu, 2002; Tsoukalidisetal., 2009).

According to J. Terninkoin, in the 1960s, Quality Control and Quality Improvement had a typically manufacturing flavor in Japan in the late 1960s and early 1970s. Akao and other researchers went to work on improving the design process so that when the new product was introduced to manufacturing, it has high quality from the beginning. The process for improving the design was called Quality Function Deployment (QFD). From 1975 to 1995, this tool/process was integrated with other improvement tools to generate a mosaic of opportunities for product developers (Van de Poel, 2007).

2.7.3 House of Quality

QFD is driven by the use of House of Quality, using a matrix that relates customer wants or needs to design characteristics so that engineering and quality efforts can be concentrated on the most important and valuable characteristics (Akao, 1990). The word ‘‘House’’ is chosen because the original QFD tool used looks similar to a house with several rooms and a roof. The matrix in the QFD House of Quality translates what the customer wants “Whats” to the design ‘‘Hows’’ (e.g. services that satisfy customer wants) (Akao, 1990). The various elements of a basic House of Quality are shown in Figure 22 and Figure 23.

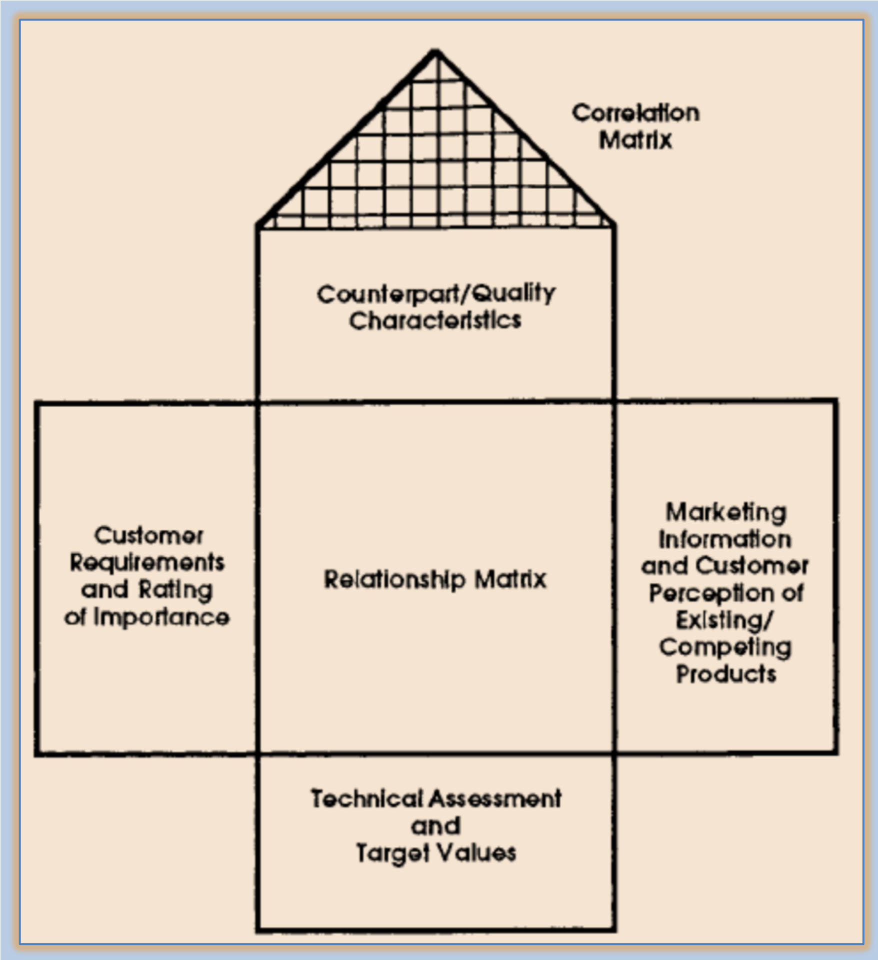


Figure 22 Basic House of Quality

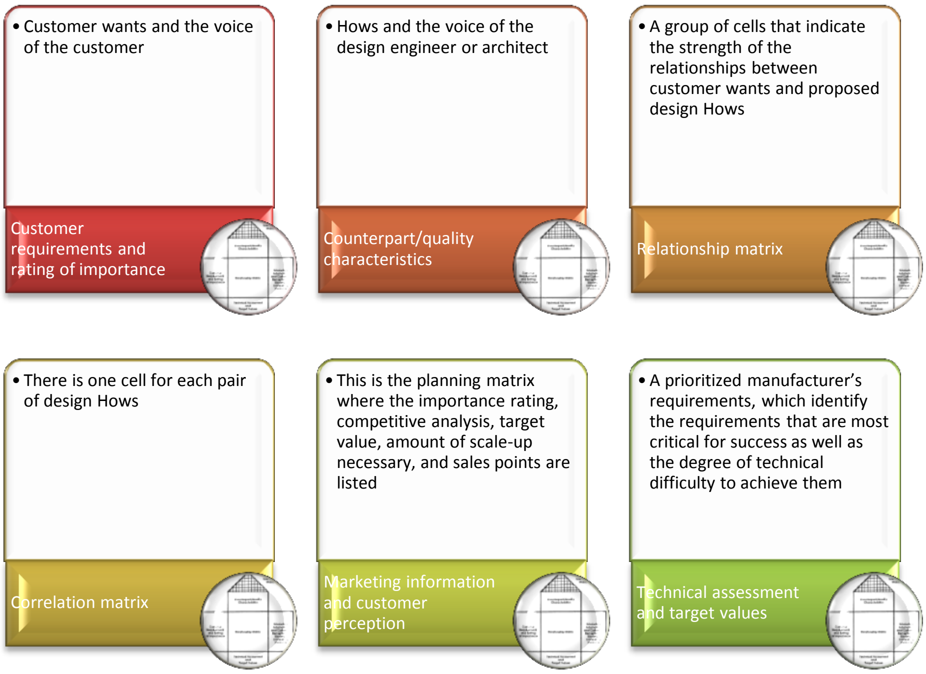


Figure 23 The elements of basic House of Quality (Akao, 1990)

2.7.4 Phases of QFD

QFD makes use of a number of matrices or HOQs (usually four phases) to define the relationships between product design and customer satisfaction (Temponi et al., 1998). QFD is an iterative process performed by a multifunctional team (Hauser, 1993). The matrices show a relationship between customer needs and product or process characteristics step by step, see Figure 24. The matrices link the needs identified at one stage of the process to the decisions that must be made at the next process stage (Griffin & Hauser, 1992). This first matrix translates the customer needs to the technical planning, and then the second matrix translates the technical requirements to component characteristics, and the third matrix translates the component characteristics to process characteristics. Finally, the fourth matrix translates the process needs to operational parameters. Therefore, the customer needs can be translated to the detailed operations through all steps or phases of QFD processes.

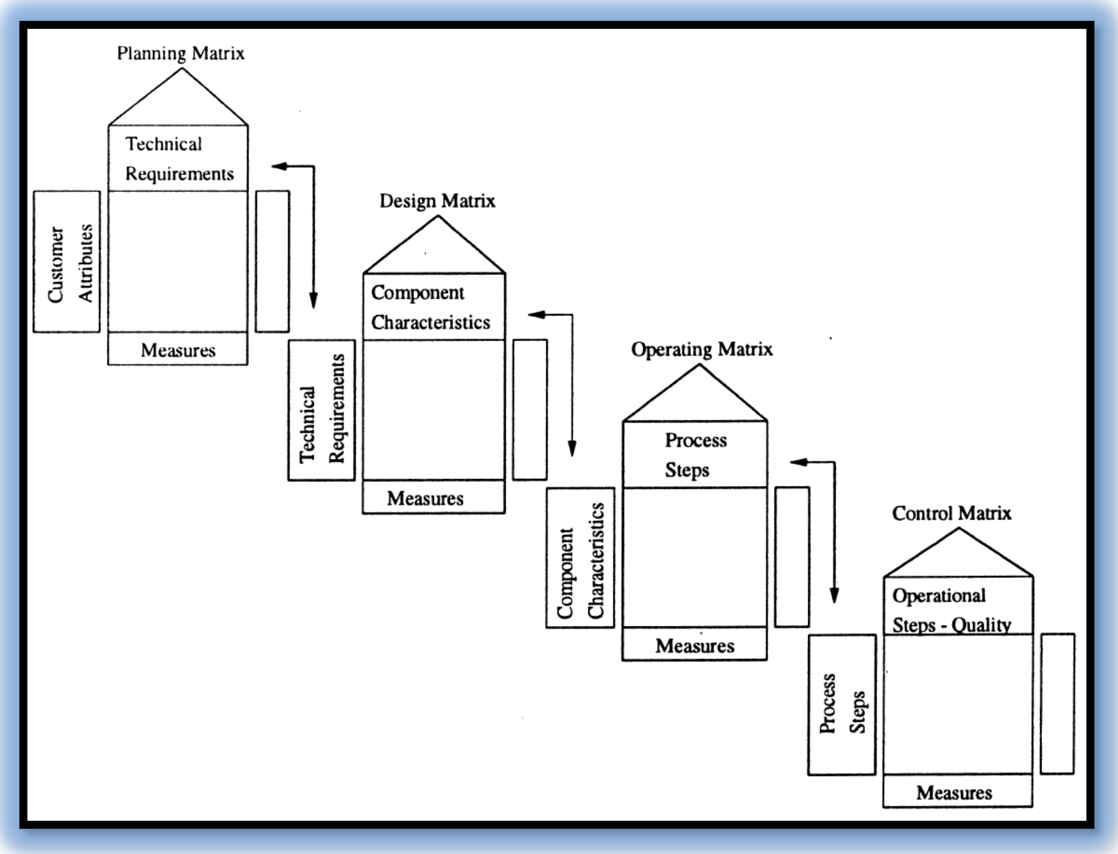


Figure 24 Quality function deployment process (Temponi et al., 1998)

2.7.5 Application areas of QFD

QFD originally aims to collect and analyze the customer's requirements, to produce products with higher quality and to meet or exceed customer's needs. Therefore, the primary functions of QFD are product development, quality management, and customer needs analysis. Later, QFD functions were used in other fields such as design, planning, decision-making, engineering, management, teamwork, timing, and costing. Essentially, there is no definite boundary for QFD's potential fields of applications (Zhou & Zhang, 2013).

2.7.5.1 QFD in electrical utilities

QFD is a method to translate customer needs into design quality, to deploy quality functions, and to deploy methods for designing quality into components and subsystems (Akao, 1994; Gargione, 1999). QFD is applied in a wide variety of services, consumer products in electronic and electrical utilities (C2C, 2013; Joiner & Ssholtes, 1988). Akao (1972) applied QFD to electrostatic copying machines and thus made electronics one of earliest QFD application sectors (Zhou & Zhang, 2013). QFD has also been applied in electrical utilities such as battery, gas burners, power systems, wind turbines and so on by companies including Pacific Gas and Electric, Florida Power and Light, etc. (Zhou & Zhang, 2013).

2.7.5.2 QFD in China's EPGO

The QFD has been applied in the quality management of energy management, but its potential benefits have not yet been exploited and realized sufficient in EPGO in China (David, Elaine, 2008). In this thesis, it will introduce the QFD to develop the methodology for smart grid strategy of the SGCC.

2.8 Excel Solver

Excel Solver is a software tool incorporated in Microsoft Excel. It helps users find the best way to allocate scarce resources. Excel Solver works by using search algorithms, and it can be used to solve both linear and nonlinear problems. The theory of Excel Solver is that the problem is solved by minimizing or maximizing an objective function to find optimal decision variables up to 200 variables within one process (ARIFetal., 2012; S & D, 1995; Dasgupta, 2008).

2.8.1 Brief introduction to Solver

In 1957, the General Problem Solver (GPS) was developed as a computer program by Herbert Simon, J.C. Shaw and Allen Newell. The GPS worked like a general problem solver (Wikipedia-1, 2013). Also, for non-linear equations systems, there are usually a wide range of different algorithms available. Both single and multiple algorithms can be implemented in a solver (Wikipedia-2, 2013). In Solver, the optimum target value in a target cell can be found iteratively by changing values in independent cell(s). The Solver Parameters interface is shown in Figure 25 (Bourg, 2006). Solver can be found or added from Add-Ins, and simple selection of Solver Add-in will make it available (Zeljkovic, 2005; Bourg, 2006; Fylstraetal., 1998).

Figure 25 Solver Parameters window (Bourg, 2006)

The algorithms can be selected through the Options interface in Solver. By clicking the Options button in the Solver Parameters interface, the Solver Options dialogue will be displayed as shown in Figure 26.

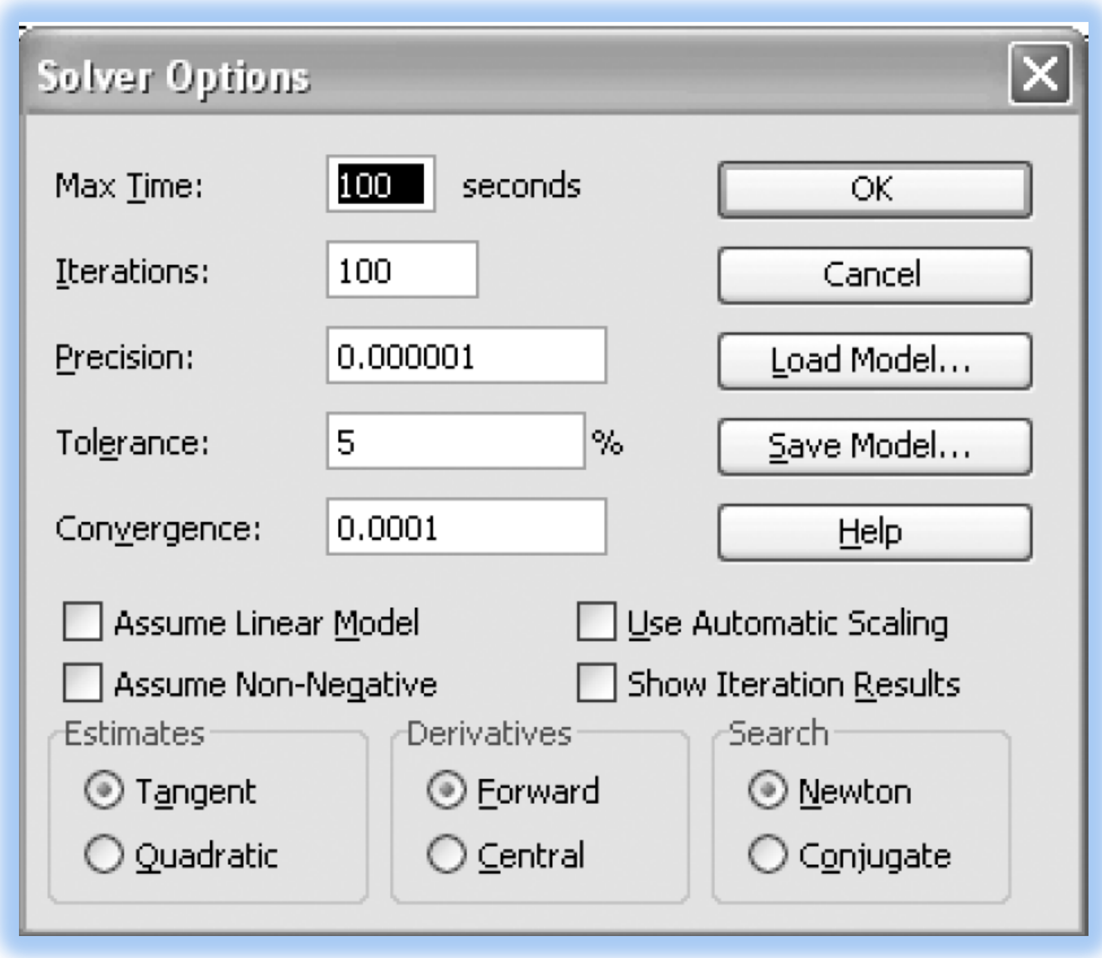


Figure 26 Solver Options window (Bourg, 2006), (Fylstra et al., 1998)

The parameters used in the Options interface are explained in detail in Table 8 (Bourg, 2006; Fylstraetal, 1998).

Max Time	**Max Time represents the maximum amount of time to allow Solver to obtain a solution, after which the process will be aborted. Solver will display a message box saying that it could not find a solution within the allowable time. You can set this value as high as 32,767 seconds (just over 9 hours), though I doubt you'll ever have to do so.**
Iterations	**Iterations specify the maximum number of iterations to allow Solver while attempting to find a solution. If the maximum number of iterations is reached before Solver finds a solution, the process will be aborted and Solver will display a message box saying that it could not find a solution within the allowable number of iterations. You can set this value as high as 32,767, though in my experience I've never had to set it above 1,000 and usually leave it at the default value of 100.**
Precision	Precision is specified as a decimal number between 0 and 1, with a default value of 1.0×10^{-6}. It is used by Solver to determine when a constraint is satisfied. The lower the value specified here, the higher the precision. Rarely do I have to change this value in practice.
Tolerance	**Tolerance is used to determine whether or not an integer-valued constraint is satisfied. Tolerance is expressed as a percentage, with a default value of 5%. If you're not using integer constraints, then Tolerance does not apply.**
Convergence	Solver considers a solution converged upon when the optimal values are within the value specified in the Convergence field over the last five solution iterations. Solver will display a message box after it converges on a solution. Solver will continue trying to converge so long as the specified maximum number of iterations or maximum time has not been reached. If either limit is reached, Solver will display a message box indicating that it could not converge.
Assume Linear Model	**Solver to use the simplex method of solution rather than the generalized reduced gradient method. In the event that you do specify this option, Solver will perform some checks to see if your model is indeed linear according to its criteria. If not, a message box will appear, warning you that your model does not fit the criteria for a linear model.**
Assume Non-Negative	Solver to automatically set lower limit constraints on all variable cells. If you know that your variables should always be greater than 0 and you want to constrain them to be so, check this option. This way you can avoid having to add a constraint manually for each variable.
Use Automatic Scaling	**In some problems the values of the independent variables and dependent variables may differ widely in magnitude. In these cases it's prudent to scale the model so that the magnitudes of the input and output values are of the same order. If you didn't already set up your model with scaling, then you can select this option to allow Solver to perform the scaling for you. In this case, it will scale your input and output values by dividing them by the initial value specified in the variable and target cells. This makes your initial guesses extra important for problems where scaling is required. It is always best to set your initial values to something realistic and reasonable for the problem under consideration.**
Show Iteration Results	Solver's progress as it iterates when solving a problem, you can check the Show Iteration Results option. When you do, a dialog box will appear, saying that Solver is paused and that the current iteration's results are displayed on the active worksheet. This option is useful when you want to see the results of each iteration step; for example, when Solver can't find a solution, you can use this option to try to gain insight as to why not. Under normal circumstances I do not check this option, since you actually have to press a button each time Solver is paused in order for it to proceed to the next step. This can become tedious if the solution for a particular problem requires much iteration.
Estimates	**Solver will estimate initial values of the independent variables. Tangent uses linear extrapolation, whereas Quadratic uses quadratic extrapolation and is said to speed convergence for nonlinear problems. Quite frankly, given today's high-speed processors, I notice little difference on convergence time for typical problems.**
Derivatives	Solver uses finite differences to compute gradients and provides two options for your control. You can use either a forward differencing scheme or a central differencing scheme. Central differencing requires more computations but is generally more accurate. Here again, the difference in processing time using either method may be imperceptible on today's processors. I generally just use central differencing. (See Recipe 10.6 for more discussion on forward differencing versus central differencing in general numerical work.)
Search	**Solver to use either Newton's method or the conjugate gradient method for solving a problem. Solver uses these methods to determine search directions during each iteration. Newton's method requires fewer computations than the conjugate method; however, Newton's method requires more memory. If memory is a concern—for example, if you're dealing with a very large problem with many variables and constraints or if your computer memory is limited—then you might want to use the conjugate method.**

Table 8 Solver's options (Bourg, 2006; Fylstraetal., 1998)

In addition, Solver has the Solver Results interface shown in Figure 27.

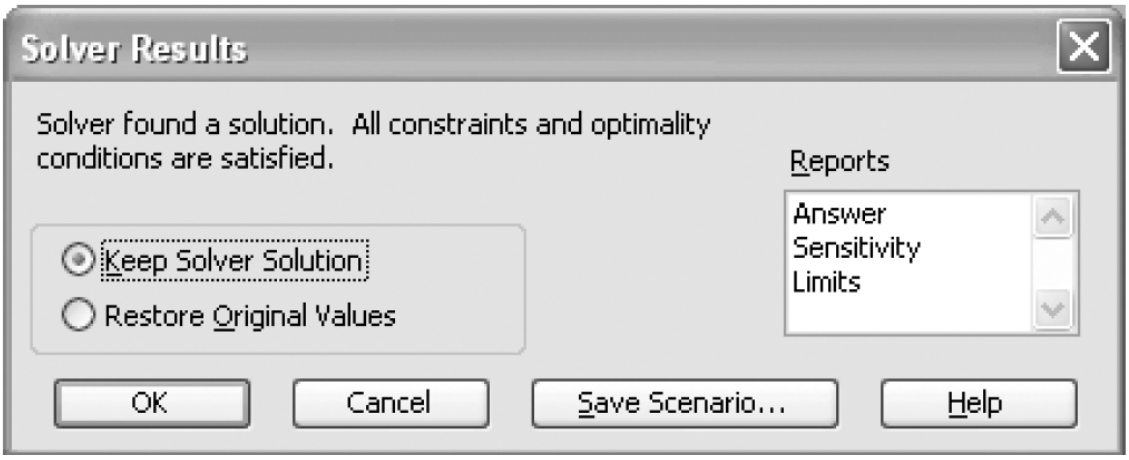


Figure 27 Solver Results interface (Bourg, 2006)

In the Solver Results, there are two options, i.e. Keep Solver Solution and Restore Original Values. Moreover, the Solver Results shows three types of Solver reports: Answer, Sensitivity, or Limits (Bourg, 2006). These reports are useful in understanding the results of a Solver solution, especially for constrained optimization problems (Bourg, 2006; Fylstraetal., 1998).

2.8.2 Using Excel Solver for Optimization problems

Excel Solver can solve linear problems using simplex method, but it is also capable of handling non-linear problems by employing a generalized reduced gradient method. Solver employs a branch and bound algorithm (Bourg, 2006).

In Solver, a designated formula cell was used for the objective function which will be maximized and minimized at optimal solution (Bourg, 2006). Excel Solver automatically finds the optimal values called decision variables in certain input cells. The decision variables should satisfy the constraints defined by formulas in the spreadsheet model in terms of the decision variables.

Slover has the capability of handling models with up to 200 decision variables. For nonlinear models, it may have up to 100 constraints besides simple bounds on the variables, but linear models can have any number of constraints. There is no limit on the number of cells participating in the calculation of the objective and constraints, or on the complexity of the formulas contained (Bourg, 2006; Fylstraetal., 1998).

Excel Solver has used for the optimization of EPGO quality and operation management due to its capability and ease to use.

2.9 Fractal Theory

The fractal theory has been applied in the area of control and monitoring system for Smart Grid (Lee & Jung, 2009).

2.9.1 Introduction

Fractal geometry is characteristic in self-similarity, and may be described by fractal dimension quantitatively (Mandelbrot, 1967). There are many fractal objects in nature, such as snowflakes, water systems, clouds, etc. (Zhou & Zhang, 2013). Fractal theory is often used to model porous media where the scaling of mass, pore space, pore surface and size-distribution of the fragments are all characterized by a single fractal dimension (Gimenez, 1997). Moreover, Katz and Thompson developed the structural expression of a porous medium, and they found that the spaces in sandstone showing self-similarity on a specific scale using ESS (Electronic Speculum Scanning) experiment (Katz & Thompson, 1985). Furthermore, they calculated the porosity with fractal statistics (Katz & Thompson, 1985). In addition, there is other research about the fractal dimensions of different fracture network properties, such as spatial distribution, density, connectivity, orientation, and length (Andersonetal., 1996; Babadagli, 2001). And the permeability of fractal porous media is simulated and calculated by using Monte Carlo technique (Yu et al., 2005). Li and Horne built a fractal model of capillary pressure curves for the Geysers rocks (Li & Horne, 2006).

2.9.2 Fractal dimension

Fractal dimension is a ratio providing a statistical index of complexity comparing how the details in a fractal pattern change with the scale at which it is measured. It can be used to measure the space-filling capacity of a pattern showing how a fractal scales differently than the space it is embedded in. So a fractal dimension may not be an integer (Sagan, 1994; Vicsek, 1992).

In fact, the fractal dimension was used by Benoit Mandelbrot for the first time when he mentioned that coastline's measured length changes with the length of the measuring stick used (Mandelbrot, 1967). Figure 28 presents the counter-intuitive notion proposed by Lewis Fry Richardson (Mandelbrot, 1967; FractalF, 2013).

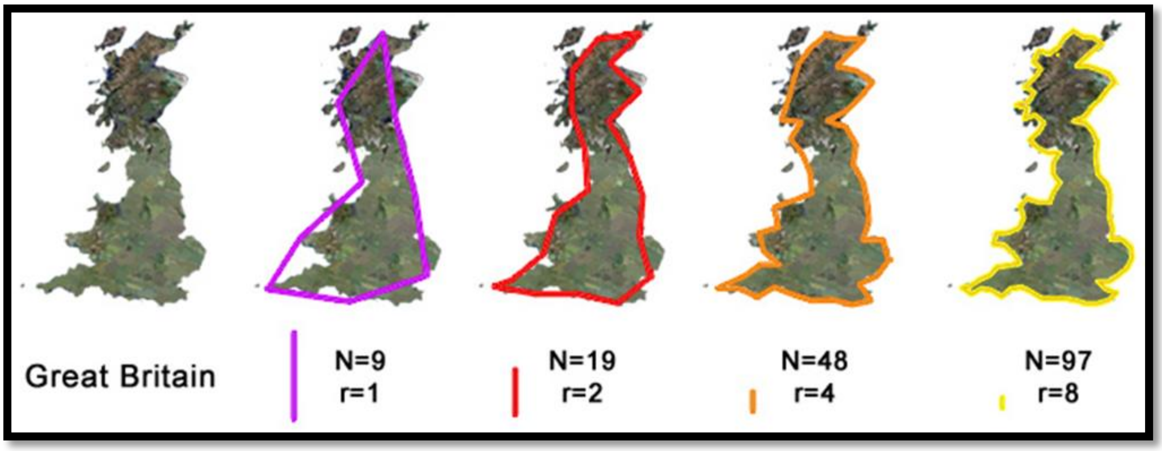


Figure 28 Coastline's measured length changes with the length of the measuring stick used (FractalF, 2013)

Figure 29 explains the relationship between the measured perimeter (N) and the magnification factor (r). When a large ruler is used (r=1 a small magnification factor), a very poor calculation will result (shown in purple), and then the value of N is 9. Therefore, the ruler length shrinks. However, when the ruler is changed to 2, and then N =19. Moreover, when the ruler is changed to 4, and then N =48, and when the ruler is 8, and then N =97 (FractalF, 2013).

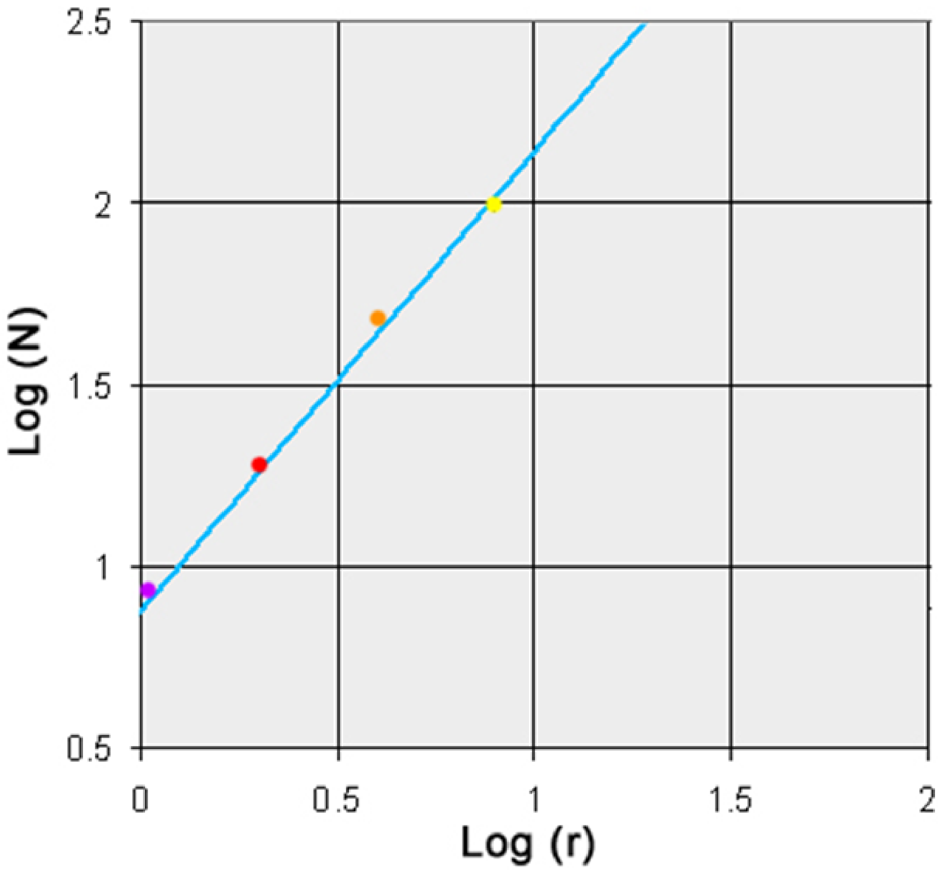


Figure 29 the relationship between the measured perimeter (N) and the magnification factor (r) (FractalF, 2013)

Further, the fractal dimension of a coastline as the geometric fractals can be defined as (FractalF, 2013):

$$D = \frac{\log(N)}{\log(r)}$$

2.9.2.1 Traditional Dimensions

The traditional dimensions include lines, squares and cubes. Bernt Rainer Wahl demonstrated a basic construction of lines, squares and cubes with unit lengths, which is shown in Figure 30 (Wahl, 2013).

