Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

The Present Situation and Development Prospect of Geothermal Power Generation in China

Duo Ji, Xiaoping Fan

21 Beijing Zhonglu, Lhasa, Tibet, P. R. China

bmwb@viip.163.com

Keywords: Geothermal power generation, Development vision, China.

ABSTRACT

The first pilot geothermal power plant with capacity 86kW was built in Dengwu village, Fengshun county, Guangdong province in 1970. This power plant generated electricity power using geothermal fluids of 92℃. After that the other six medium-low temperature geothermal power plants were built, each one with a capacity between 50-300 kW during the 1970s. The testing conclusion was that it was a feasible technology and diseconomy. Consequently, most of the plants were shut down one after another in the late 1970s with two exceptions by low-cost management. Then the one retired in 2008 due to the aging of facilities. The only Dengwu plant that has been operating has an increased capacity of 300kW. This plant has technical support from the Institute of Chinese Academy of Science. Medium-low temperature geothermal power generation paused growth almost later on. In the 1980s there were 2 MW installed in Langju, Tibet and stopped in 1990s due to insufficient supplying resources. In 1993 there was 1 MW installed in Nagqu, Tibet and stopped several years later due to heavy scaling problem. In 2011 the Huabei Oilfield tested a 400 kW of geothermal power generation. But it stopped soon after. There was 1MW unit installed in Ruili city, Yunnan province and 280 kW unit installed in Xian county, Hebei province respectively in 2017. The total capacity of medium-low temperature geothermal power generation in China is 6.23 MW, and 1.58MW are operating.

The Yangbajain pilot high-temperature geothermal power plant with 1MW unit succeeded operation in Tibet in 1977, and the total capacity increased to 25.18MW till 1991. Then there was no increase until 2009. The Yangbajain plant increased 2 MW during 2009-2010. And Yangyi tested a 400 kW + 500 kW later in Tibet. But the 16 MW Yangyi plant generated power until 2018. In addition, a 200 kW small unit was installed in Kangding city, Sichuan province in 2018. The total capacity of high-temperature geothermal power generation in China is 47.58 MW, including 3.3 MW in Taiwan, and 43.28MW are operating.

There are three reasons that could be considered for the slow growth of geothermal power generation. The first error is the idea of development. Chinese saw the low efficiency of geothermal power generation, then stopped further research. However, ORMAT developed such researches and then it became the top one low-temperature geothermal generation plant in the world. The second is insufficient national support as a priority policy. However, Turkey has increased 1,317 MW in recent years due to a tax reduction policy. The third one is insufficient preparation for geothermal resources exploration. Even though the geothermal survey estimated a 5,800 MW potential for 30 years use, it could not be used soon.

The Chinese government issued the 13th Five-year (2016-2020) Plan on Development and Utilization of Geothermal Energy in 2017. It designed a new geothermal power generation plant with a capacity of 500MW. Judging by the current development situation, it could be only reached about 50MW by the end of 2020. It would be a very difficult target, even though several large national-hold enterprises have entered geothermal development. We have to increase the effort to solve series barriers.

1. INTRODUCTION

In December 1970, a power station in Dengwu village, Fengshun county, Guangdong province, succeeded in generating electricity by using geothermal fluid of 92℃. That makes China the eighth country in the world that used geothermal energy for power generation. In later years, other six medium-low temperature geothermal power plants were built successively. These power stations had units' capacity of 50-300 kW. It succeeded especially the geothermal power plant with a capacity of 50 kW built-in Yichun city, Jiangxi province in 1971, which used a geothermal fluid of 67℃ to generate electricity. That is the lowest temperature in geothermal power generation in the world so far. Unfortunately, China has not consolidated and developed geothermal power generation technology. The geothermal power plants were shut down one after another after several years' of successful operation due to various reasons. Only the Dengwu geothermal power plant has been retained and operated up to now due to technologically updating several times. The reason for these shutdowns is the "feasible technology and diseconomy", thus abandoning the research of geothermal power generation technology. That is the failure of the development idea.

