Chile's Electricity Market Construction and Its Enlightenment

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Abstract. Chile is the first country in the world to implement electric sector reform, and is a country with more advanced renewable energy development in South American countries. This paper introduces Chile's electricity market reform procedure and market model, as well as the power crisis, and summarizes the relevant mechanisms and policies for Chile to stimulate renewable energy development. Finally, the enlightenment of Chile's electricity market reform to China is analyzed.

Introduction

Chile is the world's narrowest country with a total length of 4,300 km, an average width of 175 km, a minimum width of 96.8 km and a maximum width of 362.3 kilometers.

Chile is a country with a shortage of traditional fossil energy. It produces a small amount of fossil energy such as oil, natural gas and coal. Domestic energy supply depends heavily on imports.

This paper summarizes and analyzes the enlightenment of Chile's electricity market reform to developing countries. The full text is divided into the following parts: chapter 2, introducing the current status of Chilean power industry. The third chapter introduces the Brazilian electricity market, including the market-oriented reform process and motives, the electricity market model and the emerging power crisis. The fourth chapter introduces Chile's renewable energy development policy. The final chapter gives a summary and analysis.

Current Status of the Chilean Power Industry

Chile initiated the privatization reform of the power industry in the second half of the 1970s. It is the earliest country in the world to implement electricity market reform. The main driving force behind Chile’s power sector reform is not the power sector itself, but is largely influenced by the economic and political reform process. Chile’s electricity market is currently operating well, effectively protecting domestic electricity demand and promoting the development of new energy sources. The electricity price is relatively low, which is inseparable from its good market mode and institutional mechanism [1, 2].

This paper summarizes and analyzes the enlightenment of Chile's electricity market reform to developing countries. The full text is divided into the following parts: Chapter 2 introduces the current status of Chilean power industry. The third chapter introduces the Brazilian electricity market, including the market-oriented reform process and motives and the electricity market model. The fourth chapter introduces Chile's renewable energy development policy. The final chapter gives a summary and analysis.

Current Status of the Chilean Power Industry

Chile is one of the leading countries in Latin America in terms of renewable energy exploration. By the end of 2017, Chile's total installed capacity was 22,580 MW, an increase of 2.4% over 2016. Renewable energy accounts for 45% of the country's energy mix, non-conventional renewable energy accounts for 32.4%, and hydropower resources account for 67.6% of total renewable energy.
The power supply structure is: thermal power accounts for 55% of the total installed capacity, hydropower accounts for 27%, solar power accounts for 8%, followed by wind power of 6%, biomass and small hydropower of 2%.

According to the 2017 Energy Statistics Yearbook, by the end of 2017, 81 power generation projects under construction total 3,140 MW, a decrease of 51% from 2016. Non-conventional renewable energy accounts for 51% of the capacity under construction[3]. By 2025, the share of renewable energy in the total energy mix is expected to rise to 61.6%. Solar installations are expected to dominate the country's renewable energy installations, accounting for 41.4%. Through various fiscal incentives and favorable policy implementation, government support will be the reason for the dramatic growth of solar installations.

Chile is long and narrow. It runs north-south and is divided into 13 states from the north. 13 states were once connected by four power systems: northern system SING in the northern region (the first state, the second state), central system SIC of the central system (the first state, the second state), (3rd-10th states and capital region) and the southern two states are powered by the small-scale transmission systems Aysén (11th state) and Magallanes (12th state). The proportion of self-provided power generation for large users is also large. SING and SIC generate 90% of the country's total electricity demand and are the two largest power systems in Chile[4].

**Chile’s Electricity Market**

**Motivation and History of Chile's Power Market Reform**

Chile’s power sector privatization reform aims to eliminate the monopoly, corruption, inefficiency and lack of funds of state-owned power companies, establish a power market liberalization system, rationally allocate social resources, promote competition in the power industry and maximize social welfare. The main course is as follows[5-9]:

i) In 1978, the Chilean National Energy Commission (CNE) was established, marking the beginning of Chile's power reform.

ii) In 1981, the Chilean power sector implemented vertical and parallel splits.

iii) In 1982, Chile officially issued a new “Electricity Law” focusing on liberalization. The law divides the power industry into three parts: power generation, transmission and distribution, and is completely controlled by private capital. The state is only responsible for regulating, supervising and guiding the investment of power generation and transmission companies and eliminating vertical integration, that is, power plants cannot participate in transmission or distribution, and the law also stipulates that relevant personnel of government decision-making departments cannot enter the power industry, which are important for the effective operation of the electricity market.

iv) In 1985, the Ministry of Economic Affairs established the Electric Power and Fuel Supervision Office to supervise and investigate the technical standards for the transportation, production, supply and storage of natural gas and electric power. In the field of power, it plays a role in formulating and strengthening technical standards. The authority has made clear its authority through the law.