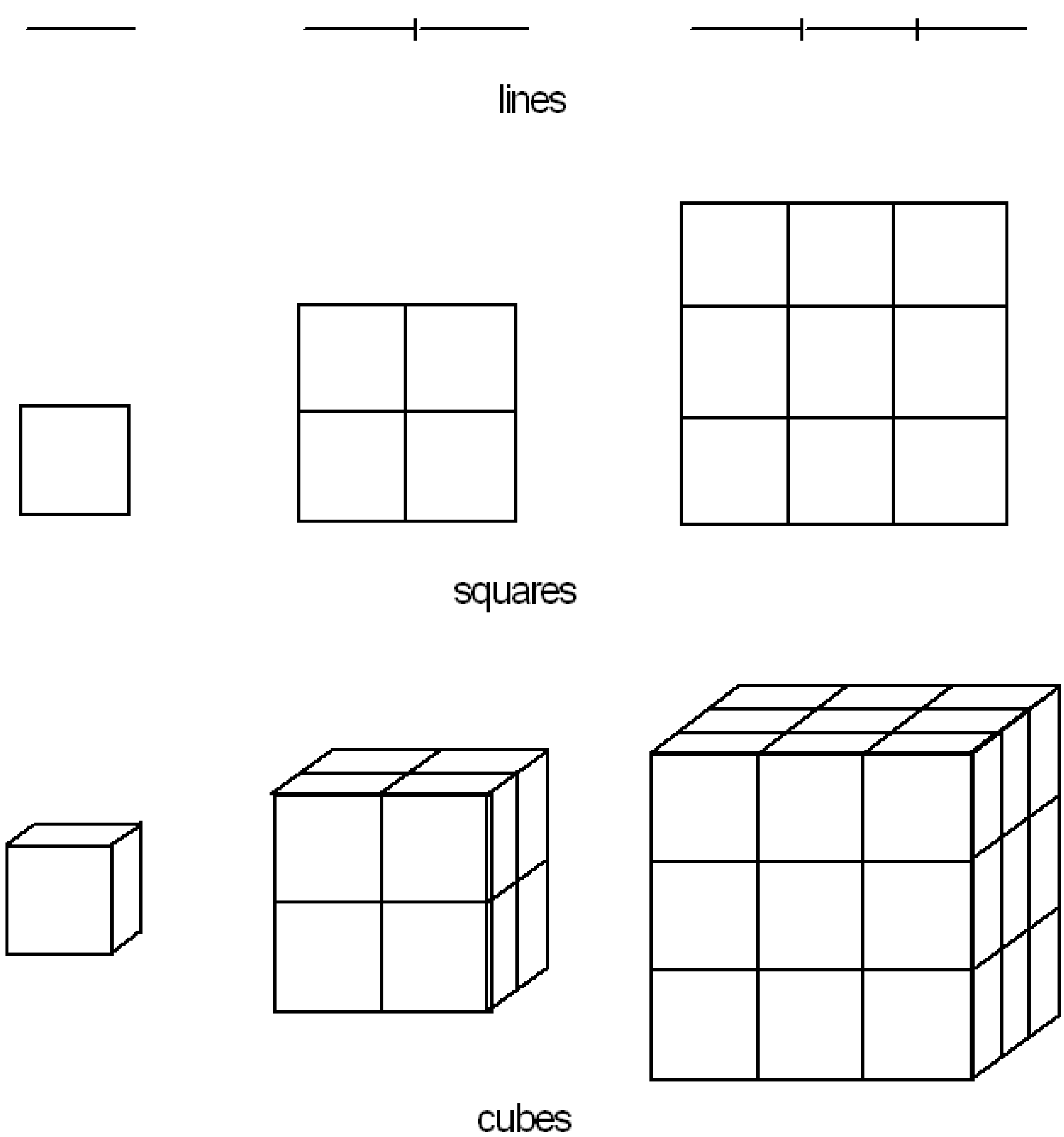


Figure 30 Basic construction of lines, squares and cubes of unit lengths (Wahl, 2013)

2.9.3 Sierpinski Gasket

Sierpinski triangle

Sierpinski triangle belongs to self-similar planar sets of Hausdorff dimension , some of the simplest are the Sierpinski gasket (formed by three self-similarities by the scaling factor 1/3) and the square 4-corner Cantor set (formed by four self-similarities by the scaling factor ¼) (Bond & Volberg, 2009; Kenyon, 1997).

Sierpinski triangle is a fractal and attractive fixed set. It is named after the Polish mathematician Walcaw Sierpinski who described it in 1915, and is also called Sierpinski gasket or the Sierpinski Sieve. In fact, similar patterns had appeared already in the 13th-century Cosmati mosaics in the cathedral of Anagni, Italy, and other places, such as in the nave of the Roman Basilica of Santa Maria in Cosmedin (Wikipedia-3, 2013).

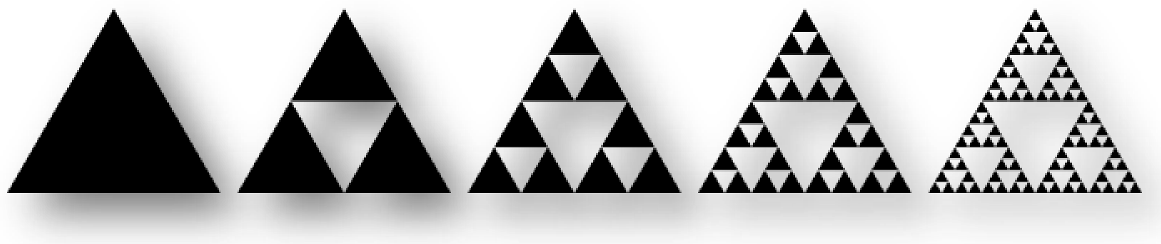


Figure 31 Sierpinski triangle evolution

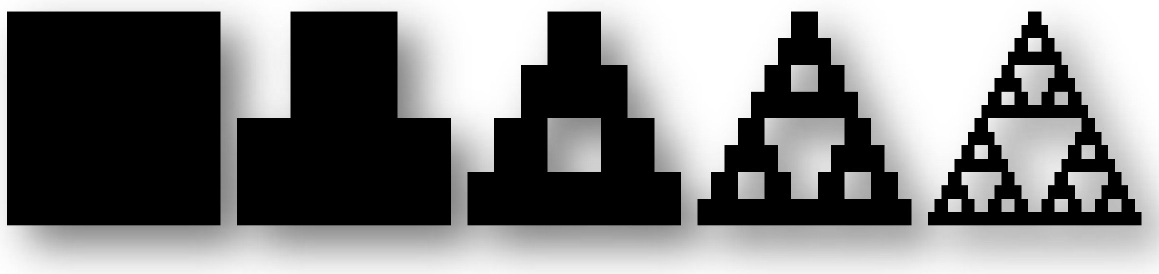


Figure 32 Sierpinski triangle evolution square

Sierpinski triangle Construction

A construction for Sierpinski triangle is shown in Figure 33. In addition, any size triangle can be supposed into a Sierpinski triangle construction. In this thesis, only an example of canonical Sierpinski triangle is used (Equilateral triangle).

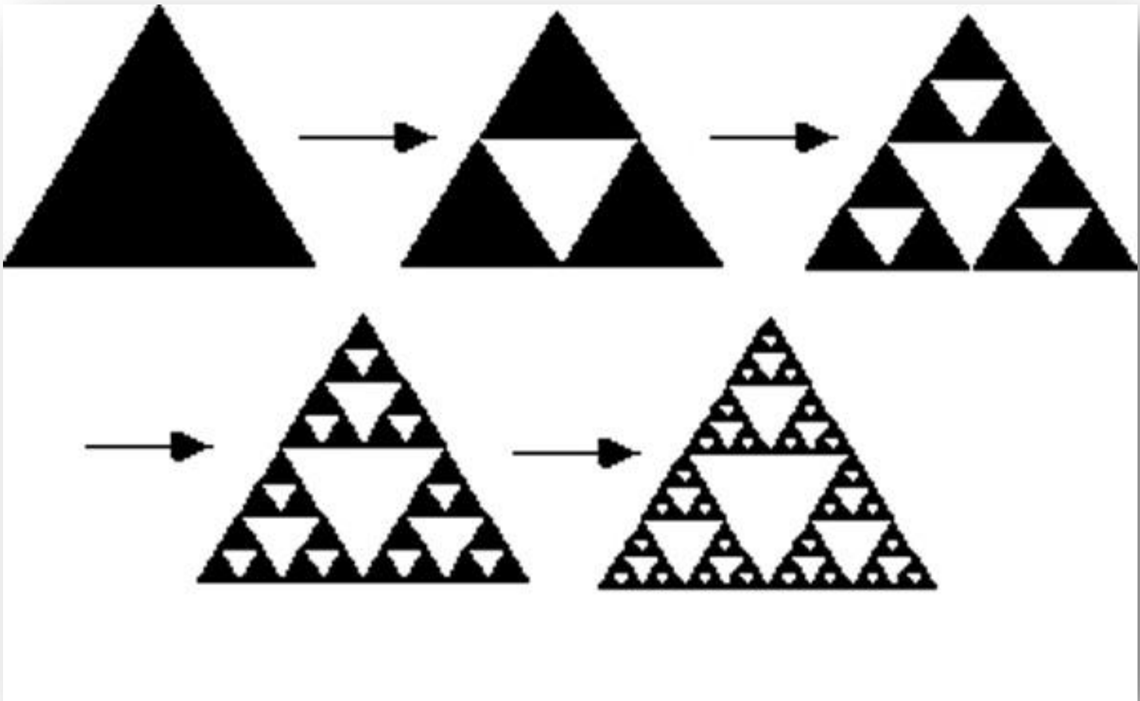


Figure 33 An construction for Sierpinski triangle

Step 1: Prepare a triangle with a base parallel to the horizontal axis (Bond & Volberg, 2009; Kenyon, 1997; Wikipedia-3, 2013).

Step 2: Create three triangles each having an area which is a quarter of the original. In addition, their dimensions are all half of the original triangle (Bond & Volberg, 2009; Kenyon, 1997; Wikipedia-3, 2013).

Step 3: Continue to infinity as the same copy of the original triangle. Then the new triangle only gets smaller and smaller (Bond & Volberg, 2009; Kenyon, 1997; Wikipedia-3, 2013).

There are 9 triangles in Step 3. Accordingly there will be 27 small triangles after next iteration, then 81. Finally, at the Nth stage, 3^n small triangles will be created (Bond & Volberg, 2009; Kenyon, 1997; Wikipedia-3, 2013).

2.10 Summary and proposal

This chapter has reviewed the state of China's electric power market and its regulation, SGCC's EPGOs, Smart Grid Strategy, equilibrium theory, Equilibrium Energy Regulation Model, 3S energy regulation strategy, fractal theory and together with QFD, and Excel Solver tool. Together they will be used for the analysis and synthesis of a sound methodology and framework for the operation optimization of SGCC EPGOs and smart grid strategies in China's electrical power market.

The SGCC EPGOs' operation optimization is a growing trend. But the existing methods based on the smart grid strategies have so far had very limited practical experience in China. Therefore, there is an urgent need for a new method for efficient regulation and optimized operation of smart grid in EPGOs in China.

The fractal theory (Self similarity & Sierpinski triangle) can be used to support the framework structure of SGCC regulation. The EPGOs in this framework are regarded as self-similarity geometry, responsible for the regulation functions of SGCC at various different levels. It can be shown that the cells or segments (EPGOs' regulation framework) of SGCC regulation exhibit structure similar to a fractal object. The definition of fractal goes beyond self-similarity per se to exclude unimportant self-similarity and include the idea of a detailed pattern repeating itself (Briggs, 1992; Vicsek, 1992).

CHAPTER 3 Characteristics of China's electricity generation

3.1 Introduction

The safe electricity supply has been important for rapid increase of Chinese economy development in the last three decades. In addition, the fast economy increase and energy generation demand have had large negative impacts on climate change in China. These will cause significant adverse effects on the world's sustainable development, according to the experts of IEA. Meanwhile, the EPGO's regulation of electrical power transmission and distribution is the natural monopoly part in Electrical Power Market. It is important to characterize the trend of China's Electrical Power Consumption.

A new CW Curve has been proposed for the identification of China's Electrical Power growth characteristics. The CW Curve not only shows the changes of China's Electricity growth, it is also a useful tool to evaluate the trend situations of a country's electrical power consumption.

In this chapter, the CW Curve was developed for analysis of the data in 1996, 2001 and 2006. A comparison and analysis will show the changes in the amounts of China's Total Net Electricity Generation (TNEG) rate and other 15 world top TNEG countries' rates and also the changes of those countries rank in a period of ten years. This chapter will also present the amount of China's TNEG, GDP, CO2 Emissions and Distribution Losses during the 30 years period of 1980-2010.

3.2 Characteristics of Chinese electrical power generation using CW curve

Electricity energy is important in every country, and it plays a key role in security, energy structure, energy conservation, emission reduction and harmonious society in sustainable energy developments in China (Liu, 2013). A CW Curve can be used for characteristic analysis of electricity generation in different countries. Since it is derived from the TNEG, the CW Curve is closely related to the economic development and to some extent the wealth of a country.

Table 9 shows world top 16 country's TNEGs (Total Net Electricity Generation) rate and their rate changes between 1996 and 2006. Table 10 lists the ranking and ranking changes of these countries in terms of TNEG in 1996, 2001 and 2006. Other related can be shown in APPENDIX II, with all the data gathered from U.S. Energy Information Administration (EIA).

Rank	Country	1996 TNEG	2006 TNEG	1996-2006 TNEG rate (‰)
1	China	1005	2717	17
2	Korea South	210	379.73	8
3	India	412	703.32	7
4	Spain	165	283.35	6
5	Mexico	156	236.39	5
6	Brazil	287	411.74	4
7	Australia	168	237.07	3
8	Italy	225	291.24	2.8
9	South Africa	186	227.74	2.6
10	US	3440	4071.26	1.7
11	Russia	804	940.64	1.6
12	Germany (East West)	520	594.84	1.4
13	UK	328	371.95	1.2
14	France	483	542.41	1.1
15	Japan	955	1032.70	0.8
16	Canada	557	594.60	0.6

Table 9 1996-2006 Total Net Electricity Generation (TNEG) Rate (‰) (EIA, 2013)

Country	Ranking 1996	Ranking 2001	Ranking 2006	TNEG ranking changes (5years+5years)
India	8	7	5	(1+2)=3
Korea South	12	11	10	(1+1)=2
Brazil	10	10	9	(0+1)=1
Mexico	16	15	15	(1+0)=1
US	1	1	1	0
China	2	2	2	0
Japan	3	3	3	0
Russia	4	4	4	0
Germany(East West)	6	6	6	0
Spain	13	13	13	0
Australia	14	14	14	0
France	7	8	8	(-1+0)=-1
Italy	11	12	12	(-1+0)=-1
Canada	5	5	7	(0-2)=-2
UK	9	9	11	(0-2)=-2
South Africa	13	16	16	(-3+0)=-3

Table 10 16 country ranking changes in TNEG in 1996, 2001 and 2006 (EIA, 2013)

Subsequently, the coordinates of the CW Curve were created by combining the last column of Tables 9 (1996-2006 TNEG rates) and the last column of Tables 10 (TNEG ranking changes). The coordinates of CW Curve are shown in Table 11. For example, for China, the x-coordinate is 0 because its TNEG Ranking change during the period is 0 and the y- coordinate is 17(‰).

Rank	Country	X-Coordinates	Y-Coordinates (‰)	Coordinates
1	China	0	17	0,17
2	Korea South	2	8	2,8
3	India	3	7	3,7
4	Spain	2	6	2,6
5	Mexico	1	5	1,5
6	Brazil	1	4	1,4
7	Australia	0	3	0,3
8	Italy	-1	2.8	-1,2.8
9	South Africa	-3	2.6	-3,2.6
10	US	0	1.7	0,1.7
11	Russia	0	1.6	0,1.6
12	Germany(East West)	0	1.4	0,1.4
13	UK	-2	1.2	-2,1.2
14	France	-1	1.1	-1,1.1
15	Japan	0	0.8	0,0.8
16	Canada	-2	0.6	-2,0.6

Table 11 The coordinate of CW Curve (EIA, 2013)

Based on Table 11, the CW Curve can be shown in Figure 34 below:

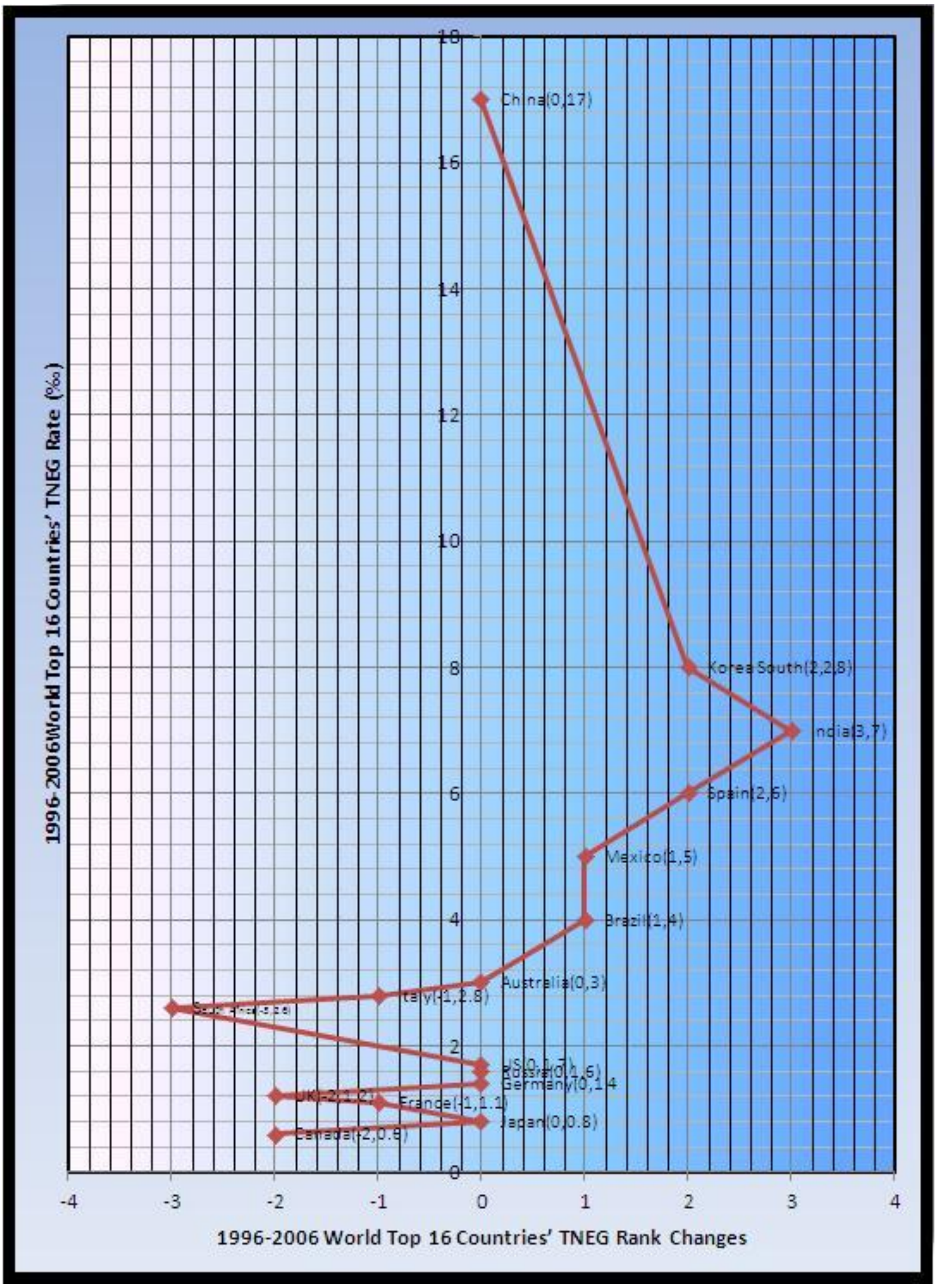


Figure 34 CW Curve

In Figure 34, the countries in lighter areas in CW Curve have weaker or negative TNEG ranking changes. The countries in the darker areas have more potential for TNEG. Therefore, the potential of the countries' TNEG were clearly shown in the CW Curve.

3.3 Analysis of the related countries using the CW Curve

The first analysis result of the CW Curve shows the ranking of countries' TNEG potential in Table 12.

Ranking No.	Continental	Country	TNEG rank changings
1	Asia(2)	India	+3
		Korea South	+2
2	Europe(1)	Spain	+2
3	South America(1)	Brazil	+1
3	North America(1)	Mexico	+1

Table 12 TNEG Ranking Potential Ability countries and continentals (EIA, 2013)

India is shown to have the highest potential for energy generation in the world. And another Asia country, South Korea, is shown in the second, followed by Spain, Brazil and Mexico. Asian countries have become an important part in world energy development.

The other analysis result of the CW Curve shows the ranking changes for the countries with zero or negative ranking changes, as given in Table 13.

Ranking No.	Continental	Country	TNEG rank changings
1	Africa	South Africa	-3
2	Europe(4)	Germany	0
		France	-1
		Italy	-1
		UK	-2
3	North America(2)	US	0
		Canada	-2
4	Asia(2)	China	0
		Japan	0
4	Eurasia(1)	Russia	0
4	Oceania (1)	Australia	0

Table 13 Ranking no. of grow less ability countries (EIA, 2013)

Therefore, South Africa is shown to have the lowest potential for TNEG, followed by UK, Canada, Italy and France. However, it is interesting that China with the biggest population and EPGO incomes has no TNEG ranking changes in ten years, and its TNEG rate has remained the highest in the CW Curve. We need to pay close attention to China's electricity generation.

Moreover, the simple statistics of the ranking of these 16 countries are shown in Table 12 (EIA, 2013), with the data gathered from EIA.

Rank	Continental	Number of Countries
1	Europe	5 countries
2	Asia	4 countries
3	America (North)	3 countries
4	Africa	1
4	America (Central & south)	1
4	Asia & Oceania	1
4	Eurasia	1

Table 14 Continental TNEG ranking of world top 16 countries (EIA, 2013)

In Table 14, the Europe, Asia and America (north) have higher potential for power generation. Russia is part of both Europe and Asia, with most of its land in Asia but more people live in the European part. It is separately listed in Eurasia for the electricity generation and consumption.

The biggest EPGOs of those 16 countries and their key indicators are shown in Table 15.

	Country	Country's Biggest EPGO	Ownership
1	China	Sate Grid Corporation of China	State -owned
2	South Korea	KEPCO	State -owned 51%
3	India	Power Grid Corporation of India	State -owned
4	Spain	Red Eléctrica de España	state-owned and public limited
5	Brazil	Centrais Eletricas Brasileiras S.A.	
6	Mexico	The Federal Electricity Commission(CFE)	State -owned
7	Australia	TransGrid	Government NSW -owned
8	South Africa	Eskom	State -owned
9	Italy	ENEL S.p.a	Partially privatize with state control
10	Russia	JSC "RusHydro"	
11	US	American Electric Power(AEP)	State -owned
12	Germany (East West)	EnBW TNG	Beteiligungsgesellschaft mbH, 46.55% ,and Oberschwäbischen Elektrizitätswerke (OEW), 46.55%
13	Japan	The Tokyo Electric Power Company, Inc.）	Private company
14	France		
15	Canada	Hydro-Québec	Québec government
16	UK	National Grid	

Table 15 Key indicators of 16 biggest EPGOs (Van de Poel, 2007; Bode & Fung, 1998; Suhardi, 2013; Joiner & Ssholtes, 1988; Keping, 2008; Kim & Horn, 1999)

Through Table 15, it can be seen that most of EPGOs are owned by a State.

Moreover, the income ranking for the biggest EPGOs is shown in Table 16.

Country's biggest EPGO/2010	**Population (2014)**	**Area sq. km (2014)**	**GDP (nominal) per Capita Rank**	**GDP (PPP) per Capita Rank**	**Ranking countries by exports**	**INCOMES 2010**	Rank
China/ State Grid Corporation of China	1,350,000,000	9,634,057	97	94	1	$226.3	1
Germany/ EnBW TNG	82,100,000	357,022	22	19	2	$23,2	2
UK / National Grid	61,900,000	242,900	24	21	10	$21.3	3
Mexico/ The Federal Electricity Commission (CFE)	110,600,000	1,916,068	64	59	13	$20.2	4
U.S./ American Electric Power(AEP)	317,600,000	9,629,091	12	7	3	$14.4	5
South Africa/ Eskom	50,500,000	1,221,037	73	77	36	$12.2	6
India/ Power Grid Corporation of India Limited (Power Grid)	1,200,000,000	2,980,000	142	129	17	$2.0	7
Australia/ TransGrid	21,500,000	7,692,024	6	10	20	$0.7	8

Table 16 Incomes rank for the biggest EPGOs in their countries (Van de Poel, 2007; Bode & Fung, 1998; Suhardi, 2013; Joiner & Ssholtes, 1988; Keping, 2008; Kim & Horn, 1999)

In Table 16, it can be found that SGCC has the highest incomes in all EPGOs in the world.

The sizes of the Countries with top 8 TNEG are ranked in Table 17.

Country's biggest EPGO/2010	Population (2014)	Area sq. km (2014)	GDP (nominal) per Capita Rank	GDP (PPP) per Capita Rank	Ranking countries by exports	INCOMES 2010	Rank
China/ State Grid Corporation of China	1,350,000,000	9,634,057	97	94	1	$226.3	1
U.S./ American Electric Power(AEP)	317,600,000	9,629,091	12	7	3	$14.4	2
Australia/ TransGrid	21,500,000	7,692,024	6	10	20	$0.7	3
India/ Power Grid Corporation of India Limited (Power Grid)	1,200,000,000	2,980,000	142	129	17	$2.0	4
Mexico/ The Federal Electricity Commission (CFE)	110,600,000	1,916,068	64	59	13	$20.2	5
South Africa/ Eskom	50,500,000	1,221,037	73	77	36	$12.2	6
Germany/ EnBW TNG	82,100,000	357,022	22	19	2	$23,2	7
UK / National Grid	61,900,000	242,900	24	21	10	$21.3	8

Table 17 Sizes of the Countries with top 8 TNEG (Van de Poel, 2007; Bode & Fung, 1998; Suhardi, 2013; Joiner & Ssholtes, 1988; Keping, 2008; Kim & Horn, 1999)

Through Table 17, it can be found that China has the biggest area in this group of countries.

The country population rank for the biggest EPGOs is shown in Table 18:

Country's biggest EPGO (2010)	Population (China,India,U.S.2014;Others 2011)	Area sq. km	GDP (nominal) per Capita Rank	GDP (PPP) per Capita Rank	Ranking countries by exports	INCOMES 2010	Rank
China/ State Grid Corporation of China	1,361,218,941	9,634,057	97	94	1	$226.3	1
India/ Power Grid Corporation of India Limited (Power Grid)	1,247,923,065	2,980,000	142	129	17	$2.0	2
U.S./ American Electric Power(AEP)	317,408,015	9,629,091	12	7	3	$14.4	3
Mexico/ The Federal Electricity Commission (CFE)	112,336,538	1,916,068	64	59	13	$20.2	4
Germany/ EnBW TNG	81,751,602	357,022	22	19	2	$23,2	5
UK / National Grid	62,435,709	242,900	24	21	10	$21.3	6
South Africa/ Eskom	50,586,757	1,221,037	73	77	36	$12.2	7
Australia/ TransGrid	23,491,527	7,692,024	6	10	20	$0.7	8

Table 18 Population rank for the biggest EPGOs in their countries (Van de Poel, 2007; Bode & Fung, 1998; Suhardi, 2013; Joiner & Ssholtes, 1988; Keping, 2008; Kim & Horn, 1999)

Therefore, several statements can be made based on the analysis of the CW Curve:

1) Amongst the 16 countries of the world's top TNEG (from 1996 to 2006), there are 5 countries from Europe, 4 countries from Asia, 3 countries from America (North), and then only 1 country each from Africa, America (Central & south), Asia and Oceania and Eurasia. Europe, Asia, and America (North) have higher potential for electricity generation.
2) The country with the highest TNEG rate (17‰) is China, and its TENG ranking has not changed in the ten years' period. Also China has the largest population and highest EPGO incomes.
3) The CW Curve also shows that the country with the strongest TNEG potential is India, and it also has the second largest population in the world. Moreover, there are two smaller countries, South Korea and Spain, at the second level of strong TNEG potential in the CW Curve, with one from Asia and the other from Europe. Further, India's biggest EPGO's income is only about 1/10 of China's SGCC.

The CW curve and other related information have highlighted the unique important position of China in terms of electricity consumption and generation. It is therefore important to have a closer look at the China's electricity generation over a longer period of time.

3.4 Longitudinal perspective on the electricity generation in China

3.4.1 China's main energy data from 1980 to 2010

China's TNEG, Gross Domestic Product (GDP) per capita, CO2 Emissions and Distribution Losses from 1980 to 2010 are shown in Table 19 and Figure 35, with the data gathered from EIA, Statistical Communiqué of the People's Republic of China and China Statistical Yearbook 2012. Exchange rate of CN￥ to US$ is according to State Administration of Foreign Exchange, published on China Statistical Yearbook 2012 (EIA, 2013; CNESD, 2013; CIA, 2013; ExchangeR, 2013).