The construction of the Yangbajain geothermal power plant benefited from the abundant high-temperature geothermal resources in Tibet and the serious power shortage in Lhasa city. The first 1000 kW pilot unit of Yangbajain geothermal power plant operated successfully in September 1977. From 1981 to 1991, eight 3000 kW units were built successively (one of them is a 3180 kW fast-loading unit that made in Japan). The total installed capacity of the plant reached 25.18 MW using a geothermal fluid with a temperature of 130-170℃ from a shallow reservoir. The power plant is still in normal operation up to now (the 1000 kW pilot unit was retired in 1986). The power generation equipment has not been renewed and technologically reformed for more than 30 years. The present situation is the aging of equipment and its low operation efficiency. The exploration results show that there are high-temperature geothermal resources in the deep reservoir of Yangbajain geothermal field; the highest temperature detected was 329℃. The potential of the deep reservoir was 87.8MW. The exploration work has stopped since 2002 due to a shortage of financial support.

The exploration work of Yangyi geothermal field in Tibet was completed from 1981 to 1991. The highest temperature of the reservoir was 207 °C, the power generation potential was 30MW, and the potential of the long-range perspective forecast was 50MW. Twenty years were wasted until the two pilot units with 400 kW and 500 kW were built in 2011 and 2012. A 16 MW unit was built and connected to the grid in 2018.

The Langju geothermal power plant in Tibet, with a capacity of 2000 kW was built in 1985, in case of absence of proven reserves of geothermal resources. It was shut down after only a few years of intermittent power generation due to insufficient resources.

The problem of Yangyi geothermal field is that it was a waste of time and resources to put the power plant there for more than 20 years without exploitation and utilization in the case of previously proven reserves of resources. The problem of Langju was anxious for success and seeking short-term successes, which led to the waste of financial investment. This is not only the problem of the idea of development, but also the problem of policy, planning, and financial support.

Like other mining's prospecting, geothermal prospecting is a high-risk industry, which needs policy and financial support. National policy orientation and the development concept are the important supports of geothermal industry development.

2. MEDIUM-LOW TEMPERATURE GEOTHERMAL POWER GENERATION

There were twelve medium-low temperature geothermal power plants with a total installed capacity of 6230 kW in China. Three of these power plants with a capacity of 1580 kW are operating (Table 1, Fig. 1).

Table 1: List of medium-low temperature geothermal power plants

No.	Location of geothermal power plant	Year of construction	Installation capacity (kW)	Power generation mode	Number of units	Fluid temperature (℃)	Remarks
1	Dengwu village, Fengshun county, Guangdong province	1970	300	Flash	1	92	
2	Houhaoyao, Huailai county, Hebei province	1971	200	Duplex		87	Shutdown
3	Wentang town, Yichun City, Jiangxi province	1971	50	Duplex		67	Shutdown
4	Reshui village, Xiangzhou County, Guangxi	1974	200	Flash		79	Shutdown
5	Huitang town, Ningxiang county, Hunan province	1975	300	Flash		98	Retired (2008)
6	Tangdongquan, Zhaoyuan city, Shandong province	1976	300	Flash		98	Shutdown
7	Xiongyue, Gaixian, Liaoning province		200			90	Shutdown
8	Langju, Tibet	1985	2000	Flash	2		Shutdown
9	Nagqu, Tibet	1994	1000	Duplex	1		Shutdown
10	Huabei oilfield	2011	400	Binary screw expander system		110	Shutdown
11	Ruili City, Yunnan province	2017	1000				
12	Xianxian, Hebei province	2017	280				

The geothermal pilot power plant with a capacity of 86 kW was operating successfully in Fengshun county, Guangdong Province, on December 12, 1970 (Table 2). This is the first geothermal power plant in China. Subsequently, the other six geothermal power plants were built in Huailai (Hebei province), Yichun (Jiangxi province), Xiangzhou (Guangxi), Ningxiang (Hunan province), Zhaoyuan (Shandong province), and Gaixian (Liaoning province), with capacities between 50-300 kW. The total capacity was 1.55MW (Zheng K.Y., 2009). Five plants were shut down one after another in the late 1970s. Poor economic efficiency was the main reason for these power plants' shutdowns, although there were no major technical obstacles. The Dengwu power plant did not stop operation until 2004 due to the aging of units, while The Huitang plant didn't stop until 2008. The Dengwu power plant is still in operation after a technical renovation in 2009 with an installed capacity of 300 kW.