v) In 1986, Chile implemented large-scale privatization. Chile’s privatization reform of the power sector aims to eliminate the shortcomings of state-owned power companies’ monopoly, corruption, inefficiency and lack of funds, establish a power market liberalization system and achieve the goal of rational allocation of social sources, promoting competition in the power industry and maximizing social welfare[10].

vi) In 1990, the privatization process of the Chilean power system was basically completed.

vii) In 1992, the Chilean Government enacted a new power system structural framework to determine the introduction of competition in the field of power generation, while the transmission and distribution sectors still have a natural monopoly. It is important that there is no restriction on the ownership of transmission lines.

viii) In 1998, the Chilean Government further made regulations: the National Power Company will be privatized by the year 2000. The privatization reform officially ended with the sale of the last state-owned power facility in 1998.
Chilean Electricity Market Mode

Chile's power system operation implements fully intelligent management. The power station can use the spot market to bid online or sign the PPA power supply agreement[11]. Both of the methods implement intelligent management. The connection with the power system and generation distribution are automatically adjusted by the system without human intervention. As shown in Figure 1, power producers in the physical market can sell or buy electricity in real time from the grid. In the financial market, electricity is mainly bought by electricity users from the power grid or distributors[4, 12].

In the spot market, the connection order of the power station with power grid is only related to the variable cost of power generation. Each type of power station of an access point of the power grid is connected to the grid in the order of low-to-high power generation variable cost. After the generators with low variable cost are all connected to the grid, the power stations with secondary low variable cost can be connected to the grid.

When the power generation of the connected power stations meets all the requirements of the time period, the remaining power stations can no longer be connected to the grid; when the variable costs of the two power stations in demand are the same, the power generation is evenly distributed. The variable cost of power generation mainly includes fuel cost, equipment maintenance cost, fitting cost and material cost, environmental monitoring cost, waste disposal cost and so on. All power generation enterprises must submit their variable costs to the economic dispatch center every week. The economic dispatch center sets the priority of grid connection for all power stations based on this data. The economic dispatch center has the right to verify it. Other companies have the right to supervise or challenge it.

According to the above connection rule, the order of priority is usually: runoff hydropower → small storage reservoir hydropower station → wind power and photovoltaic → coal power → natural gas → large reservoir hydropower station → liquefied natural gas → diesel oil. According to the above principles, run-of-river hydropower stations can usually be dispatched at all times, while liquefied gas and diesel with the highest marginal cost are often unable to dispatch or only a small amount of generation can be connected to the grid when the total electricity demand is low or during the flood season. The electricity price at a certain point in the spot market of a power station is equal to the marginal cost of the last grid connected power station at that time. The marginal cost usually depends on the generation capacity, variable operation and maintenance cost, the hydropower availability, the fossil fuel price, etc., so the spot price is very unstable[13].

Another electricity sales mode in the Chilean electricity market is through the PPA (Power Purchase Agreement) agreement. There are two ways for generators to obtain PPA. One is to participate in the PPA bidding organized by the government, and the other is to negotiate with major customers. The PPA agreement will define the electricity sales mode, time period and electricity price. The drawback of selling electricity in the PPA mode is that the seller must guarantee the

Figure 1. Chilean electricity market sales method.
electricity demand of the buyer. If the generator fails to supply power on time, it needs to follow the above rules of the spot market to buy electricity in the spot market to fulfill the power guarantee specified in the PPA[14].

In order to promote the long-term development of the power consumption market, expand the scope of enterprise participation, and form a more competitive, safe and reliable power market, the Chilean Government has adopted the measure of establishing an independent operation center. The operation center acts as an independent legal entity and operates independently with clear responsibilities. In this way, the power market is guaranteed to operate independently and properly. The operation center introduces the end-user competition mechanism by designing the flexible price of long-term users, explores the mode of the power supply enterprise selection through commercial agents, and establishes a guarantee mechanism to ensure contract execution[15].

Chile's power dispatching, system operation, short-term marginal cost estimation, open access to the transmission system, and other administrative matters are handled by the independent agency of the Load and Economic Dispatch Center (CEDC).

In November 2017, the new power system after the merger of SIC and SING was operated by the unified independent system operator National Power Dispatching Agency (CEN, former SIC's CDEC and SING's CDEC) to operate the national power system. CEN replaces the Economic Load Dispatch Center (CEDC), and is responsible for ensuring the safety of power services and transmission networks, overseeing competition in the electricity market, supervising operating companies to comply with the rules, and organizing tenders for new transmission contracts.

**Chilean Power Crisis**

The Chilean electricity market reform process has not been smooth sailing. In the past two decades, the Chilean power system has faced three crises. The first time was in the summer of 1998 and 1999, Chile suffered the worst drought in 40 years. The lack of water supply from hydropower plants led to repeated power outages, and the central power grid was seriously affected. The second crisis came from a 15% drop in natural gas exports from Argentina to Chile after the 2002 financial crisis in Argentina[8, 16].