Year	GDP per capita (US$)	CO2 Emissions (Million Metric Tons)	Distribution Losses (Billion Kilowatt hours)	TNEG (Billion Kilowatt hours)
1980	309	1,448	24	285
1981	289	1,439	25	294
1982	279	1,506	26	311
1983	295	1,593	27	334
1984	299	1,724	29	358
1985	292	1,765	40	390
1986	279	1,878	43	427
1987	299	2,010	48	472
1988	367	2,148	52	517
1989	403	2,183	58	555
1990	344	2,177	42	590
1991	356	2,295	48	643
1992	419	2,375	54	716
1993	520	2,498	60	795
1994	469	2,681	59	880
1995	604	2,722	74	956
1996	703	2,841	76	1,005
1997	774	3,129	78	1,070
1998	821	3,197	79	1,103
1999	865	3,115	86	1,172
2000	949	3,271	93	1,280
2001	1042	3,353	103	1,426
2002	1135	**3,776**	116	1,584
2003	1274	4,235	126	**1,810**
2004	**1,490**	4,744	142	2,103
2005	1732	5,463	170	2,370
2006	2070	5,936	185	2,717
2007	2652	6,326	206	3,090
2008	3414	6,684	213	3,280
2009	3749	7,573	225	3,508
2010	4434	7,997	256	3,904

Table 19 China's TENG, GDP, CO2 Emissions and Distribution Losses 1980-2010 (EIA, 2013; CNESD, 2013; CIA, 2013; ExchangeR, 2013)

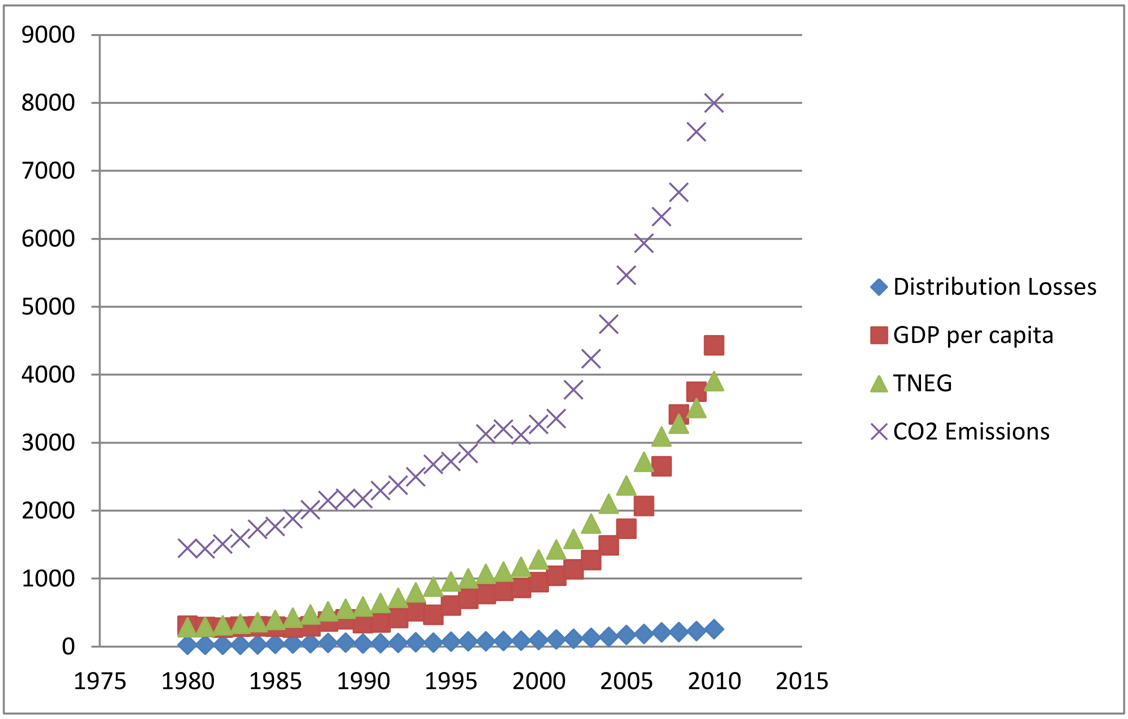


Figure 35 China's TNEG, GDP, CO2 Emissions, and Distribution Losses data (EIA, 2013; CNESD, 2013; CIA, 2013; ExchangeR, 2013)

3.4.2 Discussions on the results of TNEG, GDP, CO2 Emissions, and Distribution Losses

Figure 35 shows the trend and changes in China's TNEG, GDP, CO2 Emissions and Distribution Losses from the 1980 to the end of 2010. The TNEG illustrates the total net electricity generated in billion kilowatt-hours. The Distribution Losses illustrates the total distribution losses of electricity in billion kilowatt-hours. The CO2 Emissions illustrates the total carbon dioxide emissions from the consumption of energy in million metric tons. The GDP illustrates the Gross Domestic Product per capita in US$ are according to the State Administration of Foreign Exchange, published in China Statistical Yearbook 2012.

China's TNEG, GDP, CO2 emissions have changed over the years with a gentle upward trend until a large increase in CO2 emissions in 2002(the number of 3776 million metric tons in table 19 is highlighted in red), in TNEG in 2003(the number of 1810 billion kilowatt-hours tons in table 19 is highlighted in red) and in GDP in 2004(the number of 1490 US$ in table 19 is highlighted in red). China's Distribution Losses also has a slow upward trend over the years. These trends clearly indicate that the country's economy development becoming more and more reliant on a sustainable energy in China. However, the economy development also clearly has negative impacts on the environment with a gentle upward trend followed by a rapid increase in CO_2 emissions from 2002.

The large increases (1810 billion kilowatt-hours in 2003, 2103 billion kilowatt-hours in 2004) in net electricity generated seen in the years 2003 and 2004 can be ascribed to the big effect in China in 2002. To end the State Power Corporation's (SPC) monopoly in electricity industry, China's State Council dismantled the corporation in December 2002 and set up 11 smaller companies (Austin, 2005; U.S.EPA, 2011; Ni, 2006; CSG, 2013; SGCC, 2013a).

3.5 Summary

A CW Curve has been developed to analyze and characterize the electricity generation in 16 top TNEG countries. The results have shown that Asia, and China in particular, is an important continental area. China not only has the highest TNEG Rate, but also the largest population, the highest EPCO incomes in the world.

Secondly, China’s TNEG, GDP, CO_2 Emissions and Distribution Losses have also been studied over a period of last 30 years, corresponding to the rapid economy development in the same period (EIA, 2013; CNESD, 2013). Moreover, electrical power is considered the bellwether element of the economy development in China. However, the rapid increases of economy and electricity generation have significant negative impacts on the environment and climate change. It is also clear that the country’s sustainable electricity generation is more reliant on the electricity energy policy (or strategy) in China. Indeed, how to improve the efficiency of the electricity generation to help achieve the sustainable energy development is an important strategy in the China’s electrical power market. The energy regulation and technology development are urgently needed for China.

CHAPTER 4 Novel uniform regulation framework for EPGOs using fractal theory and QFD

4.1 Introduction

This chapter discusses a novel regulation framework for the EPGOs of the SGCC. It presents an Equilibrium Energy Regulation Model based on equilibrium theory and further identifies the problems associated with the current regulation of the SGCC. This chapter proceeds to develop a uniform model based on fractal theory and QFD methodology.

Ideal Equilibrium Energy Regulation Model (EERM)

Equilibrium theory is important to economic analysis (Arrow & Debreu, 1954). An energy regulation model based on equilibrium theory, i.e. Equilibrium Energy Regulation Model, is a fundamental approach adopted by advanced economies, e.g. UK energy regulation model. An ideal EERM model offers two key advantages, the free competitive market to balance the energy generation and consumption on one hand, and an effective regulator - Independent Regulatory Authority in the natural monopoly of transmission and distribution on the other.

China's current electric power market regulation model

Based on a report on *The China Power Generation Market Report 2012-2021,* the current regulation model for China's electrical power market may be portrayed in Figure 36 (JohnLoffman, 2011; Arrow & Debreu, 1954; Wangetal., 2010).

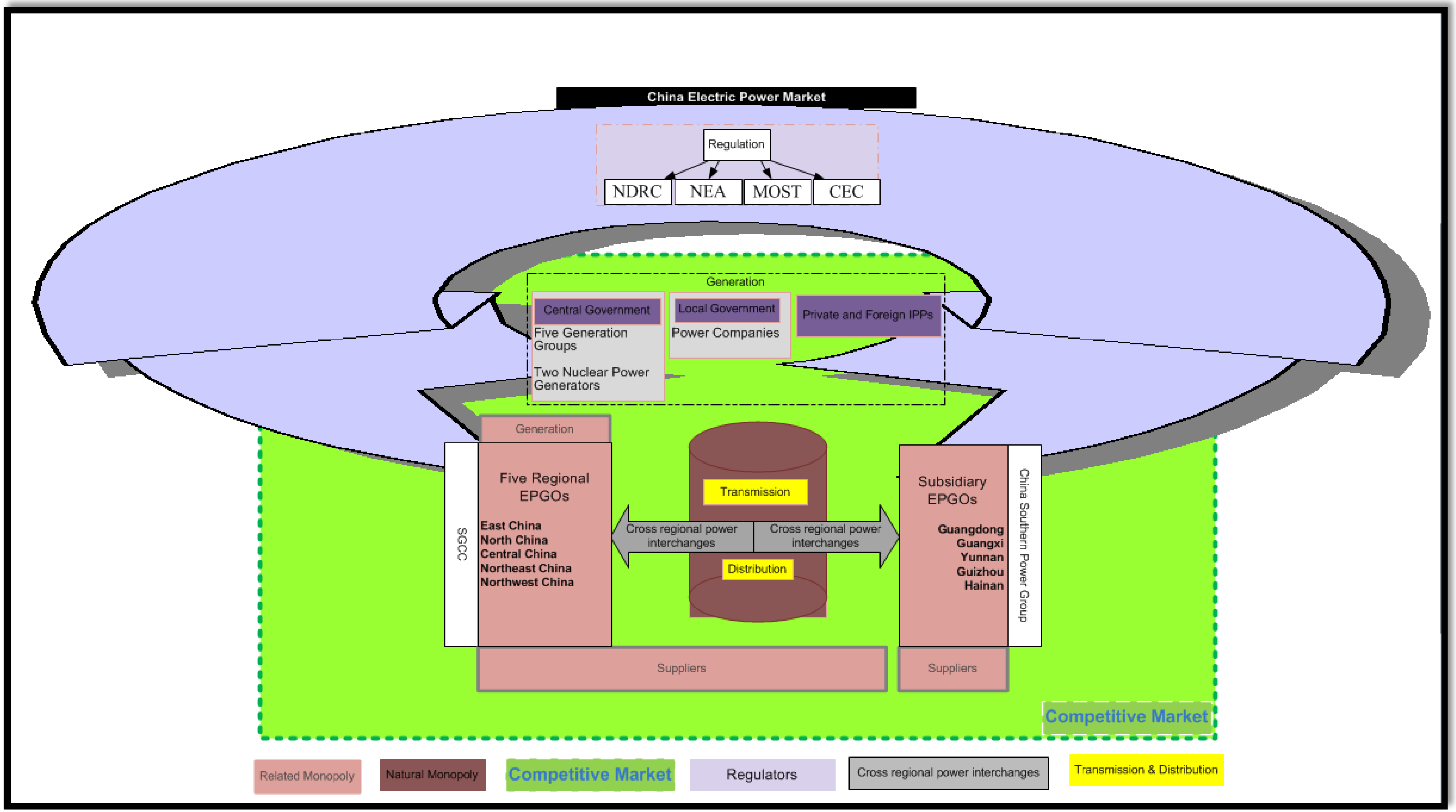


Figure 36 China's current Electric Power Market

The problems associated with China's current electric power market can be revealed by a comparison and analysis between EERM and China's electric power market in Figure 37. The problem lies in the two key aspects, i.e. lack of free competitive market in the parts of Generation and Supply in SGCC; and lack of an Independent Regulatory Authority - one single effective regulator in the natural monopoly part of market model.

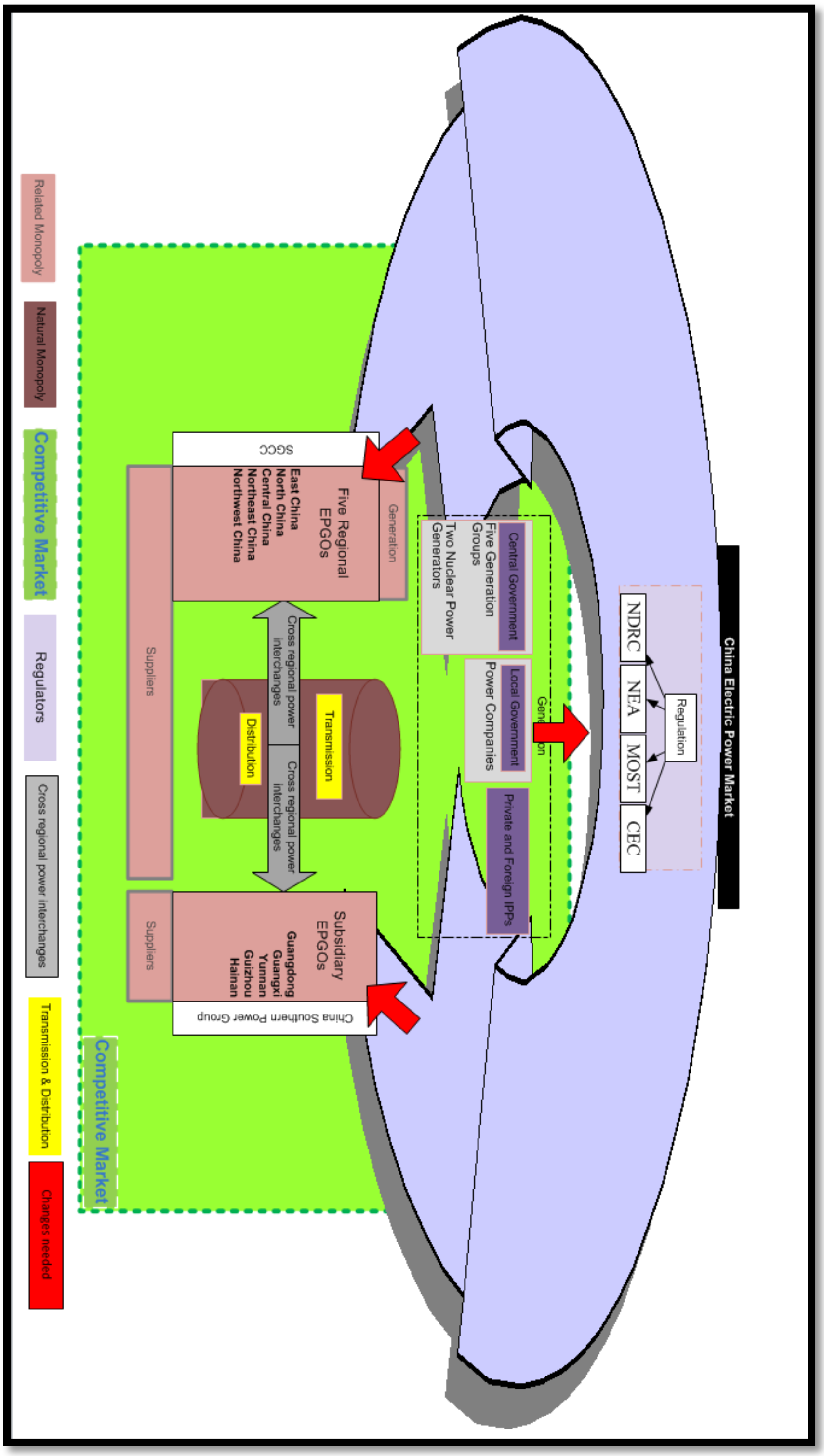


Figure 37 Problems of China's Electric Power Market

4.2 Proposed new regulation model for China's Electrical Power Market

Through the comparison between China's current electric power market and Equilibrium Energy Regulation Model, the weak areas can be readily identified shown in pink and pale purple in Figure 37. It is also critical to have one single effective regulator in China's Electrical Power Market (in pale purple colour in Figure 37) and also effective regulation strategy (in pink colour in Figure 37).

In this thesis, we only focus on effective regulation strategy of SGCC's EPGOs. The new regulation model for China's electrical power market is proposed in Figure 38.

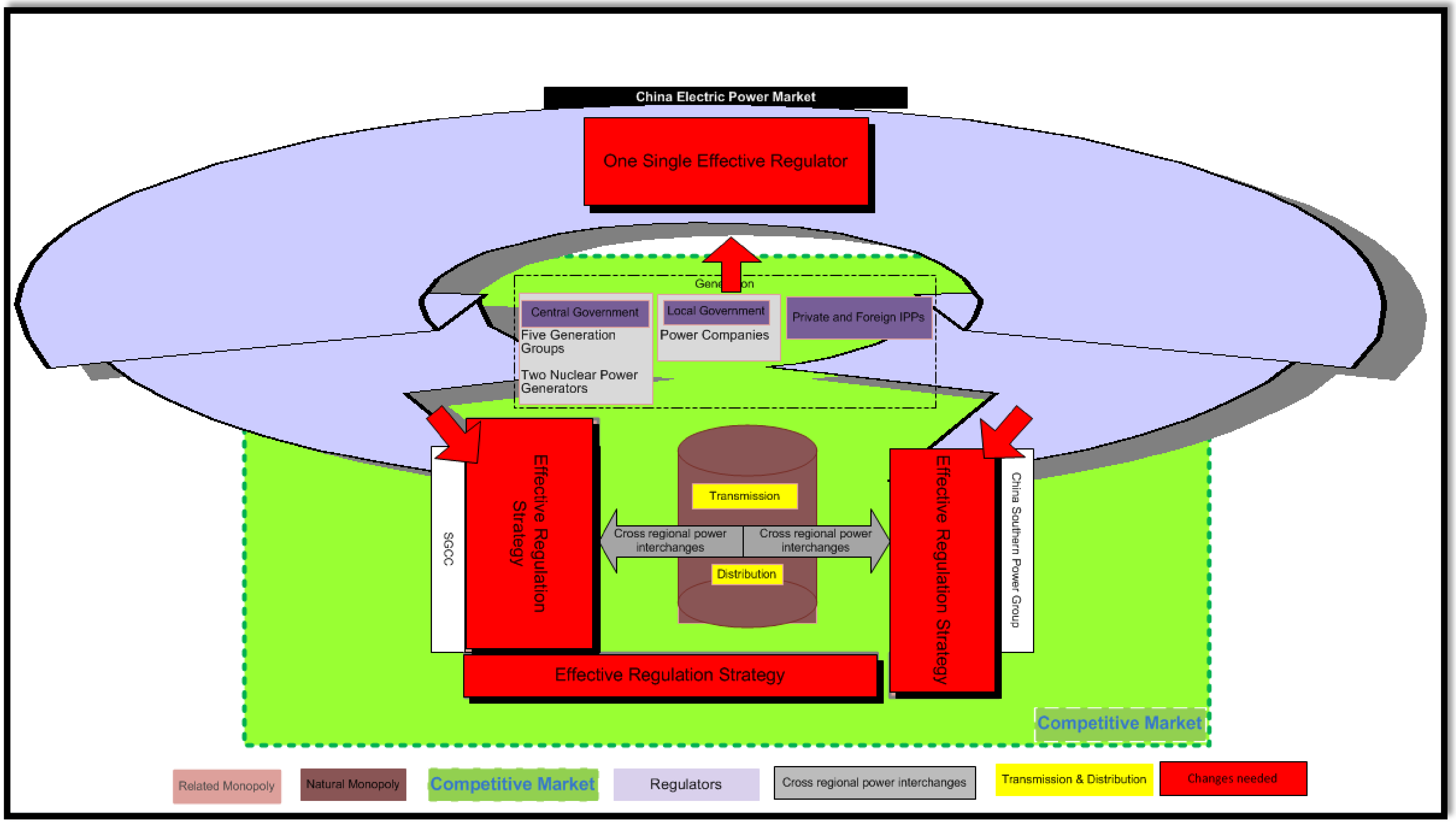


Figure 38 New China's Electrical Power Market

4.3 Effective regulation strategy for China's Electric Power Market's EPGO

4.3.1 Smart Grid and EPGO

Smart Grid is an important and new energy strategy for China's Electric Power Market's EPGO, also all over the world. Smart Grid strategy covers all parts of electrical power market and includes the technology development and energy regulation in China electric power market, e.g. power generation, transmission, distribution etc. SGCC outlined plans in 2010 for a pilot smart grid programme that maps out deployment to 2030, smart grids investments will reach at least $ 96 billion by 2020 (IEAa, 2011).

However, there are significant challenges for Smart Grid development, including regulation and optimization methodology to allow Chinese electric power grid operators to optimize their operations in terms of customer satisfaction, operational cost and environmental impacts .

Therefore, this case study has proposed a methodology based on the customer expectation (CE) to develop an effective regulation of EPGOs in China's electrical power market. Although QFD has been previously applied in China's electrical power market, they have not been used for the optimization of EPGOs' operation. It seems that the combination of three key features (QFD and mathematical optimization, together with fractal theory) will offer great prospects.

4.3.2 Effective regulation strategies using QFD

QFD is proposed to achieve the effective regulation strategies of EPGOs. In this thesis, QFD will be used for an EPGO case study in China.

4.4 Case collection

4.4.1 Case study chosen from China's Electric Power Market

There are three reasons why this thesis has chosen SGCC as an Electric Power Grid

Operator (EPGO) case study in China’s electric power market. Firstly, SGCC is the biggest EPGO in China’s electric power market. It is also the biggest EPGO all over the world (Yu, 2000; Keping, 2008; Kim & Horn, 1999; Kim & Horn, 1989; Izaguirre, 1998; Jones, 1993; Paddon, 1998). Secondly, SGCC is the biggest state owned EPGO, and SGCC is also a comprehensive EPGO, with its work areas including electrical power generation, transmission, distribution, substation, dispatching and supply. It also has some relevant business companies too (Yu, 2000; Keping, 2008; Kim & Horn, 1999; Kim & Horn, 1989; Izaguirre, 1998; Jones, 1993; Paddon, 1998). Thirdly, it has the biggest natural monopoly in transmission and distribution (Yu, 2000; Keping, 2008; Kim & Horn, 1999; Kim & Horn, 1989; Izaguirre, 1998; Jones, 1993; Paddon, 1998). The SGCC is portrayed in Figure 39 as case study for China’s electric power market.

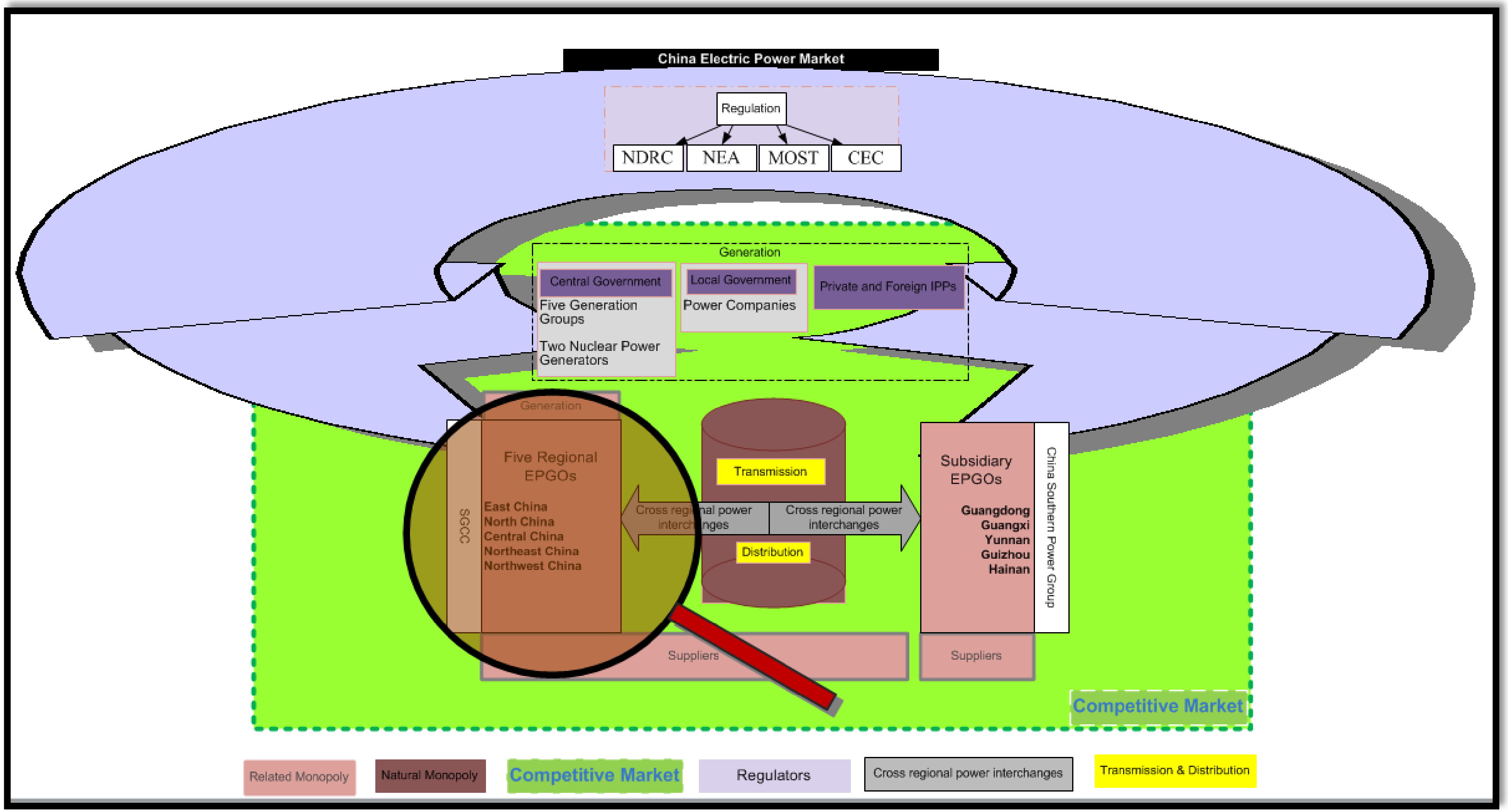


Figure 39 Case study chosen from China's Electric Power Market

4.4.2 The hierarchy of SGCC

The hierarchy of the SGCC as the national EPGO can be shown in Figure 40. There are EPGOs of different sizes at the different level of the SGCC. So they are likely to have different staff number, work area and so on. On the other hand, EPGOs may have similar structures because there is clear similarity in terms of components and functions in the SGCC (SGCC, 2011a; 2013a; 2013b).