The Langju geothermal power plant was built in 1985 with a capacity of 2000 kW in order to solve the serious power shortage in Shiquanhe Town, capital of Ngari region, Tibet. This was done without proven the resource potential of Langju geothermal field.

Only one 400 kW unit can be in operation intermittently due to insufficient steam production from the geothermal wells. The plant was shut down after several years.

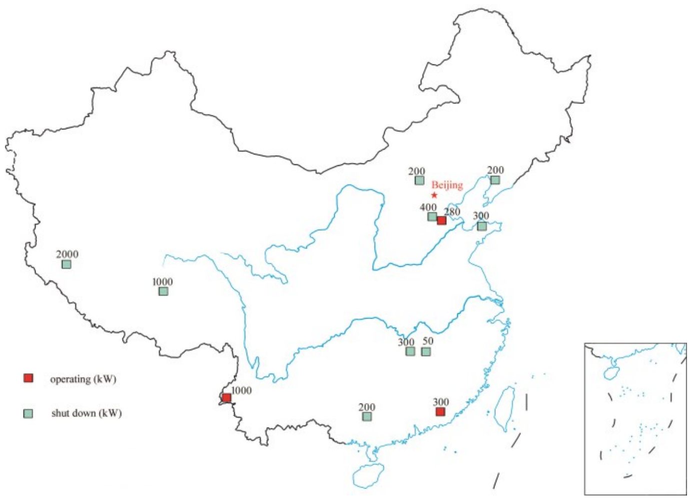

Figure 1: Distribution sketch of medium-low temperature geothermal power plants

One 1000kW geothermal power plant was built in Nagqu, Tibet, in 1994. It was shut down in 1999 because of the serious scaling of the system.

Table 2: Development process of the Dengwu geothermal power plant

Operation Year	Installed Capacity	Power Generation Mode	Hot Water Temperature	Situation
1970	86kW	Flash	92℃	Retired
1977	200kW	Duplex (Isobutane)		Interruption of operation
1982	300 kW	Flash		Shutdown by machine aging (2004)
2009	300kW	Flash		In operation

3 HIGH-TEMPERATURE GEOTHERMAL POWER GENERATION

High-temperature geothermal resources are mainly distributed in southern Tibet, western Yunnan, western Sichuan, and Taiwan, where a lot of geothermal geological exploration has been carried out. So far, only five high-temperature geothermal power plants have been built in Yangbajain, Yangyi (Tibet), Kangding (Sichuan), and Taiwan. Two geothermal power plants in Taiwan have been shut down (Table 3, Fig. 2).

Table 3: List of high-temperature geothermal power plants

No.	Name of geothermal power plant	Year of construction	Installation capacity (MW)	Power generation mode	Number of units	Fluid temperature (℃)	Remarks
1	Yangbajain, Tibet	1977-1991	25.18	flash	9	130-170	1 MW pilot unit was shut down in 1986
	Yangbajain Longyuan, Tibet	2009-2010	2	Full flow	2		
2	Yangyi Pilot, Tibet	2011-2012	0.9	Full flow	2	105-190	
	Yangyi, Tibet	2018	16		1		
3	Kangding, Sichuan Province	2018	0.2		1		
4	Qingshui, Taiwan	1978	3	Backpressure pilot			Shutdown
5	Tuchang, Taiwan	1986	0.3	Binary double-cycle			Shutdown

There were five high-temperature geothermal power plants in China with a total capacity of 47.58 MW, of these, three plants are operating with a total capacity of 43.28 MW. The Yangbajain geothermal power plant has been operating for more than 40 years and is still in normal operation. The Yangyi geothermal power plant was built with 16MW units in 2018, and it was successfully connected to the grid after several years of pilot operation. The 218℃ high-temperature information was detected in the deep reservoir in the Xiaoreshui geothermal field, Kangding city, Sichuan province. And then a small pilot geothermal power plant of 200 kW was built in 2018. The operation of two geothermal power plants in Taiwan is basically successful. Qingshui and Tuchang geothermal power plants were shut down in 1993 and 1996 respectively. The main reasons for these shutdowns are equipment aging, system scaling, and the expiration of power purchase and sale contracts.