What is more serious is that in 2007-2008, the double-strike of the natural gas supply restriction and the continuous five-year drought of the central power grid has caused the Chilean power market to self-regulate. In addition, the unconventional technologies are mainly wind and solar energy, and the society strongly opposes the new power generation project. As well as the transmission line, it has led to a power crisis that has not happened in a hundred years, with the consequences of higher power costs and congestion in the transmission network.

When the self-regulation of the electricity market fails, the Chilean government takes effective measures to prevent the situation from deteriorating in the shortest possible time. Timely adjust the power generation mode, limit the transmission voltage, and implement quotas on the supply side. In terms of demand, measures such as price increases and incentives have been adopted to reduce the electricity consumption of residents, and two-way control measures have enabled the dysfunctional power market to be effectively controlled, revitalized and operated normally.

The government sector closely related to the power industry in Chile is mainly the National Energy Council (CNE), which is responsible for formulating and coordinating national energy development and operation plans, policies and regulations to ensure the rationality of the energy sector. The Chilean government has led the development of the electricity market through government departments such as the Chilean Economic Development Agency (CORFO) and the National Energy Commission (CNE), and has diversified its power structure. The use of non-traditional renewable energy (NCRE) power generation technology has gradually formed an important investment. The Chilean General Electricity Law defines non-traditional renewable energy as: natural energy that has not been widely used on the basis of new technologies, or energy from biomass and energy from degradable organic matter. Accordingly, geothermal energy, solar energy, wind energy and ocean energy are all non-traditional renewable energy sources.
Renewable Energy Development Policy

In the past 30 years, Chile's energy policy has been based on an open competitive market. Within this framework, the state plays a regulatory role and its entrepreneurial activities are limited. It is speculated that the market will guarantee the security for energy supply. By 2050, 90% of Chile's energy will come from renewable energy and this new commitment by the Chilean state is very ambitious. Non-conventional energy currently accounts for 17% of the energy matrix. The goal for 2025 is to increase this ratio to 20%. Chile accounts for two-thirds of the total installed capacity of non-conventional renewable energy in Latin America. The main policies are as follows[17, 18]:

National Energy Plan 2012-2020

According to the Chilean government's national energy plan 2012-2020, Chile will protect the country's energy security and development from the following six aspects in the future[19, 20]:

1) Improve energy efficiency as a priority public policy with the goal of reducing energy demand by 12% by 2020;
2) Accelerate the development of renewable energy, promote the proportion of non-conventional renewable energy in the power system, accelerate and effectively use the tendering system, and develop geothermal energy;
3) Strengthen the use of conventional renewable energy sources, such as strengthening the use of water resource, to reduce external dependence;
4) Update the transmission mode, strengthen the transmission line franchise process, create a national public power grid, and realize SIC-SING cross-network connection;
5) Establish a more competitive power market, that is, establish an operation center independent of each transmission system to ensure the independence and normality of the operation of the electricity market;
6) Promote the interconnection of international power grids.

Energy in 2050: Chile's Energy Policy

In December 2015, President Michelle Bachelet administration published the "Energy in 2050: Chile's Energy Policy"[21, 22] document as a long-term energy policy for Chilean energy industry roadmap to 2050. The purpose of this document is to adopt a strong position on the future development of the energy matrix and outline the main guidelines and measures that the country will adopt. It has specific goals for 2035 and 2050 and is based on four pillars:

1) pillar 1, quality and safety of supply;
2) pillar 2, energy is the driving force for development;
3) pillar 3, environmentally friendly energy;
4) pillar 4, energy efficiency and energy education.

The goal of the National Energy Policy of 2050 is to set the requirements for Chile to embark on the path of becoming an innovative and sustainable energy leader in the region and around the world. The energy reform aims to determine the role of the state in seeking to transform from a low-safe energy environment that is highly dependent on oil and coal imports to a self-sufficient energy industry that provides the entire population with modern, reliable and affordable energy services, and decouples energy consumption from GDP growth. According to the government, the potential for hydropower generation may exceed 9,000 megawatts and plans to continue to increase the use of hydropower. It is expected that more attention will be paid to the environmental impact of the hydropower technology. Plans to fully protect natural resources are also important for cleaning up hydropower projects. The program emphasizes the consideration of modern technologies such as submarine cables and underground cables, which minimize environmental impact.

Conclusion

The privatization reform of the electricity market in Chile is seen as a successful example, and the reform experience is useful for other developing countries, because it shows that it is possible to
achieve effective competition and privatization in a smaller electricity market with large hydropower, and can increase the total social welfare.

Chile has chosen the model of “medium and long-term market and spot market” while the financial market is not perfect. The medium and long-term contract market guarantees effective expansion of investment, and the spot market is used as the deviation between contract power and actual power generation, which can discover market prices effectively.

In particular, at the beginning of the reform of electricity market in Chile, hydropower is as high as 80%. The combination of cost-pricing and centralized optimization and scheduling has certain adaptability, and improved the utilization efficiency of hydropower resources, as well as the openness and transparency of market competition, which provides reference for the construction of power market in China's hydropower-rich regions such as Yunnan and Sichuan province.

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