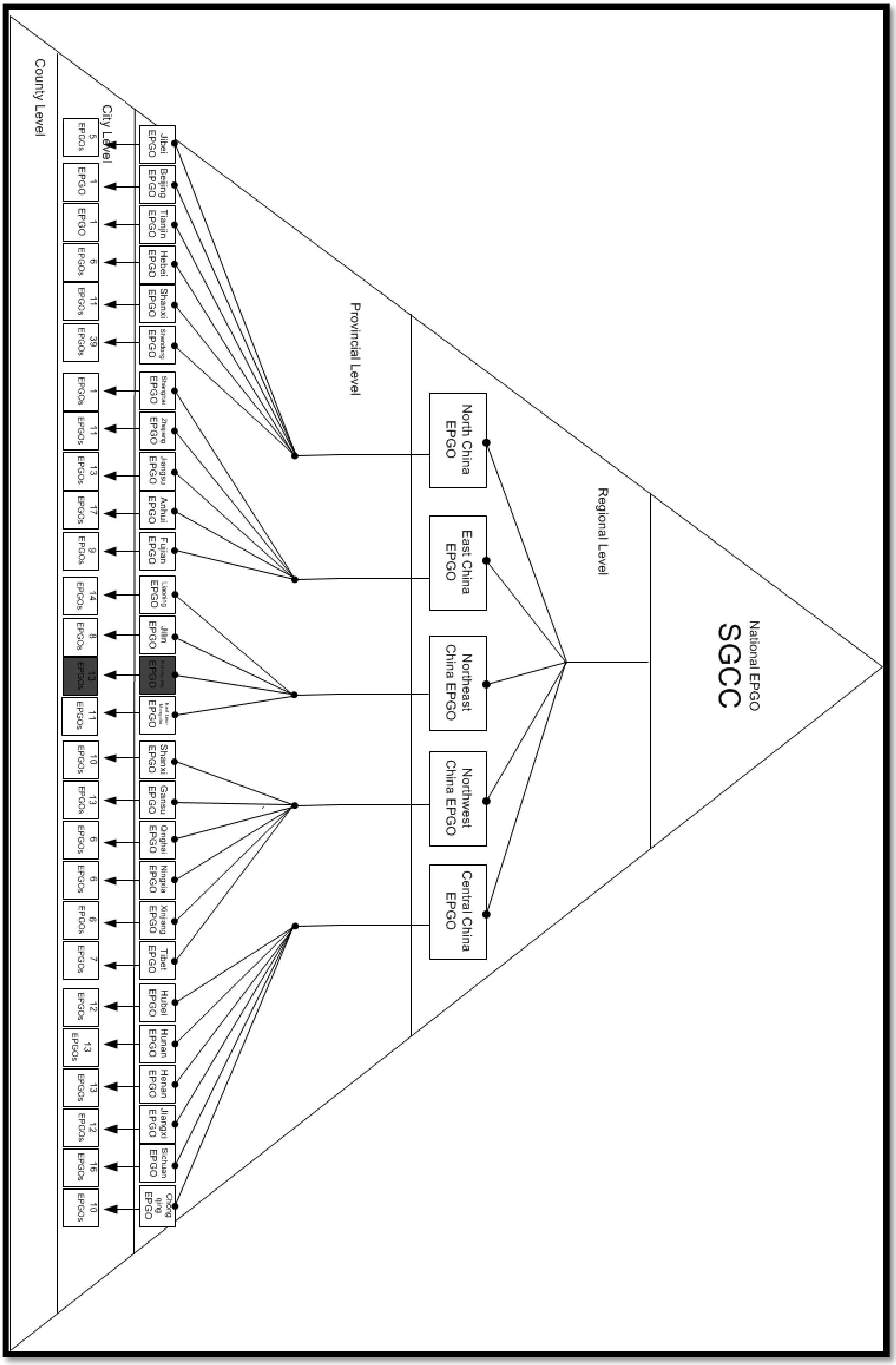


Figure 40 Regulation structure of SGCC

Shaded area is further discussed in Chapter 6

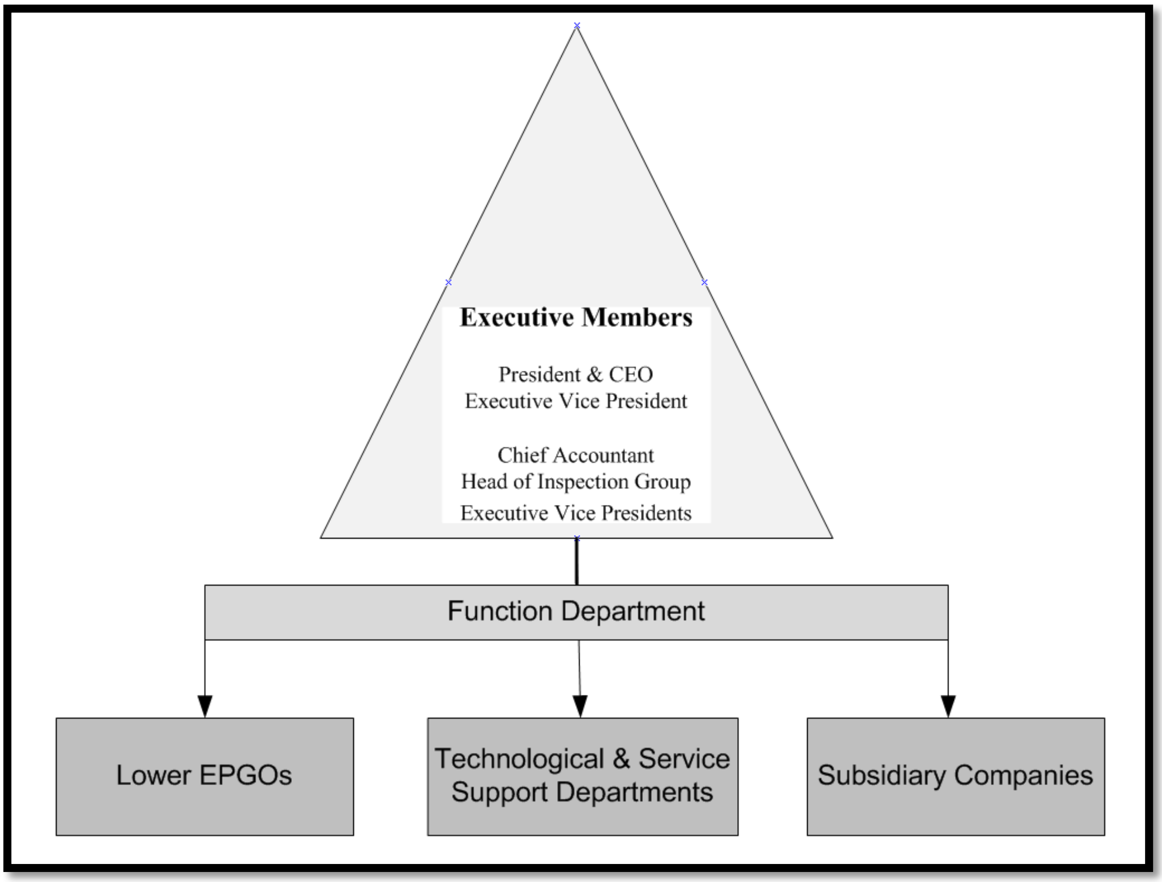


Figure 41 EPGO's regulation framework of SGCC

4.5 Application of fractal theory to SGCC's regulation structure

4.5.1 Self similarity in the EPGOs' regulation framework form of SGCC

There exists a symmetry between the EPGOs of the SGCC and the fractal structures (Self similarity & Sierpinski Gasket). Figure 41 shows how a general EPGO is subdivided in terms of the each level of EPGOs. Each EPGO with its subdivisions may be called a cell or segment in the SGCC's regulation framework. There are 318 segments (including only national, regional, provincial and city level EPGOs), 1 at the top level (national level EPGO), 5 at the second level (regional level EPGOs), 27 at the third level (province level EPGOs) and 285 at bottom level (city level EPGOs). Just as shown in Figure 41, each EPGO has similar segments (regulation framework) at each level of SGCC. Figure 40 clearly labels the names and numbers of each of the segments at all the levels of SGCC's regulation hierarchy.

4.5.2 Fractal theory with emphasis on Sierpinski Gasket in the EPGO

Fractal theory can be applied in many ways. This thesis will focus on Sierpinski Gasket, whereby the resulting fractal is self-similar. The shape of a fractal is made up of a get-together of smaller copies of itself, with each smaller copy also having a get-together of smaller copies of itself. This makes it a self-similar fractal.

Sierpinski Gasket is triangle, one of the simplest of geometric images as reviewed in Chapter 2 (Bond & Volberg, 2009; Kenyon, 1997). Therefore, there are three triangles each having an area which is exactly a quarter of the original and whose dimensions are one-half of the original triangle. That is, from each remaining triangle we remove the "middle", leaving behind three smaller triangles each of which has dimensions one-half of those of the parent triangle (and one-fourth of the original triangle). Also, all the resulting triangles created look exactly like the original. This process can be continued and the same copy of the triangle will be created, it becomes smaller and smaller.

The SGCC regulation structure may be constructed as a fractal (Sierpinski Gasket), as shown in Figure 42.

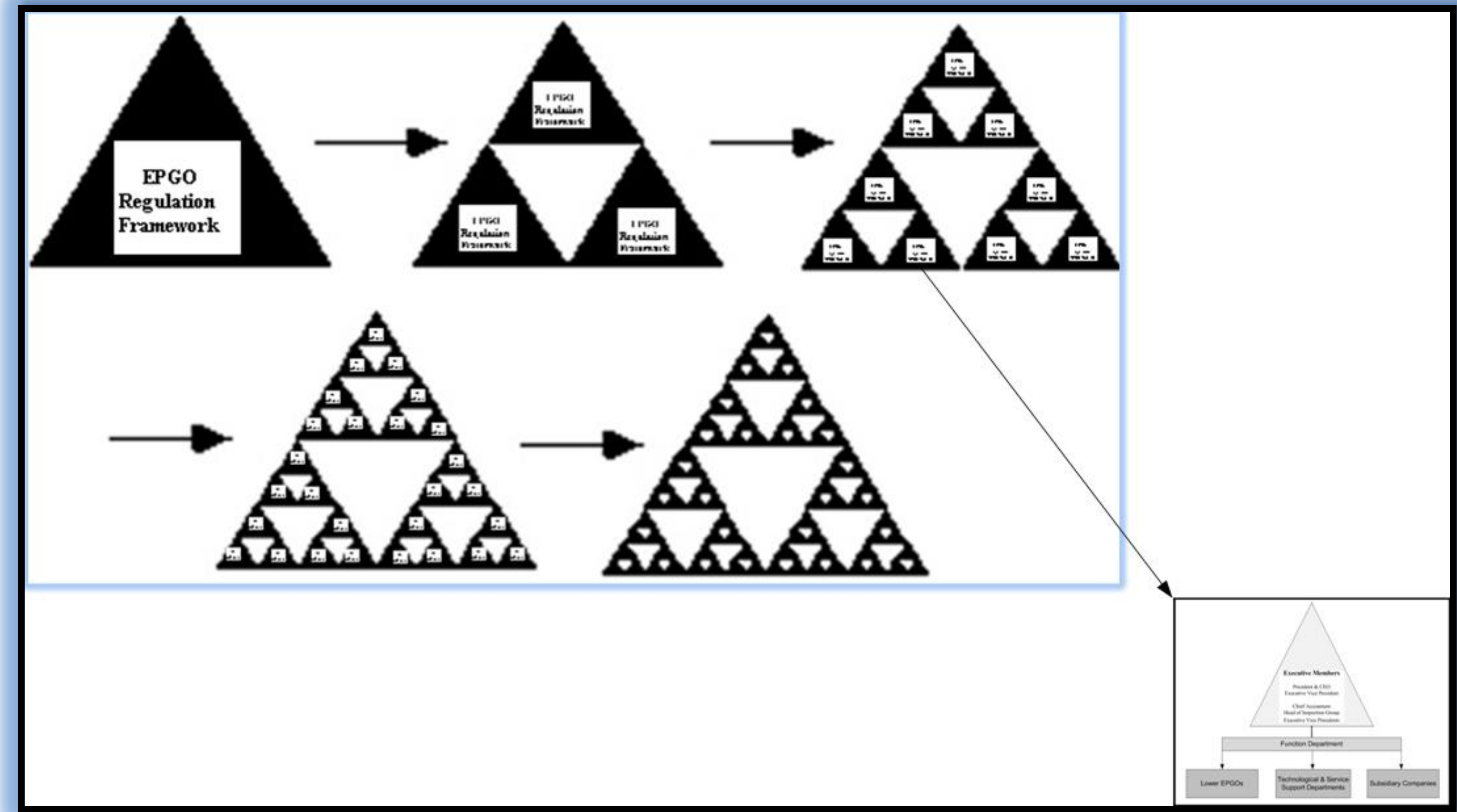


Figure 42 EPGO regulation framework construction using Fractal theory (Sierpinski Gasket)

In the regulation of the SGCC, each EPGO has similar regulation framework, repeating at different levels of the hierarchy. Further the Smart Grid Strategy in this thesis is implemented with similar structure at different levels. Both the regulation of SGCC and smart grid strategy can thus be presented as a fractal to simplify the complexity of the problem. Figure 43 shows the SGCC framework as a fractal structure.

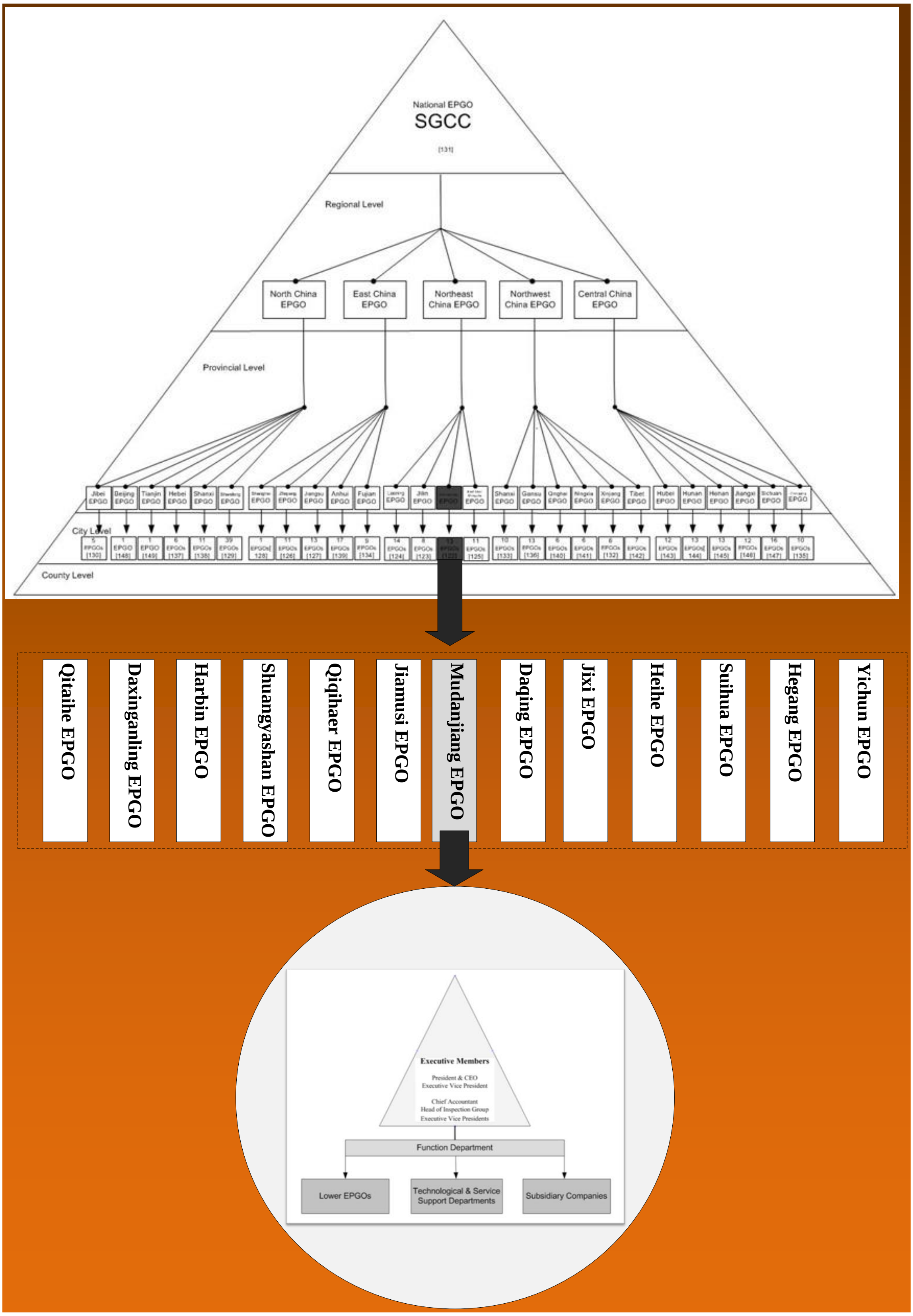


Figure 43 EPGO's regulation framework in SGCC framework

The highlighted area is use as EPGO case study in Chapter 5.

4.6 Smart Grid Strategy in SGCC's EPGO

Smart Grid Strategy (SGS) is an important strategy for enhanced safety and quality of electricity grid operations, customer services and environmental benefits. SGCC outlined plans in 2010 for a pilot smart grid programme to be deployed till 2030, it estimated that investments in smart grids will reach at least USD 96 billion by 2020 (IEAa, 2011). In this research, the smart grid strategy is extended and integrated with a general quality management framework. Various smart grid technologies can be viewed as the system design characteristics contributing to the performance improvement for the Chinese electric power grid operators in terms of customer satisfaction and environmental impacts and so on. It is important to examine the details of the smart grid strategy in detail, as shown in Figures 44-47.

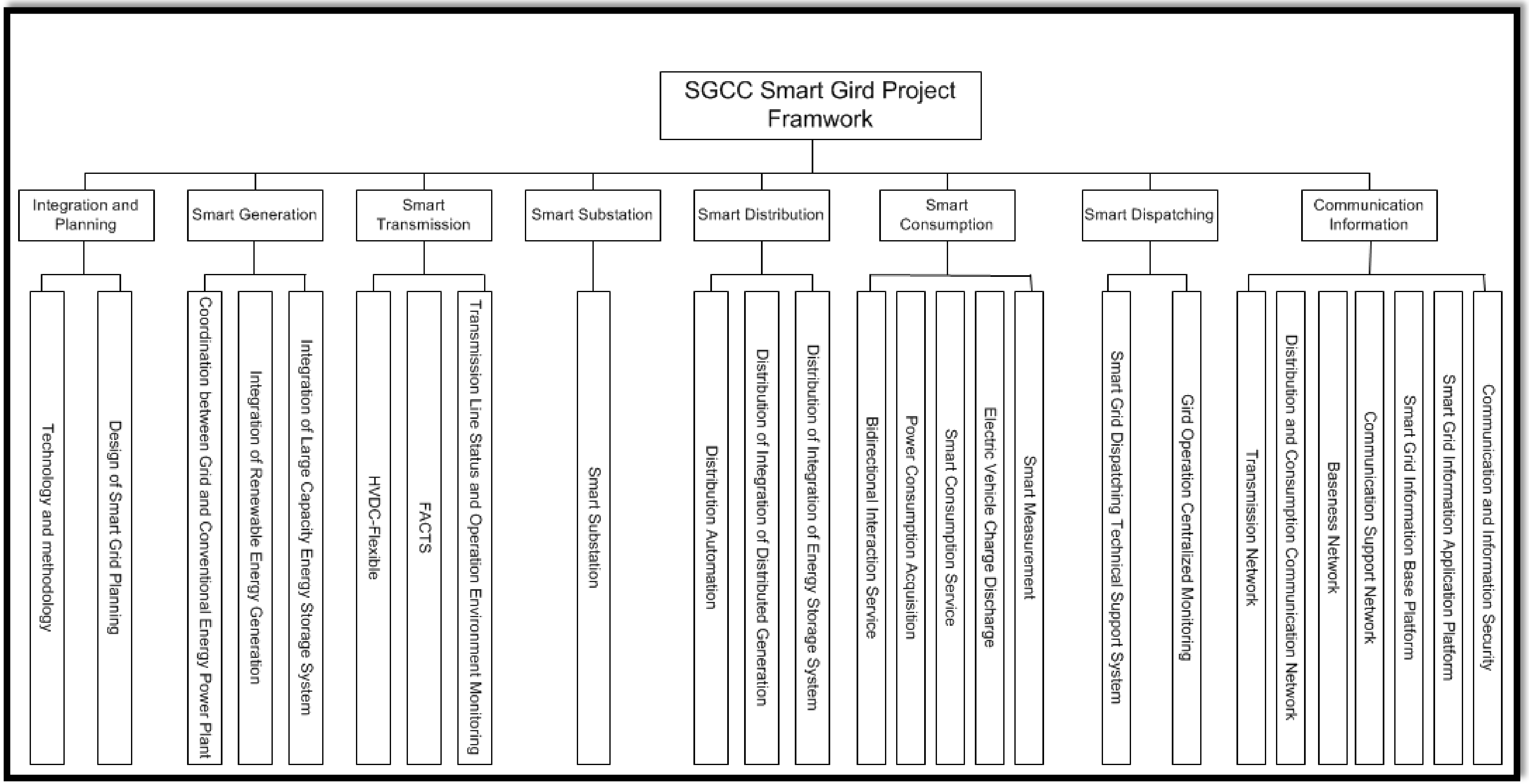


Figure 44 SGCC's Smart Grid Strategy Framework (SGCC, 2011b)

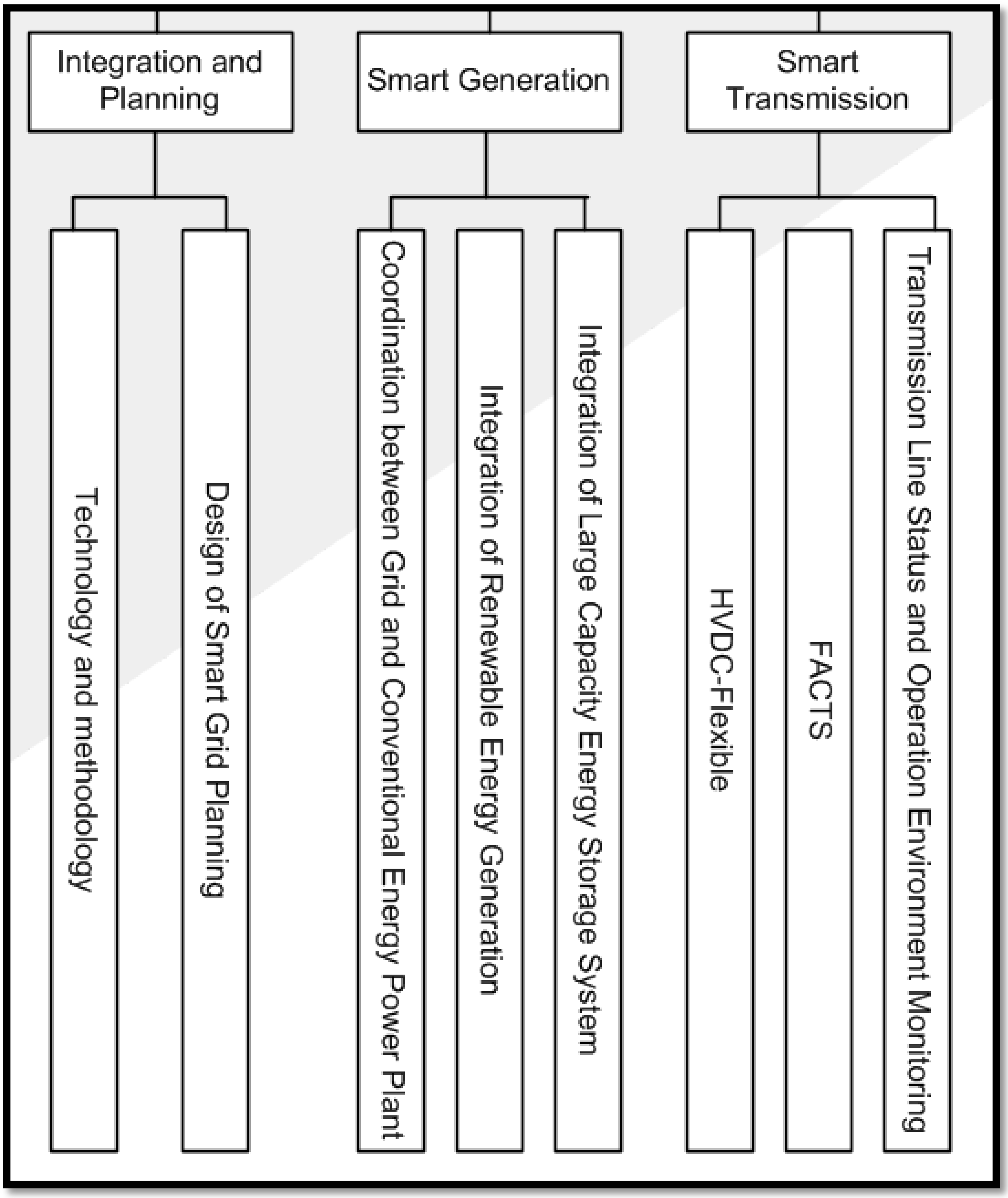


Figure 45 The blowup for part of SGCC's Smart Grid Strategy Framework-1 (SGCC, 2011b)

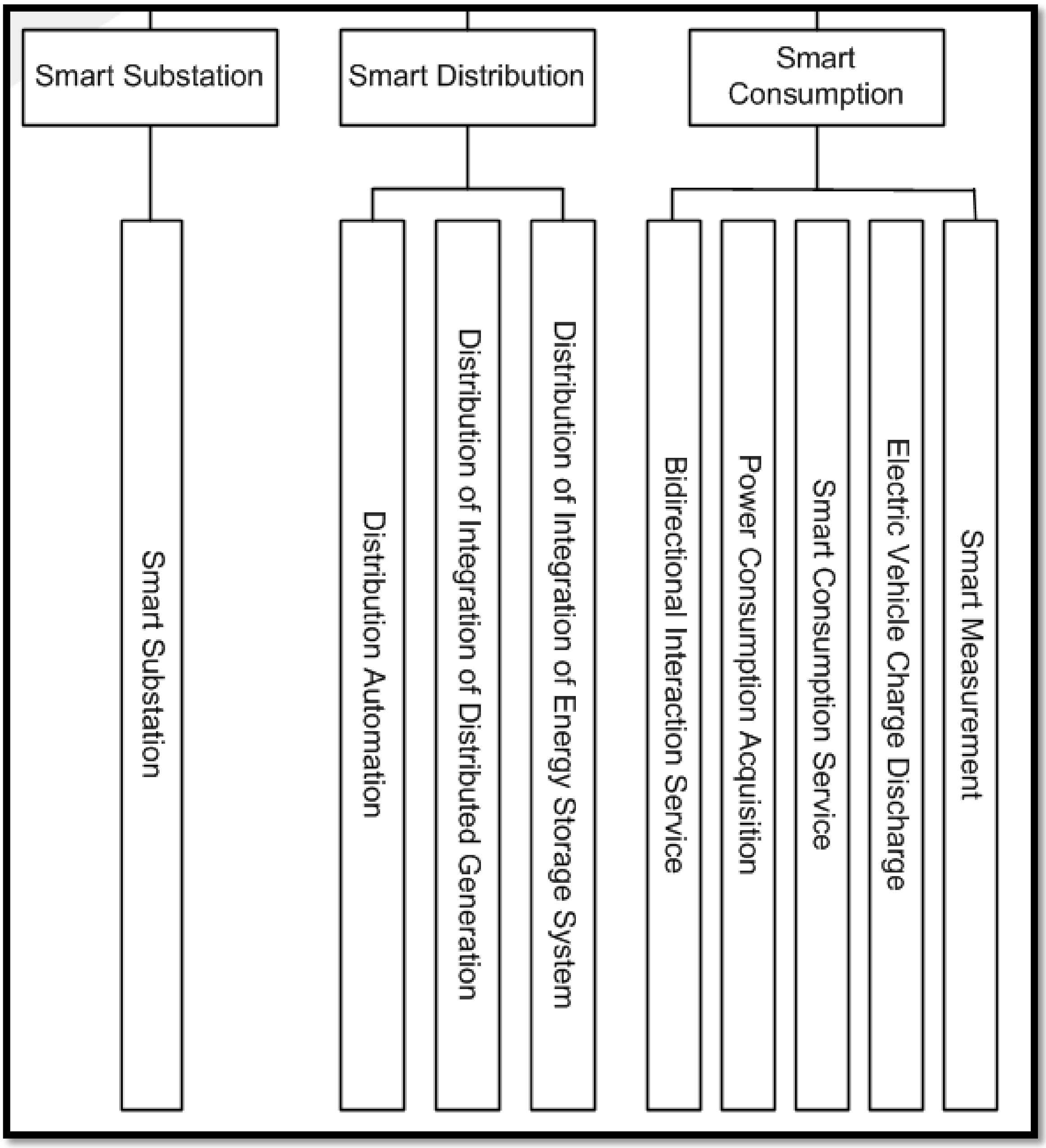


Figure 46 The blowup for part of SGCC's Smart Grid Strategy Framework-2 (SGCC, 2011b)

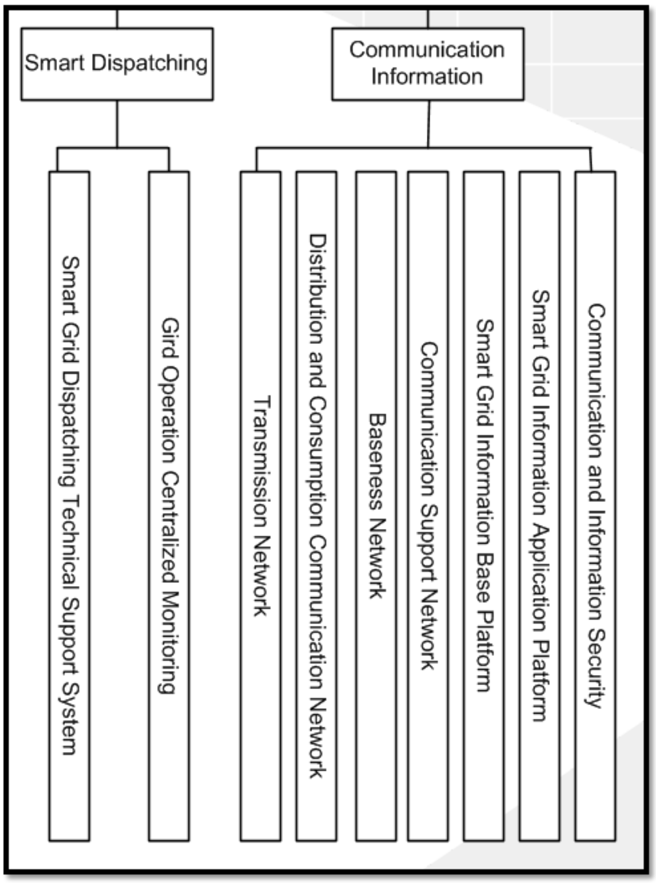


Figure 47 The blowup for part of SGCC's Smart Grid Strategy Framework-3 (SGCC, 2011b)

4.7 New 3S Strategy

4.7.1 3S Strategy

3S Strategy is a model to ensure safety of supply, sustainable development, and the safeguard of environment (3S) (Wang et al., 2010). Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Therefore, there has more improving work for sustainable development of 3S Strategy in future works.

4.7.2 Proposed new 3S Strategy

Through the study of 3S Strategy, sustainable development strategy, energy objectives of World Energy Council, and SGCC's common responsibilities in Chapter 2, a new 3S strategy can be developed. The new 3S Strategy is a model to ensure sustainable safe supply, social equity and safeguard environment.

Sustainable safe supply (EPGO):

1) Resilience measures to prevent possible disruptions
2) Security Risk Management
3) Energy efficiency measures
4) Maximizing energy reserves (e.g. Global Harmonization of Energy Reserves and Resources Terminology; maximizing energy saving &minimizing costs (Studebaker, 2008)
5) Reliable networks
6) Reliability of global energy markets
7) New technology for sustainable safe supply

Social Equity (relationship between social and EPGO):

1) Bearable electric power bills (bearable)
2) Quality service (equitable)
3) Efficiency investment (sustainable)

Safeguard environment

1) Supply-side efficiency & safety by renewable sources
2) Demand-side supply by renewable sources
3) Supply-side efficiency & safety by other low-carbon sources (LCS)
4) Demand-side supply by other LCS

4.8 New 3S Strategy and SGS in a QFD Framework

New 3S Strategy and smart grid strategies may be presented in a QFD framework (C.Rego et al., 2003).