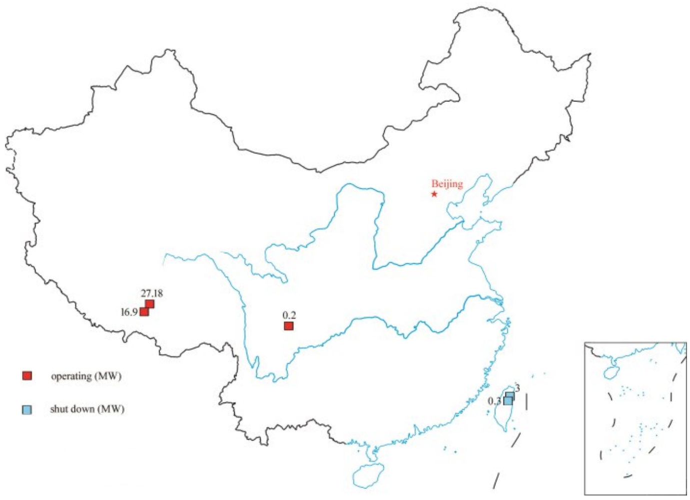

Figure 2: Distribution sketch of high-temperature geothermal power plants

3.1 Yangbajain Geothermal Power Plant in Tibet

The geothermal geological exploration was formally carried out in Yangbajain geothermal field in 1975. The exploration of a shallow reservoir was completed by 1984. The exploration depth was mostly between 206 and 457m. The highest temperature was 172℃, it was detected in a shallow reservoir, and the potential of the reserve was 16.6 MW. The main works of development and utilization of shallow reservoir were to increase the number of production wells and expand the capacity of power plants from 1985 to 1991. During this period, the high-temperature information of 202.2℃ was detected in the well ZK352. From 1992 to 1996, exploration of deep geothermal resources was carried out in the northern area of Yangbajain geothermal field. The high-temperature information of 329.8℃ was obtained in the well ZK4002. It was detected temperature information of 251℃ in the well ZK4001, and its power generation potential was 12.58 MW.

Exploration results show that the shallow reservoirs in Yangbajain geothermal field are mainly distributed in the Quaternary reservoirs in the southern area of the field. The shallow bedrock fissure reservoirs are distributed in the northern area of the field. The highest temperature of shallow reservoirs is 176℃. The deep reservoirs are located in the deep part of the northern area of the field, in which the highest temperature was 329.8℃, and its power generation potential was estimated to 87.8MW (Fig. 3). Only a few exploration works have been carried out aimed at the deep reservoirs. Therefore, there will be a lot of work to do for the exploration and evaluation of deep reservoirs.

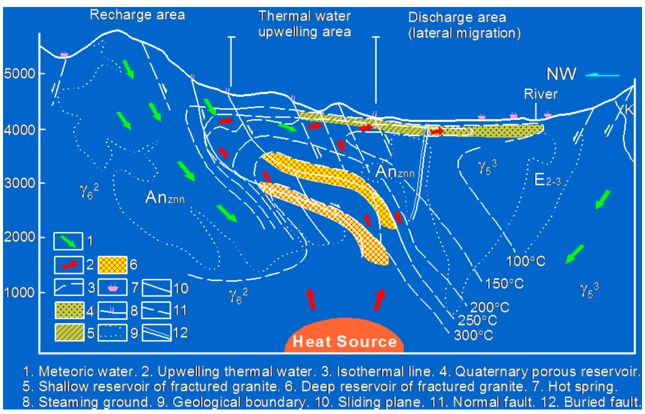

Figure 3: Reservoirs model of Yangbajain geothermal field

The first pilot unit with 1 MW of the Yangbajain geothermal power plant was built in September 1977 and successfully generated electricity that same year. The construction of two branches was completed in 1991. One branch is in the south area of the geothermal field, and one in the north. Independent transmission pipelines of geothermal fluid and generating units were established in the south and north area, respectively, and its total capacity was 25.18 MW (Table 4, Fig. 4). The power generation in summer and winter once accounted for 40% and 60% of the Lhasa grid. With the increase of installed capacity, power generation is also increasing year by year (Fig. 5). The power generation reached its maximum in 2008, which was over 140 GWh. The geothermal power plant is still the basic load of Lhasa grid, especially in winter.