4.8.1 Development of HOQ

Step 1: Customer expectations

The first step in QFD is to identify customers and also their needs. The customer needs in this case are based on the New 3S Strategies both the product and service. In order to organize and evaluate this information, this case study uses simple quality tool of Fish Affinity Diagrams.

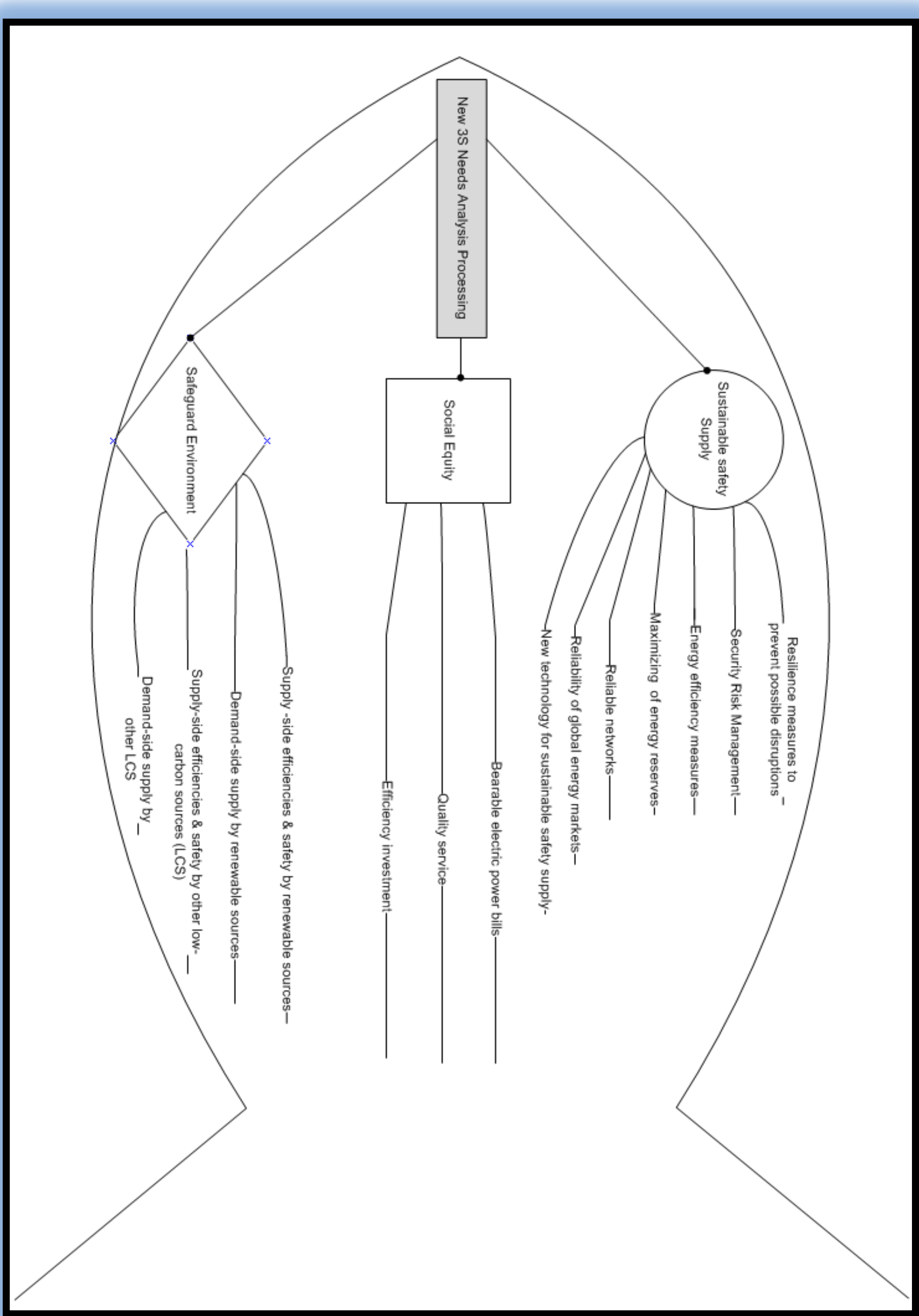


Figure 48 3S needs in fish affinity diagram

1	3S Needs	Sustainable Safety of Supply	Resilience measures to prevent possible disruption
2			Security Risk Management
3			Energy efficiency measures
4			Maximizing energy reserve
5			Reliable networks
6			Reliability of global energy markets
7			New technology for sustainable safety supply
8		Social equity	Bearable electric power bills
9			Quality service
10			Efficiency investment
11		Safeguard Environment	Supply -side efficiencies & safety by renewable sources
12			Demand-side supply by renewable sources
13			Supply -side supply by other low-carbon sources LCS
14			Demand-side efficiencies & safety by other LCS

Figure 49 Customer expectations of case study

Step 2: Technical & Managerial Features (TMFs)

The Technical Managerial Features are characteristics about the product and service of EPGO's Smart Gird Strategy that can be measured and benchmarked against the *SGCC Framework and Roadmap for Smart Grid Standards* in 2010.

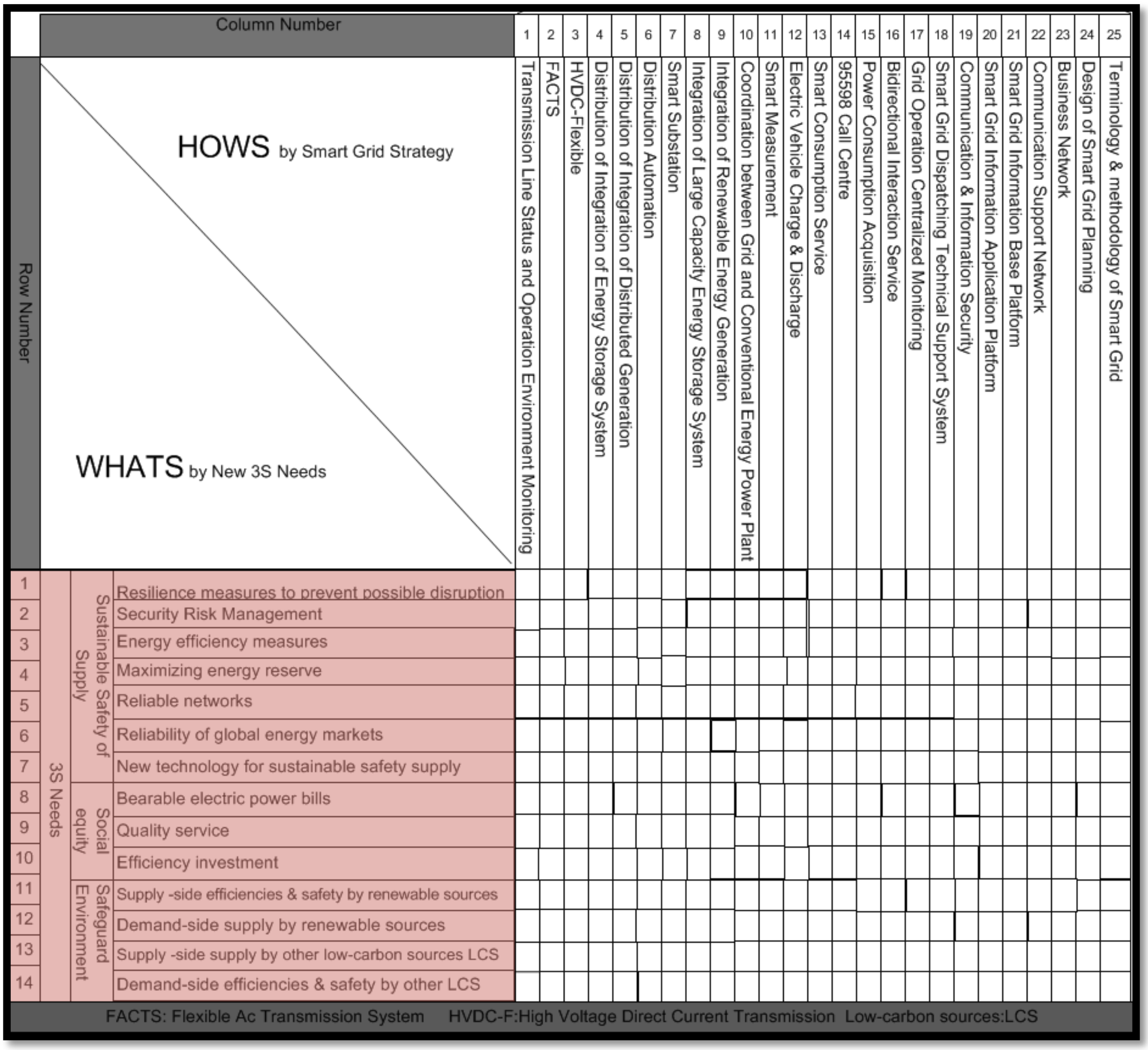


Figure 50 Technical & Managerial Features of case study

Step 3: Relationship Matrix

The relationship matrix shows the relationship between customer expectations and the ability of EPGO's TMFs to meet those needs. In this step the basic question to ask is, "what is the strength of the relationship between the TMFs and the customer expectations?" Relationships can either be weak, moderate, or strong, carrying a corresponding value of 1, 3 or 9.

4.8.2 House of Quality for New 3S needs in Smart Grid Strategy of EPGO

QFD can be used to translate the new 3S needs to the smart grid strategies, as shown in Figures 51 and 52.

Row Number		Columu Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
		HOWS by SGS	Smart Transmission			Smart Distribution			SS	Smart Generation			Smart Consumption						Smart Dispatching		Communication Information					Integration and Planning		
		WHATS New 3S	Transmission line status and operation environment monitoring	Flexible AC Transmission Systems	HVDC-Flexible	Distribution of integration of energy storage system	Distribution of integration of distributed generation	Distribution Automation	Smart Substation	Integration of Large Capacity Energy Storage System	Integration of Renewable Energy Generation	Coordination between Grid and Conventional Energy Power Plant	Smart Measurement	Electric Vehicle Charge Discharge	Smart Consumption Service	95598 Call Centre	Power Consumption Acquisition	Bidirectional Interaction Service	Grid Operation Centralized Monitoring	Smart Grid Dispatching Technical Support System	Communication & Information Security	Smart Grid Information Application Platform	Smart Grid Information Base Platform	Communication Support Network	Business Network	Design of Smart Grid Planning	Terminology & methodology of Smart Grid	Customer expectations Iimportance
1	New 3S Needs / Sustainable safety supply	Resilience measures to prevent possible disruptions	9	3		9	3	3		9	3	1	1		3	3	3	3	3	3	3	3	3	3	3	3	3	5
2		Security Risk Management	3	3			9	9	9	9	3	1	3	1	3	1												3
3		Energy efficiency measures						9	3	3		3	9		9	3												3
4		Maximizing of energy reserves	9	9	9		9			9		9	3		3	3	3	9	9	9	3	3	3	3	3	3	3	5
5		Reliable networks						9	9				3	1	3	3	3	3			3	3	3	3	3	3	3	4
6		Reliability of global energy markets	9	9	9	9	9	3	3	3	3	1	3			9	9	9	9	9	3	9	9	9	3	9	3	2
7		New technology for sustainable safety supply						9	9	9	9	3	3	9	3	3												3
8	Social equity	Bearable electric power bills	3	3	3	3	3	3	3	3	3	1																5
9		Quality service									3	1	1	3		9	3	3			3	3	9	3	9	9	9	5
10		Efficiency investment											1	9	3		3	3	3	3	3	3	3	3	3	3	3	4
11	Safeguard environment	Supply -side efficiencies & safety by renewable sources								3	3					3												2
12		Demand-side supply by renewable sources												1	3	3												2
13		Supply -side supply by other low-carbon sources(LCS)								3	9					3												2
14		Demand-side efficiencies & safety by other LCS											1	1	3	3												2
		Weight	168	138	114	114	156	189	156	222	147	119	130	125	147	186	123	117	126	126	111	123	153	123	117	129	117	3476
		Relative Weight (%)	5%	4%	3%	3%	4%	5%	4%	6%	4%	3%	4%	4%	4%	5%	4%	3%	4%	4%	3%	4%	4%	4%	3%	4%	3%	

Figure 51 House of Quality of Smart Grid Strategy of EPGO for New 3S needs

9	3		9	3	3		9	3	1	1		3	3	3	3	3	3	3	3	3	3	3	3	3	5
3	3			9	9	9	9	3	1	3	1	3	1												3
					9	3	3		3	9		9	3												3
9	9	9		9			9		9	3		3	3	3	9	9	9	3	3	3	3	3	3	3	5
					9	9				3	1	3	3	3	3			3	3	3	3	3	3	3	4
9	9	9	9	9	3	3	3	3	1	3			9	9	9	9	9	3	9	9	9	3	9	3	2
					9	9	9	9	3	3	9	3	3												3
3	3	3	3	3	3	3	3	3	1																5
								3	1	1	3		9	3	3			3	3	9	3	9	9	9	5
										1	9	3		3	3	3	3	3	3	3	3	3	3	3	4
							3	3					3												2
											1	3	3												2
							3	9					3												2
										1	1	3	3												2
168	138	114	114	156	189	156	222	147	119	130	125	147	186	123	117	126	126	111	123	153	123	117	129	117	3476
5%	4%	3%	3%	4%	5%	4%	6%	4%	3%	4%	4%	4%	5%	4%	3%	4%	4%	3%	4%	4%	4%	3%	4%	3%	

Figure 52 The blowup for relationship calculation of the House of Quality

Through the assessment methodology using the HOQ, each Smart Grid Strategy can be prioritized regarding the related customer needs.

Firstly, the most important smart grid strategy is integration of Large Capacity Energy Storage System with the strongest important impact on New 3S needs of the customer needs with a degree of importance of 6%. The reason is because there are very strong relationships between this strategy and other four customer expectations include resilience measures to prevent possible disruptions, security risk management, maximizing of energy reserves and new technology for sustainable safety supply.

The next three important Smart Grid Strategies have a degree of importance of 5%. There are including transmission line status and operation environment monitoring, distribution automation and 95598 Call Centre. For example, for the 95598 Call Centre, the reason of this because there is important impact on customer needs. Moreover, there is very strong relationship between the strategy of 95598 Call Centre and other two customer expectations include reliability of global energy markets and quality service.

Consequently, in this case study, the importance of smart grid strategy can be assessed by the above assessment methodology regarding the customer needs (e.g. New 3S needs).

4.9 Summary

In this chapter, firstly the equilibrium theory has been applied and demonstrated to develop the conceptual design of the China's electric power market model. The problems associated with China's current electric power market are discussed based on Equilibrium Energy Regulation Model (EERM).

This chapter has also detailed the design and implementation of an assessment methodology for the importance of Smart Grid Strategies in relation to the customer needs (New 3S Strategy), using QFD.

Furthermore, each single Smart Grid Strategy can be extended and optimized using additional phases of QFD. An example case study based on the 95598 Call Centre will be presented in next chapter to optimize the quality and its operations.

CHAPTER 5 Optimization of operational quality and service levels using QFD and mathematical programming

5.1 Introduction

This chapter presents a methodology for the optimization of operational quality and service levels, based on the operational data collected from the 95598 Custom Service Center at the Mudanjiang Electric Power Bureau (MEPB) and the related documents (Annual report, documents and so on). Whilst the case study example is given for the MEPB 95598 Custom Service, the actual method can be similarly applied in other operations of EPGOs at different levels of the SGCC.

The background of MEPB including 95598 Custom Service Center will first be described, the concept of target costing is then introduced before the application of QFD and the optimization of its quality operations, with detailed data and numerical example.

5.2 MEPB EPGO

China EPGOs have to develop suitable methodologies to achieve the quality and efficiency of their operations including the future smart grid strategy to meet the increasing customer expectations. Meanwhile, there are many different aspects and issues in each smart grid strategy to consider, it is important to select the case study EPGO with suitable size to avoid unnecessary complexity. Therefore, a city level EPGO MEPB and its custom service center have been selected for close studies to demonstrate the methodology.

5.2.1 MEPB Regulation Structure

MEPB is a subordinate enterprise of SGCC founded in 1946, with its electric power grids covering an area of 27,000 square kilometers (SERC, 2011). Responsible for the power supply for Mudanjiang City, Hailin City, Ninan City, Suifenhe City, Muling City, Dongning County and Linkou County, it has nearly 570,000 customers and 2138 employees in 2012 (BN, 2013). The regulation framework of MEPB EPGO as a part of SGCC can be seen in Figures 53- 58.

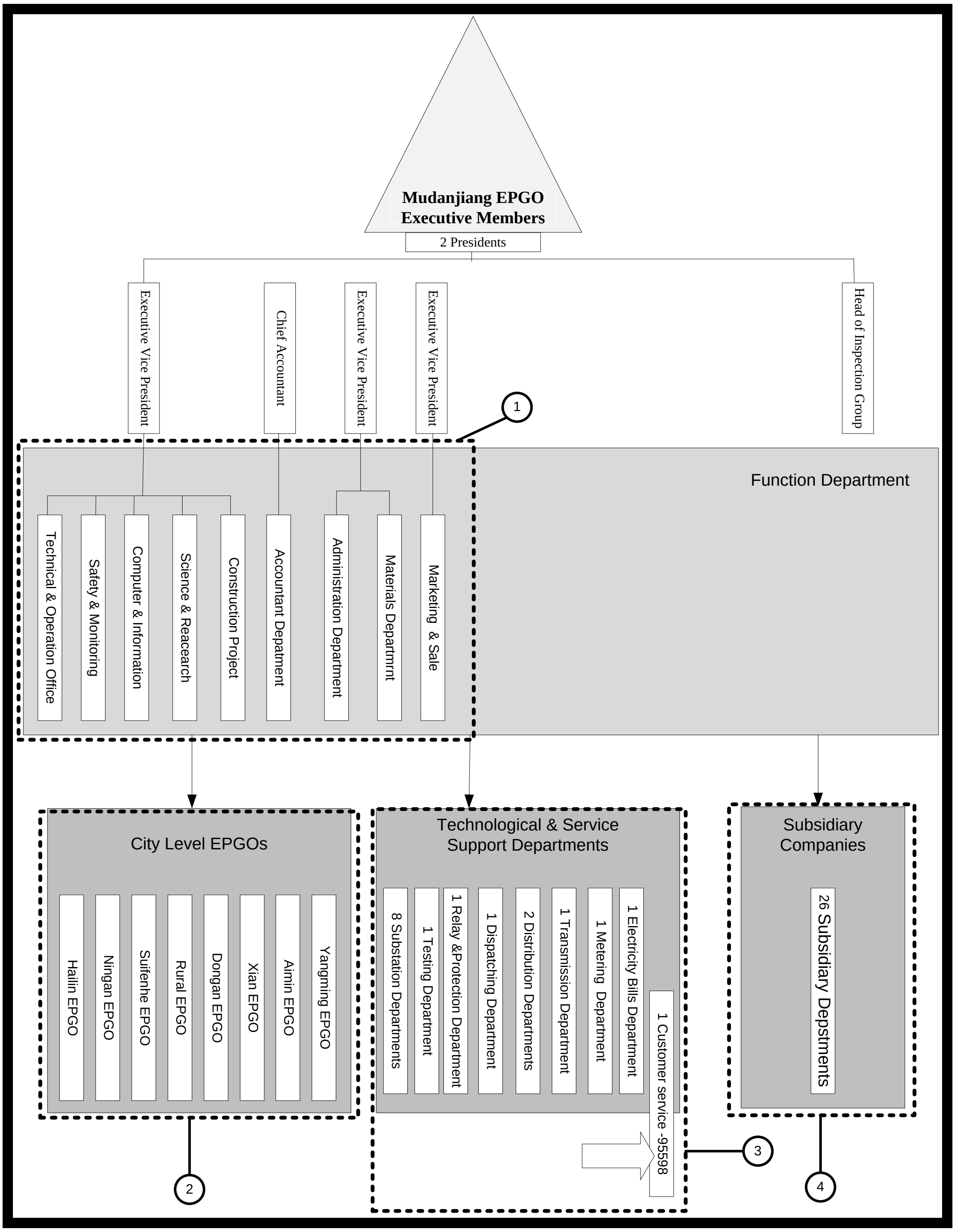


Figure 53 MEPB EPGO's regulation framework

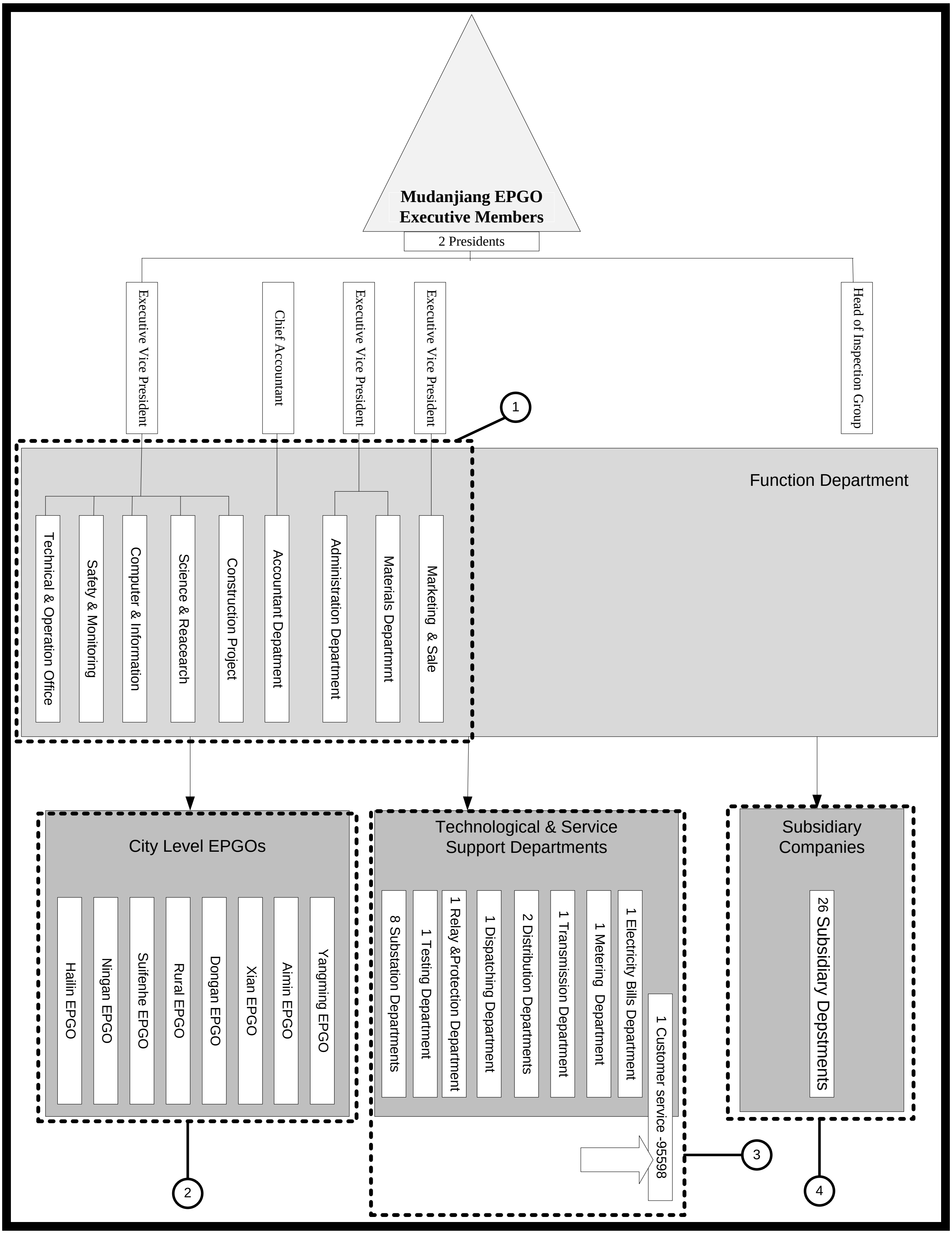


Figure 54 The blowup for part of MEPB EPGO's regulation framework

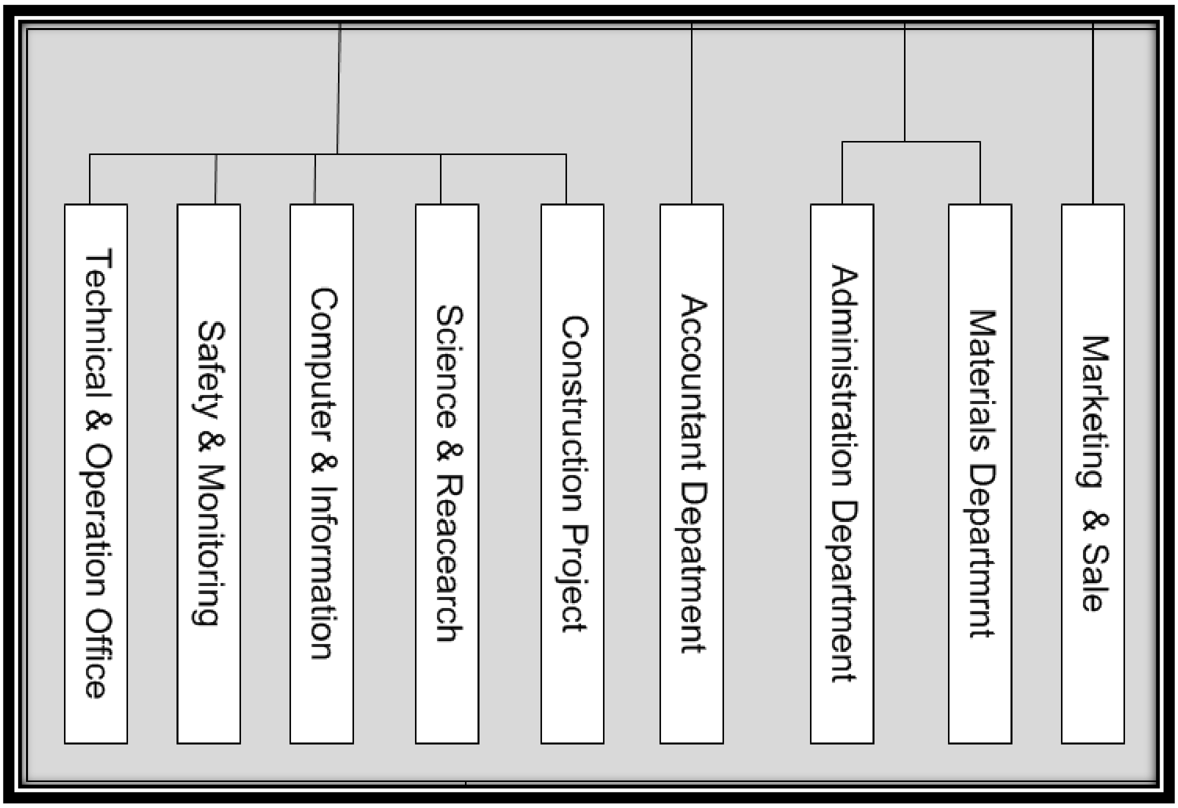


Figure 55 The blowup ① for MEPB EPGO's regulation framework

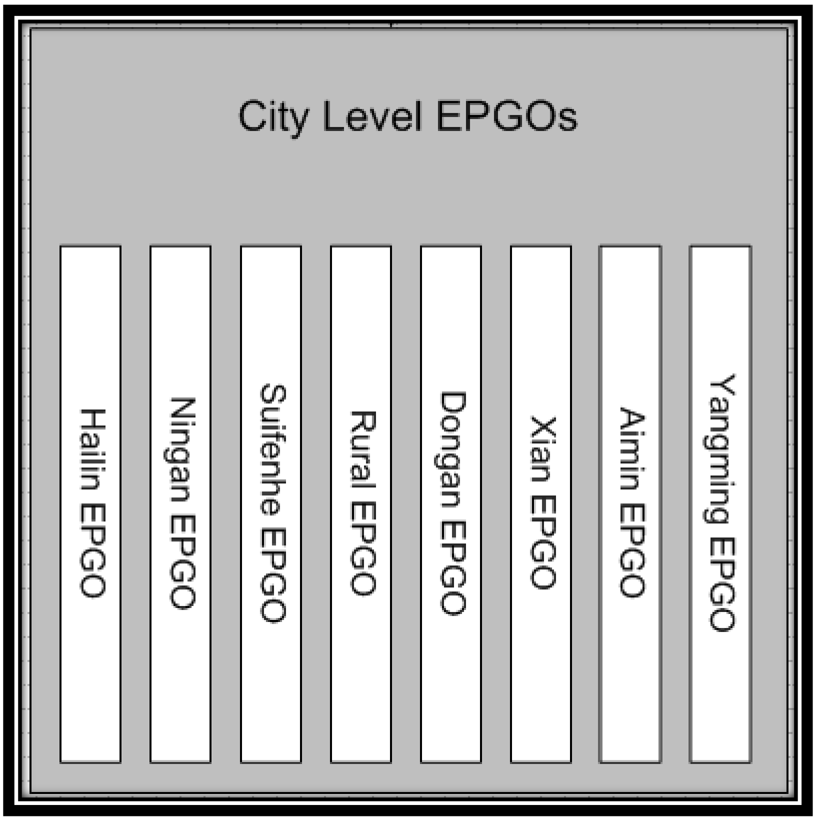


Figure 56 The blowup ② for MEPB EPGO's regulation framework

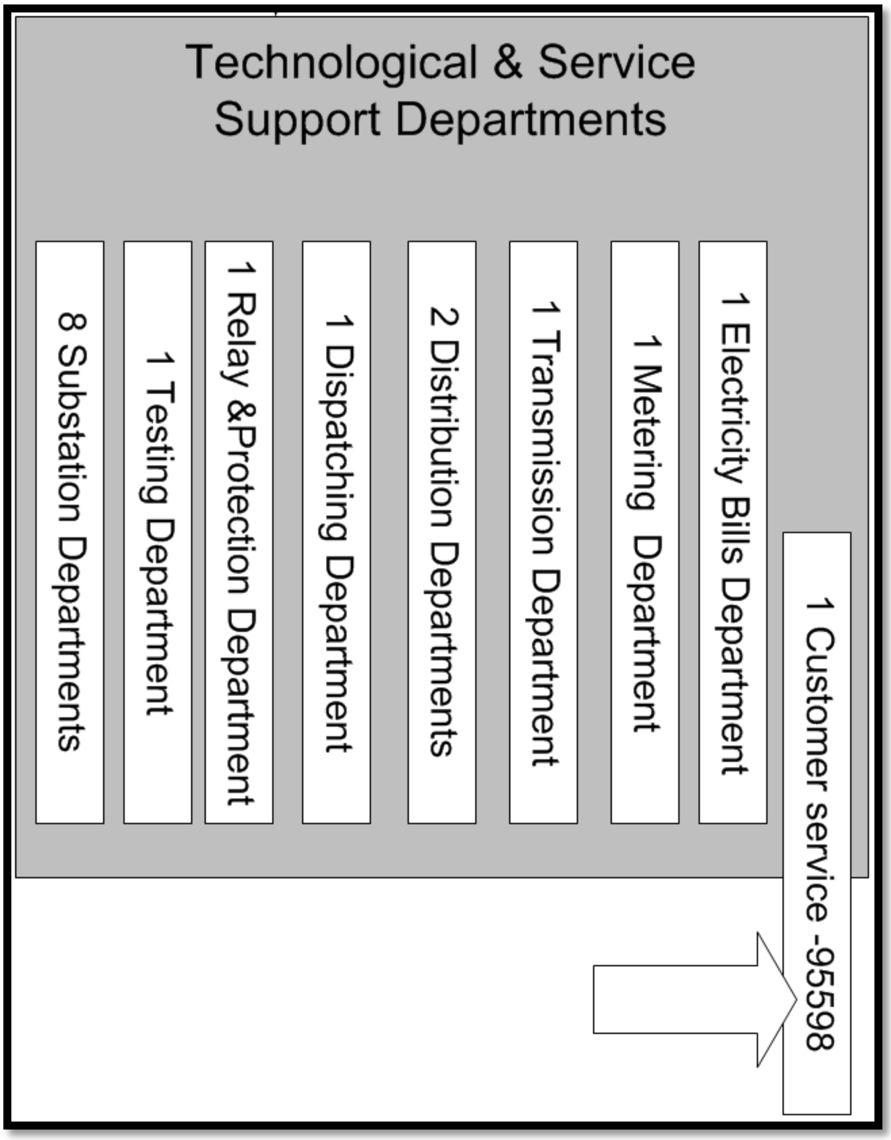


Figure 57 The blowup ③ for MEPB EPGO’s regulation framework

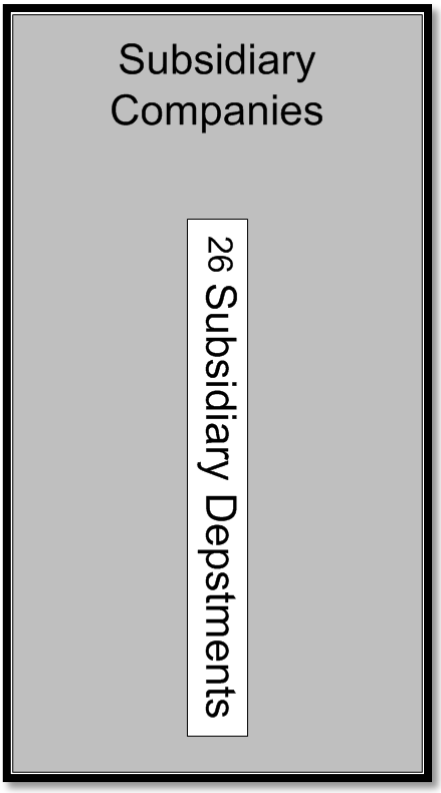


Figure 58 The blowup ④ for MEPB EPGO's regulation framework

5.2.2 MEPB's 95598 Customer Service Center

MEPB's 95598 Custom Service Center is one of the service support departments of the MEPB EPGO in Mudanjiang city in China. It incorporates 95598 Customer Hotline and 95598 Customer Website. The 95598 Customer Hotline works 24 hours a day, 7 days a week. Its services include blackout notices, power failure repairs, power consumption information inquiries, business consultation, business processing, complaints and suggestions. The whole process will be tracked and reviewed. The 95598 Customer Service Website provides non-stop power blackout notices, power consumption information inquiries, business processing information inquiries, inquiries of power supply and consumption policies and regulations, and also customer complaints (SGCC, 2011c).

5.3 Target costing (TC)

5.3.1 Target cost basic Factors

Electric power is not just a special kind of product, but also a service, and equally important is the quality of electric power and the quality of customer service (Abdyrasulova, Sulaimanova,Nurmamatov, 2011). The target costing process was identified by L. Ellram in 2000 (Ellram, 2002; AACE, 2013; ACostE, 2013; Bode & Fung, 1998; Bode & Fung, 1998; Joiner & Ssholtes, 1988). "Target costing is an emerging process whereby organizations calculate the allowable cost (i.e., target cost) for buying/producing the product or service they offer for sale by first determining the acceptable selling price in the marketplace and the organization's required internal margin on the product (Ellram, 2002; AACE, 2013; ACostE, 2013; Bode & Fung, 1998; Bode & Fung, 1998; Joiner & Ssholtes, 1988)." In the case study of MEPB's 95598 customer service center, the target cost basic factors are shown in Figure 59 on below (Ellram, 2002; AACE, 2013; ACostE, 2013; Bode & Fung, 1998; Bode & Fung, 1998; Joiner & Ssholtes, 1988):

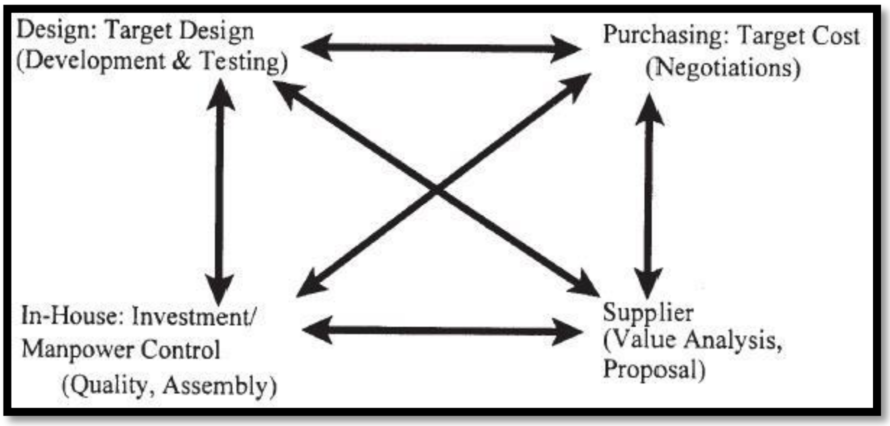


Figure 59 Target cost basic factors (Ellram, 2002; AACE, 2013; ACostE, 2013; Bode & Fung, 1998; Bode & Fung, 1998; Bode & Fung, 1998; Joiner & Ssholtes, 1988)

5.3.2 Target costing process

The target costing process for MEPB-95598 Customer Service Center is shown in Fig. 61 (Ellram, 2002).

The first step in target costing for the 95598 Customer Service Center is to identify the customer expectations and characteristics of electrical power supply service in Mudanjiang city.

In step two, the target selling price is determined according to the competitive price policy in China's Smart Grid project. The targeted selling price is regulated by China government. This is one of features associated with state owned enterprises (Yin, 2011). In the third step, the proper target cost is decided. The required profit margin is suggested by the 95598's profit commitment in the strategic planning process. In this case study, target costs are consistent to optimize max qualification (target cost was set at three selections): RMB 18000000, 16000000 and 12000000.

Step four calculates the cost breakdown, including internal cost and external purchases cost. The external purchase cost is included to services or components. If the costs are given at a high level, then the breakdown cost will come from individual component, material, or service level.

In step five, the organization works with suppliers to achieve the target costs.
In step six, the target cost of QFD has achieved and overriding target price, or at a set deadline (Deming, 1992; DoC, 2009).

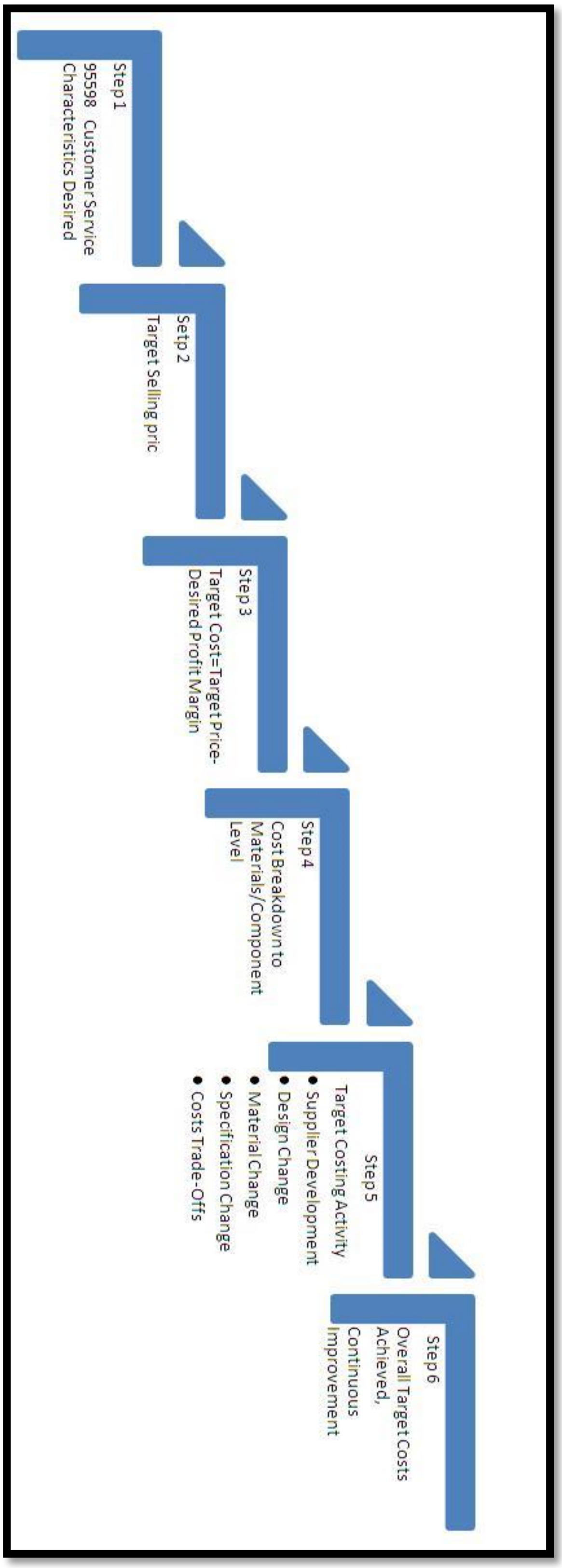


Figure 60 Target costing process of MEPB-95598 customer service center

5.4 Customer expectations and Technical & Managerial Features using target costs and QFD

The key stage of QFD for MEPB-95598 customer service is shown in the following house of quality, where both Customer Expectations (CE) and Technical & Managerial Features (TMF) are identified in Figures 61 and 62, together with the relationships between CEs and TMFs, and also the interrelationships between TMFs.

Given the relative importance of various customer expectations, the relative importance of the TMF can be determined. For example, Figure 61 shows the most important TMF is satisfaction rate of service attitude (Importance indicator: 900).

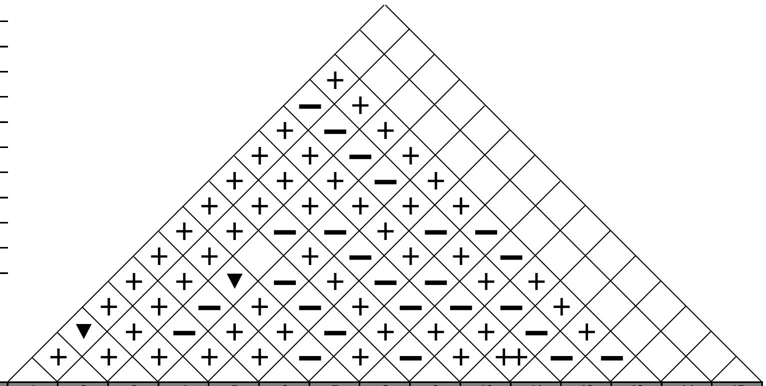
Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Title: 95598 Customer Service Center

Author: Chen Wang

Date: 31th Dec. 2013

Notes:



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	▲	▲	▲	▲	▼	▼	▲	▲	▲	▼	▲		
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Reliability of power supply	Voltage Qualification Rate	Investment innovation	Electrical Fault repair service	Overall labour productivity	Accuracy Meter reading	Average blackout time per customer	Repeatability & Reproducibility complains	Flexible Service	Satisfaction rate of service attitude	Self-service availability	Average customer wait time	Average of CSR answer speed		
1	9	13.9	5.0	Fast response			O	Θ	Θ	O	O	Θ	Θ	Θ	Θ	Θ	Θ		
2	9	13.9	5.0	Fast repairs	O	O	O	Θ	Θ	Θ	Θ	Θ	Θ	Θ	O	Θ	Θ		
3	9	5.6	2.0	Free phone call			▲	▲	▲			▲	Θ	Θ					
4	9	11.1	4.0	Quality repairs	Θ	Θ	O	Θ	Θ	Θ	Θ	O	Θ	Θ		O	O		
5	9	8.3	3.0	Easy to find out bills			O		▲			O	Θ	Θ	Θ	O	O		
6	9	8.3	3.0	Easy to pay bills			O		▲			O	Θ	Θ	Θ	O	O		
7	9	8.3	3.0	Precise meter	O	O	O	O	Θ	Θ	O	O	O	Θ					
8	9	11.1	4.0	Less happen for the same problem	Θ	Θ	Θ	Θ	Θ	O	Θ	Θ	▲	Θ		O	O		
9	9	8.3	3.0	Multiple channel to get informations(power cut, new technology or meter reading etc.)			O	▲	▲	▲		O	Θ	Θ	O	O	O		
10	9	11.1	4.0	Satisfaction with complaint handling	O	O	O	Θ	Θ	Θ	O	Θ	Θ	Θ	O	Θ	Θ		
				Target or Limit Value															
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	9	9	8	8	7	7	7	7	7	7	7	7	7		
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9		
				Weight / Importance	300.0	300.0	355.6	588.9	655.6	483.3	425.0	588.9	761.1	900.0	375.0	491.7	491.7		
				Relative Weight	4.5	4.5	5.3	8.8	9.8	7.2	6.3	8.8	11.3	13.4	5.6	7.3	7.3		

Figure 61 QFD House of Quality Model for MEPB 95598 Service

Weight / Importance	Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	▼	▲	▲	▲	▲	▼	▲	▼	▲	▲	▲
	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Reliability of power supply	Voltage Qualification Rate	Investment innovation	Electrical Fault repair service	Overall labour productivity	Accuracy Meter reading	Averrage blackout time per customer	Repeatability & Reproducibility complains	Flexible Service	Satisfaction rate of service attitude	Self-service availability	Average customer wait time	Average of CSR answer speed
5.0	Fast response			○	⊖	⊖	○	○	⊖	⊖	⊖	⊖	⊖	⊖
5.0	Fast repairs	○	○	○	⊖	⊖	⊖	⊖	⊖	⊖	⊖	○	⊖	⊖
2.0	Free phone call			▲	▲	▲			▲	⊖	⊖			
4.0	Quality repairs	⊖	⊖	○	⊖	⊖	⊖	⊖	○	⊖	⊖		○	○
3.0	Easy to find out bills			○		▲			○	⊖	⊖	⊖	○	○
3.0	Easy to pay bills			○		▲			○	⊖	⊖	⊖	○	○
3.0	Precise meter	○	○	○	○	⊖	⊖	○	○	○	⊖			
4.0	Less happen for the same problem	⊖	⊖	⊖	⊖	⊖	○	⊖	⊖	▲	⊖		○	○
3.0	Multiple channel to get informations(power cut, new technology or meter reading etc.)			○	▲	▲	▲		○	⊖	⊖	○	○	○
4.0	Satisfaction with complaint handling	○	○	○	⊖	⊖	⊖	○	⊖	⊖	⊖	○	⊖	⊖

Figure 62 Screen shot of House of Quality Model for MEPB 95598 Service

5.5 Optimization of quality and service levels of MEPB 95598 Customer Service Centre

In addition to the standard QFD procedures to evaluate and determine correct design parameters, it is possible to introduce mathematical programming in the QFD to optimize the quality and design parameters. The general optimization procedure may be shown in Figure 63.

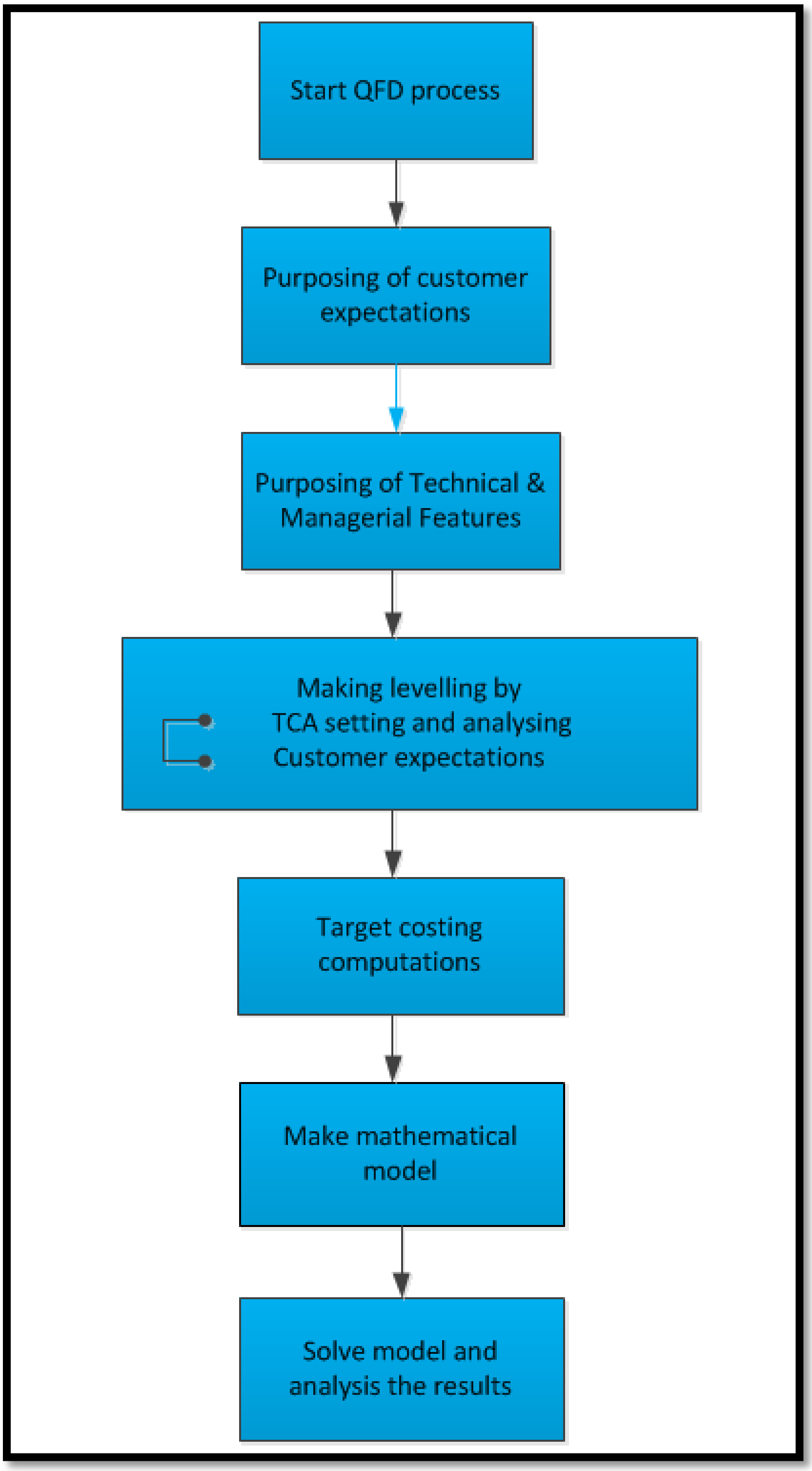


Figure 63 Optimization model for 95598's quality & cost (DoC, 2009)

TCA: Target costing activity

5.6 Model assumptions

Whilst the customer expectations and technical & managerial features (TMFs) have been identified above in the standard QFD process and each TMF may have different service levels and can be treated as a decision variable to optimize the service quality.

1330000000	5000000	1600800	25000000	722060	7200000	199189	25000000	1070576	155239	500000	25000000	200000
10000000	195127	3647200	64683	216000	2000000						43149	2071156
15000000	114521	5161600	8149425	378448757	600000	597567	114520	17926999	43200	1050000	1500000	776196

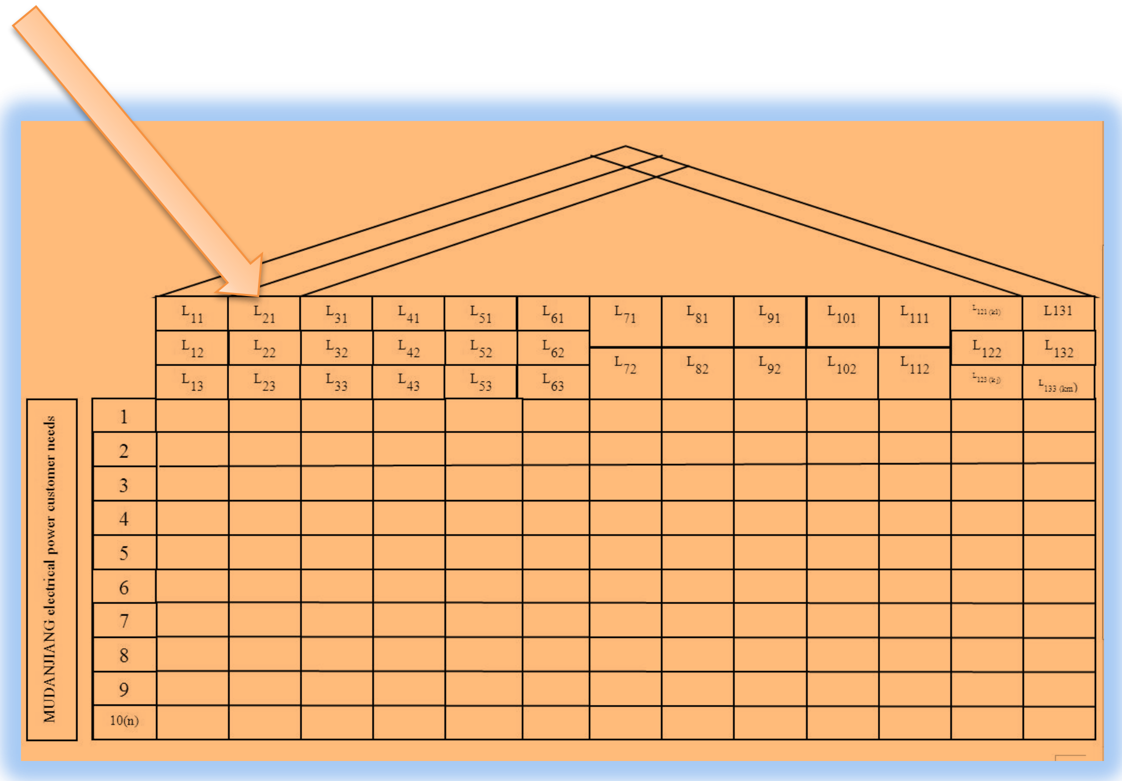


Figure 64 95598House of Quality Mathematical Model

Figure 64 shows the modified HOQ structure with all the TMFs having 2 or 3 service levels. Different service levels for a given TMR have different impacts on the service quality at different costs. For example, L_{11} is RMB1330000000 and L_{12} is RMB10000000. Each TMR should also have a target cost (which is further discussed in Section 12 and Section 13 too).

5.7 MATHEMATICAL MODEL

The mathematical model used in this section is similar to the model used in (Jariri, Zegordi, 2008), which was developed for manpower planning. The objective of the mathematical optimization here is to maximize the service quality under the target cost constraints of MEPB 95598 customer services.

5.7.1 Meanings of parameters

i : ith CE, i=1,···, n;

k: kth TMRs, k=1,···, m;

L_{KL} number of level for Kth TMRs, L=1,···, L_K;

u_{ikL}: the intensity that the L_{th} level of the kth TMRs has on ith customer expectations (u_{ikL} are the elements of HOQ) ;

w_i: weight for ith customer expectations;

x_{KL}: decision variable:

1 if kth TMR performs at level L

0 Otherwise;

c_{KL}: the cost for implement in level L for kth TMRs;

S_i the summation of effects of TMRs for ith customer expectations (notice its computation in the formula) ;

γ_{ikj}: the relation between technical requirements (roof of HOQ).

5.7.2 Relationship Matrix

The relationship matrix is the main matrix inside the HOQ. It is usually completed by the QFD team. These weights will be used later, responsible for trade-off states for contradictory characteristics and responsible for an absolute weight at the bottom of the matrix (CCRSM, 2013).

In this thesis, values 1, 3 and 9 are used to represent “unimportant”, “Neutral”, and “important”, respectively.

The mathematical model for mathematical programming is described as follows:

$$\max Z = \sum_{i=1}^{n} w_i \, s_{i,} \tag{1}$$

Subject to:

$$\sum_{L=1}^{L_k} x_{kL} = 1, k = 1,2, \ldots, \mathrm{m}, \tag{2}$$

$$s_i = \sum_{k=1}^{m} \sum_{L=1}^{L_k} u_{ikL} \, x_{kL}$$

$$+ \sum_{k=1}^{m-1} \sum_{j=k+1}^{m} \sum_{L=1}^{L_k} \sum_{v=1}^{L_j} r_{ikj} \, x_{kL} x_{jv,} \quad i = 1, \ldots, \mathrm{n}, \tag{3}$$

$$\sum_{L=1}^{L_k} C_{kL} x_{kL} \le TC_k \, , k = 1, \ldots, \mathrm{m}, \tag{4}$$

$$\sum_{i=1}^{\mathrm{m}} TC_i \quad \le Target\ cost, \tag{5}$$

$$x_{kL} \epsilon \{0,1\}. \tag{6}$$

Firstly, this is a mathematical programming with the objective function shown in Equation (1).

Secondly, s_i corresponds to the customer satisfaction computed by Equation (3) for customer expectation i.

Thirdly, γ_{ikj} shows the interrelationship between the TMR attributes k, and j for the ith CE in the roof of the House of Quality.

Equations (4) and (5) have been used to limit the service costs to the target costs calculated.

C_{KL} can be taken as the price of stated solution or as the cost of developing this solution. Moreover, x_{kL} is the decision variable, each taking an integer number, 0 or 1. Each TMR has two or more service levels and one of these levels will be the optimum solution which maximizes the customer satisfaction. Therefore, the model general represents an integer programming problem, linear or nonlinear.

5.8 Data collection

The data needed for the above QFD optimization were obtained from the marketing research and benchmarking data of relevant Annual Reports, documents and so on, as follows.

5.8.1 MEPB operational attributes

The MEPB operational attributes can be seen in Tables 20 (SGCC, 2005-2010; 2007; 2008; JOBYUN, 2012; PowerIE, 2013; MEPB, 2008; Wang, 1997; 2003; Wang & Chen, 2002; Wang et al., 2002).

Operational attribute	Value
Number of 95598 Managers	4
Number of 95598 Customer Service Assistants	1
Number of 95598 Customer Service Representative (CSR)	6
Number of Departments Related to 95598 Contact Center	29
Number of 95598 Contact Center	1
Monthly wage of Customer Service Representative (CSR)(Average)	￥3000
Monthly wage of related department staff (Average)	￥3000
Monthly wage of engineer (Average)	￥4500
Monthly wage of manager (Average)	￥5000
Monthly wage of technological staff (Average)	￥3500
Number of electrical power customers	570000
Manager wage per hour	￥28.74
Staff wage per hour	￥21.97
Yearly customer service events (based on 2007)	10605
Substation electrical power bureaus	8
Substation operators	181
Departments	10
Engineers of electrical fault repair	60
Mudanjiang Rural Electrical Power System construction fees (2007)	￥1,330,000,000
Total Electrical Power System investment including repair fee, new equipment and technology	￥47,210,000
2006 Research funding	￥8,149,425.29
2005 Research Funding	￥ 1,600,800.00
2007 Research Funding	￥ 3,647,200.00
2011 Research Funding	￥ 5,161,600.00

Table 20 Operational Attributes of MEPB (SGCC, 2005-2010; 2007; 2008; JOBYUN, 2012; PowerIE, 2013; MEPB, 2008; Wang, 1997; 2003)

5.8.2 Related operation data of Heilongjiang Electric Power Company Limited

The relevant operation data of Heilongjiang Electric Power Company Limited can be seen in Table 21 (SGCC, 2008).

Operational attribute	**Value**
First stage of 2011 Technology development research project (Number)	82
2011 Technology development research investment total cost	￥3,1400,000
Average investment of each technology development research project in each Subsidiary companies	￥1,256,000
Subsidiary companies	25
Subsidiary electrical power supply companies (City level)	12
Electrical power system construction fees (based on 2007)	￥32,500,000,000
Average investment of electrical power system construction fees (based on 2007) in each subsidiary electrical power supply companies (City level)	￥2,708,333,333.33
Average investment of SG186 system investment in each Subsidiary electrical power supply companies (City level)	￥258,620,689.65

Table 21 Related data of Heilongjiang Electric Power Company Limited (SGCC, 2008)

5.8.3 Number of working and national holiday days

The numbers of working and national holiday days (national festivals and commemoration days) are given in Table 22.

National Festivals pay	11 days
Holidays pay	104 days
Working days	250 days
Total	365 days

Table 22 Chinese holidays on national festivals and commemoration days

5.8.4 Training, research and system investments of SGCC

The data on SGCC's training, research and system can be seen in Table 23 (SGCC, 2005-2010; 2007).

Item	Value
2011 Training investment	￥3,536,000,000.00
2011 Training employees	3280000
2011 Training investment/employee	￥1078.05
2011 Research Funding	￥6,452,000,000.00
2010 Research Funding	￥6,129,000,000.00
2009 Research funding	￥5,138,000,000.00
2005 Research funding	￥2,001,000,000.00
2007 Research funding	￥4,559,000,000.00
2006 Research funding	￥2,836,000,000.00
Subsidiary companies	50
Subsidiary Province Power Grid Companies	29
Average investment of each company in 2006	￥56,720,000
SG186 system investment	￥90,000,000,000.
Average investment of SG186 system investment in each province electrical power supply company	￥3,103,448,275.85

Table 23 Related data of State Grid Cooperation of China (SGCC, 2005-2010; 2007)

5.8.5 Facilities and advertisement costs

The relevant facilities costs are shown in Table 22 (Product168, 2013; ZGQY, 2013).

Cost item	Value
Computer	￥3000
Assistant facility	￥3000
Related system facility	￥10000
others	￥20000

Table 24 Relevant facilities cost (Product168, 2013; ZGQY, 2013)

The annual advertising cost is ￥200,000.00. Remote auto electric meter reading system average cost is ￥250,000 and infrared electric meter reading system is 75,000 for each substation electrical power bureaus.

5.8.6 Staff wages

The annual wages for managers and other staff are given in Tables 23, 24, together with the organization structure change cost for MEPB 95598 custom service center in Table 25, 26 and 27.

National Festivals pay	11(days)* 21.97RMB*300%=725.01RMB
Holidays pay	104(days)*21.97RMB*200%=4569.76RMB
Working days	250*21.97RMB/hour=5492.50RMB
Total	10787.27RMB

Table 25 Annual staff wages/hour for customer service staff or back-office staff

National Festivals pay	11(days)* 28.74RMB/hour *300%=948.42RMB
Holidays pay	104(days)* 28.74RMB/hour *200%=5977.92RMB
Working days	250*28.74RMB/hour =7185RMB
Total	14111.34RMB

Table 26 Annual manager wages/hour

Occupational	Staff Number	Recruit staff Number	Head-hunters cost(RMB)
Manager	4	2	36,000.00
Customer Service Assistant	1	1	12,600.00
Customer Service Representative (CSR)	6	5	54,000.00
Total	11	8	102,600.00

Table 27 Organization structure change cost for MEPB 95598 custom service center

5.9 Numerical Example

The HOQ for the MEPB's 95598 customer service centre operations has ten customer expectations and thirteen TMRs as follows (Jiao & Chen, 2006):

Customer expectations:

1. Fast response
2. Fast repairs
3. Free phone call
4. Quality repairs
5. Easy to find out bills
6. Easy to pay bills
7. Precise meter
8. Less happen for the same problem

9. Multiple channels to get information (power cut, new technology or meter reading etc.)
10. Satisfaction with complaint handing

Technical & Managerial Requirements (TMRs):

1. Reliability of power supply
2. Voltage qualification rate
3. Investment innovation
4. Electrical fault repair service
5. Overall labor productivity
6. Accuracy meter reading
7. Average blackout time per customer
8. Repeatability & reproducibility complains (Emergency contact; new meter reading reader for using)
9. Flexible service
10. Satisfaction rate of service attitude
11. Self-service availability
12. Average customer wait time
13. Average of CSR answer speed

Each TMF may have different service levels and can be treated as a decision variable to optimize the service quality. For example, for the TMR Reliability of Power Supply, the service level is able to use a 15000000 RMB for equipment investment, or a 10000000 RMB for innovative technology investment of electrical power system or a 1330000000 RMB for rural electrical power system upgrade investment.

1. Reliability of power supply
   = {Equipment investment; Innovative technology investment in electrical power system; Rural electrical power system upgrade investment}

   L_{13} L_{12} L_{11}
   C_{13}=15000000 C_{12}=10000000 C_{11}=1330000000

2. Voltage qualification rate
   = {Improving the reactive power and voltage profile with multiple channel organization regular meetings; Reactive power and voltage profile technology

training of distribution substation operator; Voltage regulation apparatus investment }

L_{23} L_{22} L_{21}
C_{23}=114521 C_{22}=195127 C_{21}=5000000

3. Investment innovation
   = {2011 research funding; 2007 research funding; 2005 research funding}

   L_{33} L_{32} L_{31}
   C_{33}=5161600 C_{32}=3647200 C_{31}=1600800

4. Electrical fault repair service
   = {Malfunction network monitoring; Training of fault repair engineers; Preventive maintenance and management system}

   L_{43} L_{42} L_{41}
   C_{43}=8149425 C_{42}=64683 C_{41}=25000000

5. Overall labor productivity
   = {Mutual supervision in three directions; Talent management brings the deepest, broadest and freshest experience technology experts; Seamless service line management}

   L_{53} L_{52} L_{51}
   C_{53}=378448757 C_{52}=216000 C_{51}=722060

6. Accuracy meter reading
   = {Infrared meter reading system; Remote auto meter reading system; Manual meter reading}

   L_{63} L_{62} L_{61}
   C_{63}=600000 C_{62}=2000000 C_{61}=7200000

7. Average blackout time per customer
   = {Management innovation; Quality control and improvement}

   L_{72} L_{71}
   C_{72}=597567 C_{71}=199189

8. Repeating & relapsing complaints

= {Evaluation of repeating & relapsing complaints; Assessment and analysis of the repeating & relapsing complaints by SG 186 system}

L_{82} L_{81}

C_{82}=114520 C_{81}=25000000

9. Flexible service
   = {Arrangement flexible meetings and interactions with the special customer needs; Flexible working arrangements in continuous shift}

   L_{92} L_{91}

   C_{92}=17926999 C_{91}=1070576

10. Satisfaction rate of service attitude
    = {Recruitment of new staffs; Improving CSR integrated skills by training}

    L_{102} L_{101}

    C_{102}=43200 C_{101}=155239

11. Self-service availability
    = {Equipment; Technology research}

    L_{112} L_{111}

    C_{112}=1050000 C_{111}=500000

12. Average customer wait time
    = {Equipment and facilities; Customer service representatives (CSRs); System software support}

    L_{123} L_{122} L_{121}

    C_{123}=1500000 C_{122}=43149 C_{121}=25000000

13. Average of CSR answer speed
    = {Communication skills training; Database and decision support; Smart customer record system for 95598 center}

    L_{133} L_{132} L_{131}

    C_{133}=776196 C_{132}=2071156 C_{131}=200000

5.10 Voice of the customer in case study

Using VoC (Voice of Customer) to design goals of MEPB 95598 is an effective solution to satisfy customer satisfaction. At the same time, enterprises do not usually have the time, resources or willingness to openly work with their customers to establish quality standards. Therefore, using VoC to set up an effective 95598 customer service model for SGCC is an important requirement for SGCC for two reasons. Firstly, power supply services have been receiving a growing attention by the society; secondly, cost control has been becoming a growing concern for the SGCC enterprise. Since the power industry reform, SGCC started to change for the customer service-oriented enterprise to maintain a competitive advantage. This creates a potential misalignment between what the SGCC believes the customer wants and what they are really looking for. This mismatch is especially likely in the soft skill areas. As a result, the case study could encourage 95598 customer center behaviors that customers find useful. In this case study, the VoC is the same as customer expectations.

5.11 Weights of the relationship matrix in the HOQ

U111 means that, for the first (i = 1) CE, if one uses the first (k = 1) TMR and if it performs at the first (L = 1) level, then, the customer satisfaction would be U111. In this case:

i =1---→Fast response;

k =1---→Reliability of power supply;

L=1---→use 15000000 RMB equipment investment.

Then, the influence of the service level (L=1) of the first TMR (k=1) on the customer needs (i=1) is believed to be very strong, hence u 111 = 9.

Other u_{ikL} can also be similarly determined as follows:

$u_{1121}=5$ $u_{1122}=9$ $u_{1123}=1$ $u_{1131}=1$ $u_{1132}=9$ $u_{1133}=5$

$u_{2021}=1$ $u_{2022}=9$ $u_{2023}=5$

$u_{3091}=9$ $u_{3092}=5$

$\mathcal{U}_{4011}=5$ $\mathcal{U}_{4012}=5$ $\mathcal{U}_{4013}=5$ $\mathcal{U}_{4041}=5$ $\mathcal{U}_{4042}=9$ $\mathcal{U}_{4043}=5$

$\mathcal{U}_{5111}=9$ $\mathcal{U}_{5112}=1$

$\mathcal{U}_{6101}=9$ $\mathcal{U}_{6102}=5$

$\mathcal{U}_{7061}=1$ $\mathcal{U}_{7062}=5$ $\mathcal{U}_{7063}=9$

$\mathcal{U}_{8071}=5$ $\mathcal{U}_{8072}=1$ $\mathcal{U}_{8081}=1$ $\mathcal{U}_{8082}=9$

$\mathcal{U}_{9031}=1$ $\mathcal{U}_{9032}=5$ $\mathcal{U}_{9033}=9$

$\mathcal{U}_{1051}=9$ $\mathcal{U}_{1052}=9$ $\mathcal{U}_{1053}=1$

If there is a strong positive correlation between the TMRs 10 and 11, then $\gamma_{i1011} = 9$ for all i. However, the correlations are not considered in the following example.

In this case study, the weights for the customer expectations are obtained by averaging the values given by three professional staffs both in UK and SGCC who have been in EPGOs for more than 5 years:

(w1;w2;w3;w4;w5 w6; w7; w8; w9; w10) = (5; 5; 2; 4; 3; 3; 3; 4; 3; 4).

5.12 Evaluation of the case study mathematical model

Given the above data and evaluation, the mathematical model for the case study can be shown as follows, including the objective function and all the constraints:

$$max\, z = 5s_1 + 5s_2 + 2s_3 + 4s_4 + 3s_5 + 3s_6 + 3s_7 + 4s_8 + 3s_9 + 4s_{10}$$

S.t.

$$x_{11} + x_{12} + x_{13} = 1,$$

$$x_{21} + x_{22} + x_{23} = 1,$$

$$x_{31} + x_{32} + x_{33} = 1,$$

$$x_{41} + x_{42} + x_{43} = 1,$$

$$x_{51} + x_{52} + x_{53} = 1,$$

$x_{61} + x_{62} + x_{63} = 1,$
$x_{71} + x_{72} = 1,$

$x_{81} + x_{82} = 1,$

$x_{91} + x_{92} = 1,$

$x_{101} + x_{102} = 1,$

$x_{111} + x_{112} = 1,$

$x_{121} + x_{122} + x_{123} = 1,$

$x_{131} + x_{132} + x_{133} = 1,$

$s_1 = 5x_{121} + 9x_{122} + x_{123} + x_{131} + 9x_{132} + 5x_{133}$

$s_2 = x_{21} + 9x_{22} + 5x_{23}$

$s_3 = 9x_{91} + 5x_{92}$

$s_4 = 5x_{11} + 5x_{12} + 5x_{13} + 5x_{41} + 9x_{42} + 5x_{43}$

$s_5 = 9x_{111} + x_{112}$

$s_6 = 9x_{101} + 5x_{102}$

$s_7 = x_{61} + 5x_{62} + 9x_{63}$

$s_8 = 5x_{71} + x_{72} + x_{81} + 9x_{82}$

$s_9 = x_{31} + 5x_{32} + 9x_{33}$

$s_{10} = 9x_{51} + 9x_{52} + x_{93}$

$1330000000x_{11} + 10000000x_{12} + 15000000x_{13} \leq TC_1$,

$5000000x_{21} + 195127x_{22} + 114521x_{23} \leq TC_2$,

$1600800x_{31} + 3647200x_{32} + 5161600x_{33} \leq TC_3$,

$25000000x_{41} + 64683x_{42} + 8149425x_{43} \leq TC_4$,

$722060x_{51}$ $+216000x_{52}$ $+378448757x_{53}$ $\leq TC_5$,

$7200000x_{61}$ $+2000000x_{62}$ $+600000x_{63}$ $\leq TC_6$,

$199189x_{71}$ $+597567\ x_{72}$ $\leq TC_7$

$25000000x_{81}$ $+114520\ \ x_{82}$ $\leq TC_8$

$1070576x_{91}$ $+17926999x_{92}$ $\leq TC_9$

$155239x_{101}$ $+43200x_{102}$ $\leq TC_{10}$

$500000\ x_{111}$ $+1050000\ x_{112}$ $\leq TC_{11}$

$25000000x_{121}$ $+43149x_{122}$ $+1500000x_{123}$ $\leq TC_{12}$,

$776196x_{131}$ $+2071156\ x_{132}$ $+200000x_{133}$ $\leq TC_{13}$,

$TC_1 + TC_2 + TC_3 + TC_4 + TC_5 + TC_6 + TC_7 + TC_8 + TC_9 + TC_{10} + TC_{11} + TC_{12} + TC_{13} \leq 18000000$

$TC_1 + TC_2 + TC_3 + TC_4 + TC_5 + TC_6 + TC_7 + TC_8 + TC_9 + TC_{10} + TC_{11} + TC_{12} + TC_{13} \leq 16000000$

$TC_1 + TC_2 + TC_3 + TC_4 + TC_5 + TC_6 + TC_7 + TC_8 + TC_9 + TC_{10} + TC_{11} + TC_{12} + TC_{13} \leq 12000000$

$x_{KL} \in \{0,1\}$

5.13 Optimization results of the case study model

The above model and data were entered into the Excel solver, including the objective function, constraints and decision variables. Figures 65-67 show the actual screen shots of the model interface. Given an overall target cost, the model can be solved and the solutions are given in Table 28, which shows the optimum objective function can be used to improve the service processes and the service quality in terms of customer satisfaction and the corresponding optimum service levels.

In Figure 65, MEPB-95598 Customer Service Center has identified the customer expectations and characteristics of electrical power supply service in Mudanjiang city.

The 10 customer expectations are fast response, fast repairs, free phone call, quality repairs, easy to find out bills, easy to pay bills, precise metering, less reoccurrence of the same problem, multiple channels to get information, satisfaction with complaint handing.

In addition, the weights for the customer expectations are as follows:

(w1;w2;w3;w4;w5 w6; w7; w8; w9; w10) = (5; 5; 2; 4; 3; 3; 3; 4; 3; 4).

Moreover, the proper target cost is determined and the target cost was set at RMB 12000000.

Furthermore, the TMRs are determined as follows:

1. Reliability of power supply
   = {Innovative technology investment in electrical power system}

   L_{12} C_{12}=10000000

2. Voltage qualification rate
   = {Reactive power and voltage profile technology training of distribution substation operator}

   L_{22} C_{22}=195127

3. Investment innovation
   = {2005 research funding}

   L_{31} C_{31}=1600800

4. Electrical fault repair service
   = {Training of fault repair engineers}

   L_{42} C_{42}=64683

5. Overall labor productivity
   = {Talent management brings the deepest, broadest and freshest experience technology experts}

   L_{52} C_{52}=216000

6. Accuracy meter reading
   = {Infrared meter reading system}

   L_{63} C_{63}=600000

7. Average blackout time per customer
   = {Quality control and improvement}

   L_{71} C_{71}=199189

8. Repeating & relapsing complaints
   = {Evaluation of repeating & relapsing complaints}

   L_{82} C_{82}=114520

9. Flexible service
   = {Flexible working arrangements in continuous shift}

   L_{91} C_{91}=1070576

10. Satisfaction rate of service attitude
    = {Recruitment of new staffs}

    L_{102} C_{102}=43200

11. Self-service availability
    = { Technology research}

    L_{111} C_{111}=500000

12. Average customer wait time
    = {Customer service representatives (CSRs)}

    L_{122} C_{122}=43149

13. Average of CSR answer speed
    = {Smart customer record system for 95598 center}

    L_{131} C_{131}=200000

Therefore, the optimum objective function was obtained with a value of 349. This optimum objective function can be used to improve the service processes of EPGO, i.e. the service quality in terms of customer satisfaction and the corresponding optimum service levels.

	TMR														
Target Cost	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Objective Function**	**Answer Report**
18000000	2	2	1	2	2	3	1	2	1	1	1	2	2	401	12
16000000	2	2	1	2	2	3	1	2	1	1	1	2	1	361	13
12000000	2	2	1	2	2	3	1	2	1	2	1	2	1	349	15

Table 28 Results of case study

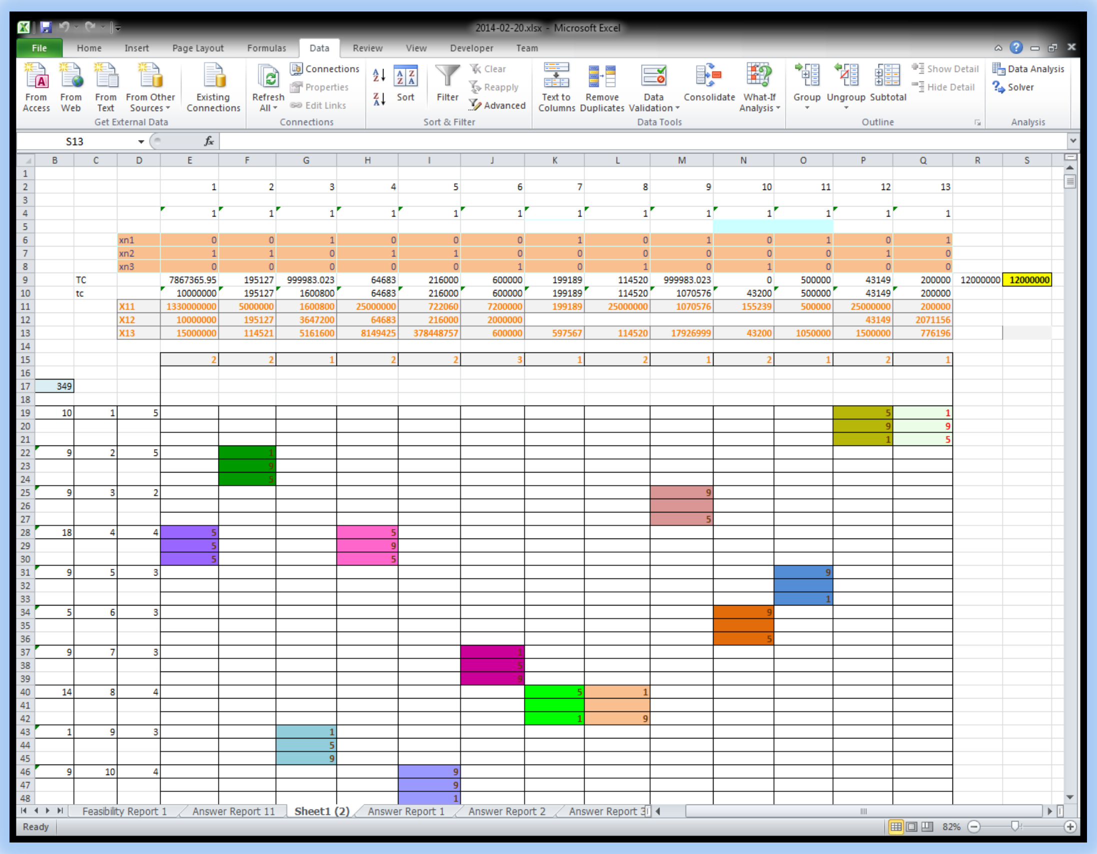


Figure 65 A screen shot of results of Target Cost 12000000

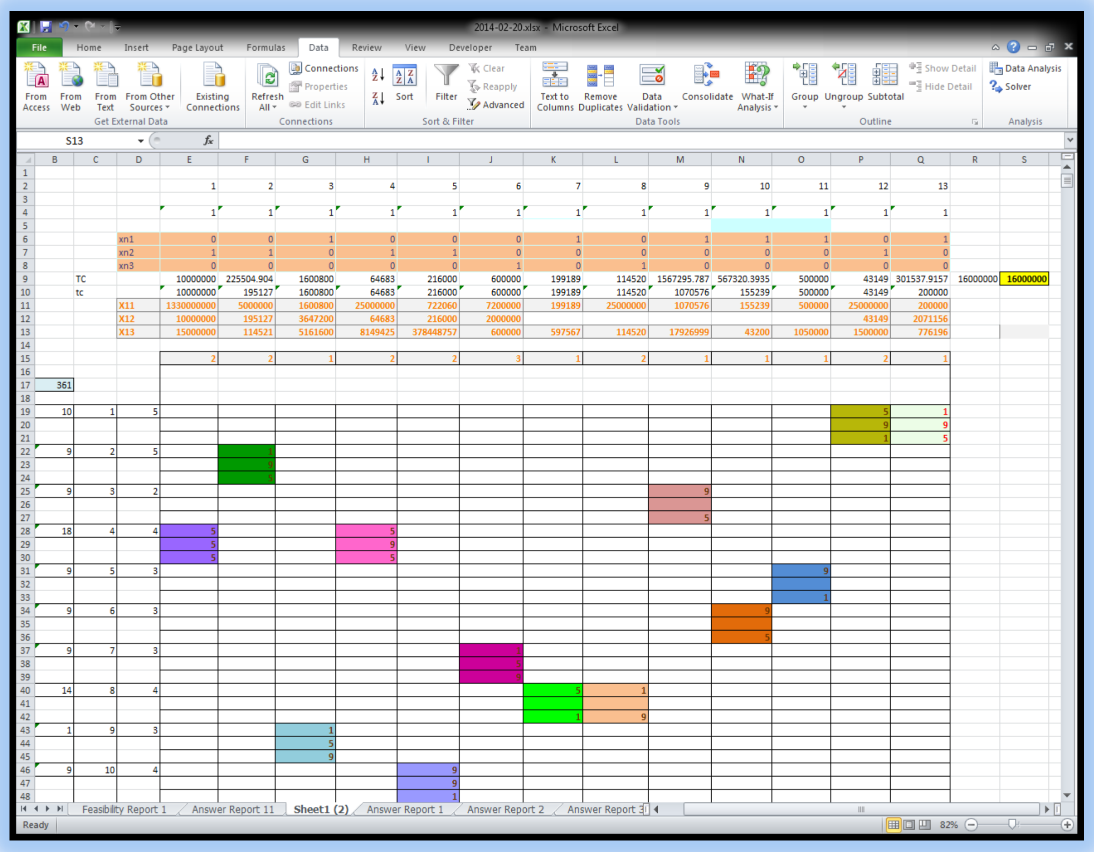


Figure 66 A screen shot of results of Target Cost 16000000

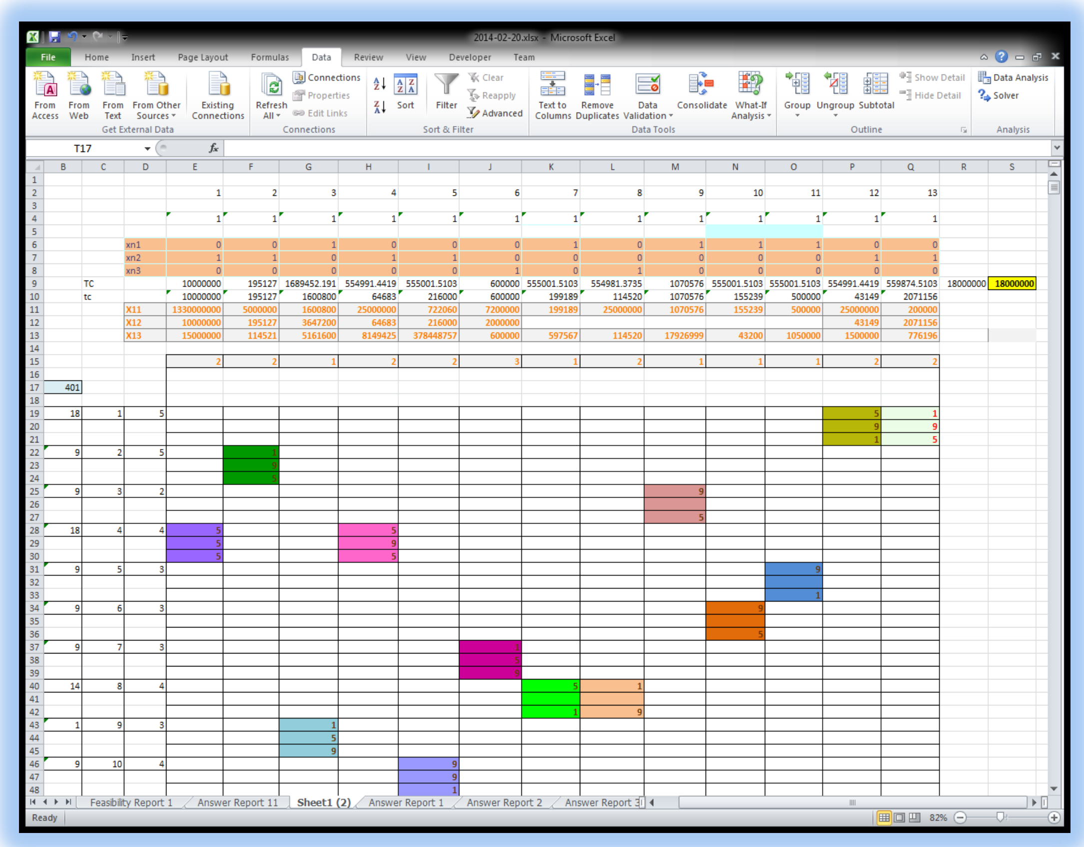


Figure 67 A screen shot of results of Target Cost 18000000

5.14 Summary

The feasibility of optimization of the operational quality has been demonstrated with an example of the 95598 Customer Services in the MEPB EPGO. The optimum quality can be achieved within the target cost constraints. It should be straight forward to apply the same method to optimize the operations of other services in the same EPGO or other EPGOs at the other levels of SGCC. Further it is also possible to integrate the different services of an EPGO into a large QFD model and optimize its operations using the similar mathematical optimization algorithm.

The case study has largely centered on the service processes of the EPGO, but the principle is also applicable to technological processes. Ultimately, this methodology can be used to design and optimize the future smart grid strategies and operations.

CHAPTER 6 Conclusions and recommendations for future work

This chapter draws important conclusions of the investigations, highlights the contributions to knowledge, and recommends the work for future studies.

6.1 Conclusions

This dissertation started with an overview of the background of China's electric power market and particularly the SGCC. The research problem and the needs for a sound framework and methodology for the effective regulation and optimization of the operations and quality management are identified and discussed. Based on the critical literature review of the research, the steps or aspects of the solution to the problem have been progressively presented, with the research aim and objectives largely achieved with the following conclusions.

First, China's electricity generation have been shown by means of a CW curve to have a unique position compared with other major economies, and its ranking in the TNEG have remained the highest over the 10 years studied (1996-2006). Further, the data have clearly indicated that China's TNEG has also been closely correlated with the economic growth and the carbon emissions during the 30 years period of 1980-2010.

Second, Compared with the Equilibrium Energy Regulation Model, there are clear deficiencies and problems with the current regulation of China's electric power market. The improvements in the integration of regulation strategies and the formation of one single effective regulator have been identified and recommended.

Third, a uniform regulation structure and framework based on fractal theory and QFD has been developed to integrate the existing and future electric power strategies, including smart grid strategy and sustainable development strategy. Through the use of QFD, the EPGO functions and operations can be prioritized and appropriately designed.

Further, the QFD methodology has been extended to achieve the optimization of quality and service operations given the target cost of the business processes. The quality may be interpreted as a total quality involving the needs and expectations of various customers or stakeholders. The approach can be applied to both business and technical processes of the EPGOs.

6.2 Contributions to knowledge

The research has resulted in a number of contributions to the knowledge which are summarized as follows:

1) A novel CW Curve has been proposed for the characterization of China's electricity consumption and generation in comparison with other related countries. The CW Curve can also be used for characteristics analysis in different countries and /or different energy sectors.

2) Based on current problems associated with China's electric power market and the Equilibrium Energy Regulation Model, a new regulation model for China's electric power market has been presented.

3) A novel regulation structure based on fractal theory has been presented to manage the operations of EPGOs at different levels of the SGCC. This structure is further integrated with the QFD framework to design and prioritize the operations in the context of smart grid strategies.

4) A novel methodology has been applied to the optimization of quality and service levels using QFD and mathematical programming. Although the example is given for a city level EPGO's 95598 customer service center operations, it can be extended to other areas (both business and technological) and other EPGOs at different levels, ultimately including all the smart grid operations.

5) A new 3S Strategy has been developed based on the standard 3S Strategy, Sustainable Development Strategy and Energy Trilemma.

6.3 Recommended future work

This research undoubtedly is limited by the time and resources available. Based on the research already conducted, the following areas can be thus recommended for future work.

Firstly, the research and the data collection have been largely based on the SGCC in China. These studies can be readily extended to wider industries and also other countries. Based on a considerably larger amount of data it will be possible to expand the research findings, e.g. better characterization of electricity/energy consumption and generation.

Secondly, the customer expectations in the proposed QFD framework have centered on the new 3S strategy, which more reflect the needs of wider customers or stakeholders (i.e. society). Although the detailed needs of the individual customers are also identified in the case study of the 95598 Customer Service Centre, full customer expectations of various stakeholders in different parts of the system can be developed in the future to support the QFD implementation.

Thirdly, a new regulation model for China's electric power market has been proposed in this thesis. There have been some new developments in both smart grids and the wider government reform including the electric power market. The latter is going to have great impacts on the future Chinese electric power market. It will be worthwhile to further develop and validate the proposed regulation model with the practical systems.

Moreover, in the mathematical optimization of the QFD, the correlations between the TMRs are not considered, with the mathematical models simplified to be linear ones. They can be incorporated generally in a nonlinear model to simulate more realistic operations in the future.

REFERENCES

Akao, Y., 1990. *QFD:Integrating Customer Requirements into Product Design.* Cambridge, Productivity Press.

Akao, Y., 1994. *Development History of Quality Function Deployment,* Tokyo: Asian Productivity Organization.

Ancillotti, E., Bruno, R. & Conti, M., 2013. 'The role of communication systems in smart grids: Architectures,technical solutions and research challenges. *Italian National Research Council (CNR), Institute for Informatics and Telematics (IIT),* 36(1), pp. 1665-1697.

Anderson, A., McBratney, A. & FitzPatrick, E., 1996. Soil mass, surface, and spectralfractal dimensions estimated from thin section photographs. *Soil Science, Society of America Journal ,* 60 (4) (1), pp. 962-969.

ARIF, C et al., 2012. Estimating Crop Coefficient in Intermittent Irrigation Paddy Fields UsingExcel Solver. *Rice Science,* 19(2)(2), pp. 143-152.

Ataul B., Jin J., Walid S., and Arunita J., 2014. Challenges in the Smart Grid Applications. *International Journal of Distributed Sensor Networks,* 2014 (2014), Article ID 974682,pp1.

Arrow & Debreu, 1954. Existence of an equilibrium for a competitive economy. *Econometrica,* Vol. 22, No. 3. (Jul., 1954)(Econometric Society), pp. 265–290.

Austin, A., 2005. *Energy and Power in China: Domestic Regulation and Foreign Policy,* London: The Foreign Policy Centre.

Babadagli, T., 2001. Fractal analysis of 2-D fracture networks of geothermal reservoirsin south-western Turkey. *Journal of Volcanology and GeothermalResearch,* 112(1), pp. 83-103.

Bode, J. & Fung, R. Y., 1998. Cost Engineering with Quality Function Deployment. *Computers ind.Engng ,* Vol.35(Nos 3-4), pp. 587-590.

Bond, M. & Volberg, A., 2009. The Power Law for Buffon's Needle Landing Near the Sierpinski Gasket. *math CA,* arXiv:0911.0233v1 (1), pp. 1–34.

Bourg, D. M., 2006. *Excel Scientific and Engineering Cookbook'. Chapter 9, Using Classical Methods for Solving Equations.* 1 edition ed. Sebastopol: O'Reilly Media.

Briggs, J., 1992. *Fractals:The Patterns of Chaos.* London, Thames and Hudson, pp. 148.

Calderaro, V., Hadjicostis, C., Piccolo, A. & Siano, P., 2011. FailureIdentification in Smart Grids based on Petri Net Modeling. *IEEE Trans. on Industrial Electronics,* 10.1109/TIE.2011.2109335(I), pp. 2-7.

Cecati, C., Citro, C. & Siano, P., 2011. Combined Operations of RenewableEnergy Systems and Responsive Demand in a Smart Grid. *IEEE Trans. on Sustainable Energy, in press,* 10.1109/TSTE.2011.2161624(I), pp. 2-8.

Chan, L.-K. & Wu, M.-L., 2002. Quality function deployment: A literature review. *European Journal of Operational Research ,* 143 (1), pp. 463.

China's Energy Policy 2012, 2012. *Global Times.* [Online] Available at: http://www.globaltimes.cn/content/740169.shtm [Accessed 2 January 2014].

China's Research Reprot for Electric Vehicle, 2013. *Research In China.* [Online] Available at: http://www.pday.com.cn/Htmls/Report/201104/24511257.Html [Accessed 29 September 2013].

CIA, 2013. *Central Intelligence Agency.* [Online] Available at:https://www.cia.gov/library/publications/the-world-factbook/rankorder [Accessed 7 May 2013].

CNESD, 2013.*The People's Republic of China on the 2012 National Economic and Social Development.*[Online]Availableat:http://en.wikipedia.org/wiki/Historical_GDP_of_the_People's_Republic_of_China [Accessed 15 August 2013].

CNNMoney, 2013. *CNNMoney.com,Fortune Global 500 Ranking.* [Online] Available at: :http://money.cnn.com/magazines/fortune/global500/2011/countries/China.html

[Accessed 8 May 2013].

CSG, 2013. *China Soulthern Grid Comoany.* [Online] Available at: http://www.csg.cn/ [Accessed 2 January 2013].

David, Elaine, 2008. *Quality function deployment in construction*, Economics.

Deming, W., 1992. *Out of the crisis.* p. ix. 3 ed. Madras: Productivity and Quality.

DoC, U., 2009. *Designing education project,* Maryland: National Oceanic and Atmospheric Administration U.S. Department of Commerce.

DoE-1, 2011. *U.S Department of Energy.* [Online] Available at: http://www.oe.energy.gov [Accessed 25 Octomber 2013].

EIA, 2013. *U.S Energy Information Administration.* [Online] Available at: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=12&cid=regions&syid=1996&eyid=2011&unit=BKWH [Accessed 30 July 2013].

Ellram, L. M., 2002. *The Role of Purchasing and Supply Management in Strategic CostManagement in the Supply Chain.* Tempe, AZ, CAPS Research.

EP, 2003. Shall be responsible for ensuring a secure, reliable and efficient electricity system. *Official Journal of the European Union,. Official Journal of the European Union, Common Position (EC),* 4/2003(OJ 2003 C 50 E), p. 1.

EPRI, 2009. *EPRI's Report to NIST on the Smart Grid Interoperability StandardsRoadmap,* Palo Alto: EPRI .

Erol-Kantarci, M. & Mouftah, H., 2011. Wireless multimedia sensorand actor networks for the next generation power grid. *Ad HocNetworks,* vol. 9(no. 5), pp. pp 542-551.

Fractal Dimension, 2013. *Fractal Foundation.* [Online] Available at:

http://fractalfoundation.org/OFC/OFC-10-4.html [Accessed 19 August 2013].

Fylstra, D., Lasdon, L., Watson, J. & Waren, A., 1998. 'Design and Use of the Microsoft Excel Solver. *Interfaces,* Volume 28(5), pp. 29-55.

Gaoa, J. et al., 2012. A survey of communication/networking in Smart Grids. *Future Generation Computer Systems,* 28 (2012)(1), pp. 391–404.

Gargione, L. A., 1999. *Using Quality Function Deployment (QFD) in the Design Phase of an Apartment Construction Project.* CA, USA, University of California, Berkeley.

GENI, 2013.*Global Energy Network Institute (GENI), Chinese Grid Summary.*[Online]Availableat:ttp://geni.org/globalenergy/library/national_energy_grid/china/chinesenationallectricitygrid.shtml[Accessed 19 August 2013].

Gimenez, D., 1997. 'Fractal models for predicting soil hydraulic properties: areview. *Engineering Geology,* 48(1), pp. 161-183.

Glover, J. U., S.Sarma, M. & Overbye, T. J., 2011. *Power System Analysis & Design.* 1 ed. Stamford: Nelson Education,Ltd.

Griffin, A. & Hauser, J., 1992. *The voice of the customer,* Cambridge: Marketing ScienceInstitute.

Gungor, V., Lu, B. & Hancke, G., 2010. Opportunities and Challengesof Wireless Sensor Networks in Smart Grid. *IEEE onTrans. Ind. Electron,* vol. 57, no. 10(I, II), pp. 3557-3564.

Hauser, J., 1993. How Puritan-Bennett used the house ofquality. *Journal of Product Innovation Management ,* 11(3)(271-271), pp. 61-70.

ICD, 2013. *Smart Grid in China- - a R&D Perspective,* Shanghai,China: Innovation Center Denmark.

IEA, 2006. *World Energy Outlook 2006,* PARIS: International Energy Agency .

IEAa, 2011. *Technology RoadmapSmart Grids,* Paris: International Energy Agency.

IEEE-SG-1, 2011. *IEEE Smart Grid.* [Online] Available at: http://smartgrid.ieee.org/ieee-smart-grid [Accessed 25 Octomber 2011].

Izaguirre, A., 1998. Private participation in the electricitysector - recent trends. *Public Policy for thePrivate Sectorr*, 1 December , pp. 5-12.

Jamison, M. A., 1997. *A Further Look at Proper Cost Tests for Natural Monopoly ,* Florida: University of Florida Public Utility Research Center.

Jariri, Zegordi, 2008. Quality Function Deployment, Value Engineering and Target Costing, an IntegratedFramework in Design Cost Management:A Mathematical Programming Approach. *Scientia Iranica,* Vol. 15(No. 3), pp. 405.

Jiao, J. x. & Chen, C.-H., 2006. Customer Requirment Manmegment in Product Development: A Review of Research Issues. *Concurrent engineering: research and application,* Vol.14(No.2), pp. 11.

JOBYUN, 2012. *State Grid Corporation of China.* [Online] Available at: http://www.jobyun.com/hot_%B9%FA%BC%D2%B5%E7%CD%F8 [Accessed 1 December 2012].

The China Power Generation Market Report 2012-2021, 2011. Canterbury, Kent: John Loffman Research.

Joiner, B. L. & Scholtes, P. R., 1988. *Total Quality Leadership Management by Control,* Badger: Center for qulity and productivity improverment ,University of Wisconsin-Madison.

Jones, L., 1993. *'Appropriate regulatory technology: Theinterplay of economic and institutional conditions.* s.l., Proceedings of the World Bank AnnualConference on Development Economics.

Katz, A. & Thompson, A., 1985. Fractal sandstone pores: implications for conductivity and pore formation. *Physical Review Letters ,* 54 (12) (1), pp.1325-1328.

Purnendu, K.. D., 2008. Chromatographic peak resolution using Microsoft Excel Solver: The merit of time shifting input arrays. *J Chromatogr A,* 1213(1), pp. 50–55.

Kenyon, R., 1997. Projecting the one-dimensional Sierpinski gasket. *Israel J. Math. 97 ,* 1(1), pp. 221–238.

Keping, Y., 2008. China's Governance Reform from 1978 to 2008. *East Asian Studies,* No. 76(ISSN 1865-858X), pp.7-23.

Kim, S. R. & Horn, A., 1989. *Regulation policies concerning natural monopolies in developing and transition economies,* New York: United Nations.

Kim, S. R. & Horn, A., 1999. *Regulation policies concerning natural monopolies in developing and transition economies,* Uinted Nationals: Economic & Social AFFAIRS.

Lavigne, N. & Wotherspoon, D., 2008. *Sustainable Development: What communicators need to know and do to stay ahead of the game.* New York , IABC International Conference.

Lee, K. & Jung, M., 2009. *Fractal-based Control and Monitoring System for Smart Grid(FrCMSG).* Kiyoul Lee, APIEMS.

Li, K. & Horne, R., 2006. 'Fractal modeling of capillary pressure curves for the Geysersrocks. *Geothermics ,* 35(1), pp. 198-207.

Liu, Z., 2013. *'Electric Power and Energy in China.* 1 edition (June 11, 2013 ed. Beijing: WILEY.

Lu, D. et al., 2011. 'Energymanagement and operational planning of a microgrid witha PV-based active generator for Smart Grid Applications. *IEEE Trans. on Industrial Electronics,* 10.1109/TIE.2011.2119451(I), pp. 3-9.

Luo, Z., Chen, K., Xiang, M. & Cai, L., 2010. *An approach of Sustained data acquisition for active RFID systems with low power consumption.* China, '. Advanced Computer Theory and Engineering (ICACTE), 2010 3rd International Conference.

Mandelbrot, B., 1967. How long is the coast of Britain?' Statistical selfsimilarity and fractional dimension. *Science ,* 155 (1967)(1), pp. 636-638.

MEPB, 2008. *Mudanjiang Electrical Power Bureau 2007 year book.* 1 Edition ed. Mudanjiang: Mudanjiang Electrical Power Bureau,SGCC.

Miao X., Zhang, K.. Chen, X., 2009. Development Countermeasure of Constructing Smart Grid. *Electric Power Construction,* vol. 30((6)), pp. pp6- 10.

Miao, X., Zhang, Y.-F. & Liu, J., 2009. *Chinese Road of Smart Grid,* Beijing: State Grid.

Milligan, M. et al., 2012. *Renewable Electricity Futures Study: Bulk Electric Power Systems: Operations and Transmission Planning,* New York: National Renewable Energy Laboratory of the U.S. Department of Energy.

NETL, 2008. *NETL Modern Grid Intiative-Powering Our 21st-Century Economy,* U.S.: U.S. Department of Energy, National Energy Technology Laboratory.

Ni, C. C., 2006. *China's Electric Power Industry and Its Trends,* Japan(IEEJ): Elctric Power,Nuclear Power & Coal Group Industrial Research Unit, The Institute of Energy Economics.

NIST, 2009. *NIST Framework and Roadmap for Smart GridInteroperability Standards Release 1.0',* Maryland: NIST Special Publication1108.

OECD, 2013. *Organisation for Economic Co-operation and Development.* [Online] [Accessed 19 November 2013].

Paddon, M., 1998. *Restructuring and privatization of utilities in Asia Pacific region,* ILO: Geneva: '. Loretta de Luca(ed.), Labour and Social Dimensions ofPrivatization and Restructuring (Public Utilities:Water, Gas, Electricity).

Palensky, P. & Dietrich, D., 2011. Demand Side Management: DemandResponse, Intelligent Energy Systems, and Smart Loads. *IEEETrans. on Industrial Informatics, Inf.,* vol. DigitalObject Identifier: 10.1109/TII.2011.2158841(I), pp. 99.

Pepermans, G. et al., 2003. *Distributed Generation: Definition, Benefits And Issues,* leuven: CIRED.
PowerIE, 2013. *Power. IN-EN.* [Online] Available at: http://power.in-en.com/html/power-09380938571426293.html (Chinese) [Accessed 8 August 2013].

Product168, 2013. *Product168.* [Online] Available at: http://product.it168.com (Chinese) [Accessed 8 August 2013].

Rego, C., Alidaee, B., Kochenberger,G. , 2003. *Managerial Issues in Complex Planning Procedures: A Case Study of QFD',* Mississipp,USA: The University of Mississippi, University of Colorado Denver, Hearin Center for Enterprise Science.

Saber, A. & Venayagamoorthy, G., 2011. Plug-in Vehicles and RenewableEnergy Sources for Cost and Emission Reductions. *IEEE Trans. on Industrial Electronics,* vol.58(no.4), pp. 1229-1238.

Sagan, H., 1994. *Space-Filling Curves.* 1 ed. Berlin: Springer-Verlag.

Sarlos, T., 2012. *China: State Grid Corporation of China Profile,* Austin,TX, United States : Zpryme Smart Grid Insights,Zpryme Research & Consulting.

SDC, 2013. *Sustainable Development Commission.* [Online] Available at: http://www.sd-commission.org.uk/pages/history_sd.html [Accessed 28 July 2013].

SERC, 2011. *State Electricity Regulatory Commission People Republic of China.* [Online] Available at: http://www.12398.gov.cn/html/information/245300011/245300011201100005.shtml [Accessed 31 May 2013].

S.G., 2014. IEEE & Smart Grid. [Online] Available at: http://smartgrid.ieee.org/ieee-smart-grid/conceptual-model [Accessed 2 January 2014].

SGCC, 2005-2010. *Corporate Social Responsibility Report 2005-2010',* Beijing: State Grid Corporation of China.

SGCC, 2007. *'State Grid Corporation of China's 2007 Yearbook'. pp 58..* 1 Edition ed. Beijing: State Grid Corporation of China.

SGCC, 2008. *State Grid Corporation of China's 2008 Yearbook.* 1 Edition ed. Beijing: State Grid Corporation of China.

SGCC, 2011a. *Corporate Social Responsibility Report 2011,* Beijing: State Grid Corporation of China (SGCC).

SGCC, 2013a. *Organization framework of SGCC. State Grid Corporation of China.* [Online] Available at: http://www.sgcc.com.cn/gsjs/zzjg/default.shtml [Accessed 2 January 2013].

SGCC, 2013b. *Corporate Profile of SGCC. State Grid Corporation of China.* [Online] Available at: http://www.sgcc.com.cn/ywlm/aboutus/profile.shtml [Accessed 12 Noverber 2013].

SGCC, 2011c. *95598 Hotline. State Grid Corporation of China (SGCC).* [Online] Available at: http://www.sgcc.com.cn/ywlm/customerservice/hotline/index.shtml [Accessed 1 May 2013].

SGCC, 2012c. D*istribution and transmission of SGCC*. *State Grid Corporation of China.* [Online] Available at: http://www.jibei.sgcc.com.cn/gywm/xsdw/bjsbdgs/2012/12/440997.shtml [Accessed 16 May 2013].

SmartGridGov, 2011. *What is smart grid. Smart Grid Gov.* [Online] Available at: http://www.smartgrid.gov/the_smart_grid#smart_grid [Accessed 20 February 2013].

SGCC, 2013z. *HVDC Flexible. State Grid Corporation of China (SGCC).* [Online] Available at: http://www.epri.sgcc.com.cn/prgc/english/Product_Solution/HVDC_Flexible/ [Accessed 25 September 2013].

SGIC, 2013. *FACTS. Smart Grid Information Clearinghouse.* [Online] Available at: http://www.sgiclearinghouse.org/?q=node/2180 [Accessed 25 September 2013].

SGN, 2013. *Smart grid Network.* [Online] Available at: http://www.china.smartgrid.com/keyplayers/policy-regulation [Accessed 9 May 2013].

Studebaker, J. M., 2008. *Maximizing Energy Savings and Minimizing Costs'. ISBN-10:*

1420088726,pp169.. 1 ed. Lilburn: Fairmont Press.

Suhardi, A. R., 2013. *Quality Function Deployment to Improve Quality of Service.* Bangkok, The 2nd IBSM, International Conference on Business and Mangement.

Sustainable development, 2014. *Wikipedia.* [Online] Available at: http://en.wikipedia.org/wiki/Sustainable_development [Accessed 7 January 2014].

Sullivan, L., 1986. Quality function deployment. *QualityProgress ,* 19(6), pp.39–50.
Solver, 2013. *Wikipedia.* [Online] Available at: http://en.wikipedia.org/wiki/Solver [Accessed 15 August 2013].

Sierpinski triangle, 2013. *Wikipedia.* [Online] Available at: http://en.wikipedia.org/wiki/Sierpinski_triangle [Accessed 19 August 2013].

Temponi, C., Yen, J. & Tiao, W. A., 1998. Theory and MethodologyHouse of quality: A fuzzy logic-based requirements analyses. *European Journal of Operational Research,* 117(1), pp. 340-354.

Temponi, C., Yen, J. & Tiao, W. A., 1998. Theory and MethodologyHouse of quality: A fuzzy logic-based requirements analyses. *European Journal of Operational Research,* 117(1), pp. 340-354.

Tsoukalidis, I., Karasavvoglou, A., Mandilas, A. & Valsamidis, S., 2009. Application of Quality Function Deployment on an Alternative Transportation System(Paratransit System. *European Research Studies,* Vol. XII(Issue 2), pp. 131-148.

U.S.EPA, 2011. *China's Energy Markets: Anhui, Chongqing, Henan, and Guizhou Provinces,* New York: U.S. Environmental Protection Agency.

UHVC-SGCC, 2013. *UHV Corner, State Grid of China Corporation.* [Online] Available at: http://www.sgcc.com.cn/ztzl/tgyzl/default.shtml, [Accessed 9 May 2013] [Accessed 9 May 2013].

Van de Poel, I., 2007. Methodological problems in QFD and directions for future Development. *Research in Engineering Design,* Vol. 18(Issue 1), pp. 21-36.

Vicsek, T., 1992. *Fractal growth phenomena.* Singapore,New Jersey, World Scientific, pp.31; 139–146.

Vicsek, T., 1992. Fractal growth phenomena. *World Scientific,* Issue SBN 978-981-02-0668-0, pp. 10.

Wahl, B. R., *Calculating: Fractals Dimension,* 2013. *www.wahl.org.* [Online] Available at: http://www.wahl.org/fe/HTML_version/link/FE4W/c4.htm [Accessed 19 August 2013].

Wang, C., 1997. Discussion and Analysis of Modern Power Supply Bureau Management. *Electrical Power Supply Corporation Management*, 1 May, pp. 12-13.

Wang, C., 2003. *China 95598 custom service center Management.* 1 Edtion ed. Beijing: China Electric Power Publication(CEPP).

Wang, C., Chen, D., 2002. *Study of Power Customer Service System's Approach to Quality Problems.* 1 Edition ed. Haerbin: Heilongjiang Province Power System Book.

Wang, C., H.Pei, l., Y. Hua, W. & L.Cunyuan, 2002. *Reformation of China 95598 custom service center Management Using TQC.* 1 Edition ed. Haerbin: Institute of Electrical Engineering of Heilongjiang, China.

Wang, C., Yang, Q.-P. & Song, Y.-H., 2010. *Power Crises Study for Restructuring China's Energy Regulation Using Equilibrium Theory.* 1 Edition ed. San Francisco, USA 20-22: World Congress on Engineering and Computer Science.

Wang, Y., 2012. *China's Smart Grid Program: One Goal, Two Main Lines, Three Stages and More.* [Online] Available at: http://smartgrid.ieee.org/october-2012/684-china-s-smart-grid-program-one-goal-two-main-lines-three-stages-and-more [Accessed 1 May 2013].

Wang, Z., Wan, Y. & Wang, C., 2013. *Research on Engineering Change Knowledge Representation and Retrieval Technology Based on Ontology.* London, The 19th International Conference on Automation and Computing program.

Walsh, S., Diamond, D., 1995. Non-linear curve fitting usingMicrosoft Excel Solver. *Talanta,* 42(4)(4), pp. 561–572.

WEC, 2013. *World EnergyIssues Monitor,* London W1B 5LT, United Kingdom: World Energy Council.

WEC, 2014. *The world is far away from achieving environmentally sustainable energy systems,* World. [Online] Available at: http://www.worldenergy.org/news-and-media/press-releases/the-world-is-far-away-from-achieving-environmentally-sustainable-enegy-sysyems/ [Accessed 2 January 2014].

WRI, 2014. *World Resouces Institue.* [Online] Available at: http://projects.wri.org/sd-pams-database/china/regulations-electricity-supervision-and-control [Accessed 29 January 2014].

Xu, L., 2012. *2012 China Smart Grid Construction Investment Outlook,* Beijing: Smart Grid Times & Consulting Research.

Yin, Z., 2011. *A study of Competitive Price for China Smart Grid Project.* Beijing, Journal of Modern Business, pp. 1.

Yu, B., Zou, M. & Fen, Y., 2005. Permeability of fractal porous media by Monte Carlosimulations. *International Journal of Heat and Mass Transfer ,* 48 (13) (1), pp. 2787-2794.

Yu, K., 2000. Governance and good governance. *Social Sciences Academic Press,* 1(1), pp. 1-2.

Zeljkovic, 2005. *An example of using microsoft excel solver for power network calculations,* Banja Luka: University of Banja Luka, Department of power Engineering,

Zhou, F. & Zhang, X., 2013. Assessment of heat transfer in an aquifer utilizing fractal theory. *Applied Thermal Engineering ,* 59 (1), pp. 445-453.

APPENDIXES

APPENDIX I

Publications Resulted from This Research

Publications Resulting from This Research:

1. Chen Wang, Qing-Ping Yang and Yong-Hua Song, "Power Crises Study for Restructuring China's Energy Regulation Using Equilibrium Theory" in *World Congress on Engineering and Computer Science 2010*, San Francisco, USA October 20-22,2010, pp. 889–893.

2. Chen Wang, Qing-Ping Yang, Kai Cheng. "Electric Power Transmission Company Regulation Methodology Using Equilibrium Theory and Quality Function Deployment". *5th Annual Student Research Conference Brunel University ResCon*, June 2012.

3. Chen Wang, Qing-Ping Yang, Kai Cheng. "Regulation and Optimization Methodology Using Quality Function Deployment and Mathematical Programming for Chinese Electric Power Grid Operators". *Electric Power System Research* (to be submitted).

4. Chen Wang, Qing-Ping Yang and Kai Cheng, "Optimization Assessment Methodology for Smart Grid in a Chinese EPGO Case Study Using Quality Function Deployment, Equilibrium Theory and Fractal Theory" *Energy* (to be submitted).

APPENDIX II

CW Curve Research Data

Rank	Country	TNEG(Billion Kilowatt hours)
1	**US**	**4071**
2	**China**	**2717**
3	**Japan**	**1032**
4	**Russia**	**940**
5	**India**	**703**
6	**Germany**	**594**
7	**Canada**	**594**
8	**France**	**542**
9	**Brazil**	**411**
10	**Korea South**	**379**
11	**UK**	**371**
12	**Italy**	**291**
13	**Spain**	**283**
14	**Australia**	**237**
15	**Mexico**	**236**
16	**South Africa**	**227**

TNEG and country rank of World Top 16 Countries in 2006 (EIA, 2013)

Rank	Country	TNEC(Billion Kilowatt hours)
1	**US**	**3816**
2	**China**	**2528**
3	**Japan**	**982**
4	**Russia**	**819**
5	**Germany(East West)**	**549**
6	**Canada**	**529**
7	**India**	**517**
8	**France**	**447**
9	**Brazil**	**382**
10	**Korea South**	**365**
11	**UK**	**348**
12	**Italy**	**316**
13	**Spain**	**254**
14	**Australia**	**219**
15	**South Africa**	**201**
16	Mexico	195

TNECand country rank of World Top 16 Countries in 2006 (EIA, 2013)

Rank	Country	TNEG(Billion Kilowatt hours)
1	**US**	**3745**
2	**China**	**1426**
3	**Japan**	**975**
4	**Russia**	**843**
5	**Germany(East West)**	**571**
6	**Canada**	**549**
7	**France**	**548**
8	**India**	**520**
9	**UK**	**360**
10	**Brazil**	**322**
11	**Italy**	**265**
12	**Korea South**	**258**
13	**South Africa**	**221**
14	**Spain**	**204**
15	**Australia**	**198**
16	**Mexico**	**197**

TNEG and country rank of World Top 16 Countries in 2001 (EIA, 2013)

Rank	Country	TNEC(Billion Kilowatt hours)
1	**US**	**3557**
2	**China**	**1314**
3	**Japan**	**930**
4	**Russia**	**721**
5	**Germany(East West)**	**520**
6	**Canada**	**505**
7	**France**	**421**
8	**India**	**383**
9	**UK**	**338**
10	**Brazil**	**303**
11	**Italy**	**287**
12	**Korea South**	**253**
13	**Spain**	**207**
14	**Australia**	**189**
15	**South Africa**	**181**
16	**Mexico**	**168**

TNEC and country rank of World Top 16 Countries in 2001 (EIA, 2013)

Rank	Country	TNEG(Billion Kilowatt hours)
1	**US**	**3447**
2	**China**	**1005**
3	**Japan**	**961**
4	**Russia**	**806**
5	**Canada**	**557**
6	**Germany(East West)**	**520**
7	**France**	**483**
8	**India**	**412**
9	**UK**	**329**
10	**Brazil**	**286**
11	**Italy**	**227**
12	**Korea South**	**211**
13	**South Africa**	**187**
14	**Australia**	**168**
15	**Spain**	**165**
16	**Mexico**	**154**

TNEG and country rank of World Top 16 Countries in 1996 (EIA, 2013)

Rank	Country	TNEC(Billion Kilowatt hours)
1	**US**	**3253**
2	**China**	**920**
3	**Japan**	**916**
4	**Russia**	**702**
5	**Germany(East West)**	**489**
6	**Canada**	**473**
7	**France**	**384**
8	**India**	**323**
9	**UK**	**316**
10	**Brazil**	**276**
11	**Italy**	**247**
12	**Korea South**	**200**
13	**South Africa**	**166**
14	**Spain**	**151**
15	**Australia**	**156**
16	**Mexico**	**130**

TNEC and country rank of World Top 16 Countries in 1996 (EIA, 2013)

Country	Ranking 1996	Ranking 2001	Ranking 2006	Country rank changing Number 1996-2001,2001-2006
India	8	7	5	(1+2)=3
Korea South	12	11	10	(1+1)=2
Brazil	10	10	9	(0+1)=1
Mexico	16	15	15	(1+0)=1
US	1	1	1	0
China	2	2	2	0
Japan	3	3	3	0
Russia	4	4	4	0
Germany	6	6	6	0
Spain	13	13	13	0
Australia	14	14	14	0
France	7	8	8	(-1+0)=-1
Italy	11	12	12	(-1+0)=-1
Canada	5	5	7	(0-2)=-2
UK	9	9	11	(0-2)=-2
South Africa	13	16	16	(-3+0)=-3

Computations of World top 16TNEG countries rank changings in 1996, 2001, and 2006 (EIA, 2013)