Table 4: List of installed capacity of the Yangbajain geothermal power plant

Name of power plant	Machine number	Installed capacity	Power generation mode	Year of start running	Present situation
Yangbajain pilot (Branch 1)	No.1	1MW	flash	1977	Retired（1986）
South Yangbajain (Branch 1)	No.2	3MW	flash	1981	In operation
	No.3	3MW	flash	1982	In operation
	No.4	3MW	flash	1985	In operation
North Yangbajain (Branch 2)	No.5	3.18MW	flash	1986	In operation
	No.6	3MW	flash	1988	In operation
	No.7	3MW	flash	1989	In operation
	No.8	3MW	flash	1991	In operation
	No.9	3MW	flash	1991	In operation
Yangbajain Longyuan (Branch 2)	No.1	1MW	Full flow	2009	In operation
	No.2	1MW	Full flow	2010	In operation

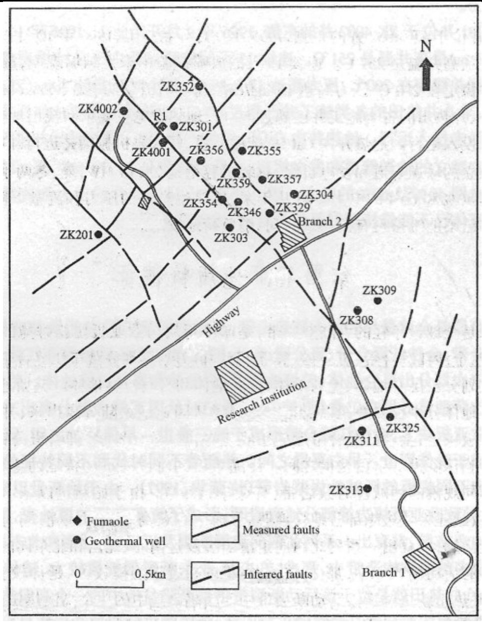

Figure 4: Diagram of the Yangbajain geothermal power plant and well distribution

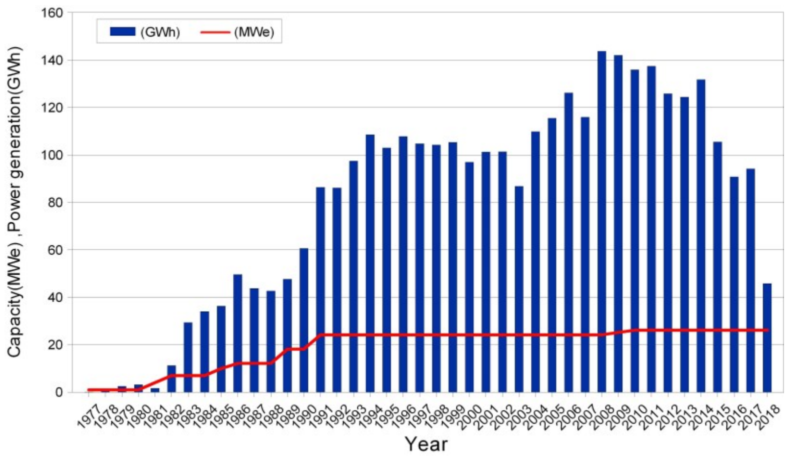

Figure 5: Power generation diagram of the Yangbajain geothermal power plant

The Yangbajain geothermal field is the first one used for high-temperature geothermal power generation in China. The development's work was that it was constructed while exploring. Series of problems gradually emerged in the power plant and the geothermal field in the past 40 years of operation. Among these problems were surface subsidence, shrinkage of a shallow reservoir, aging of generating units and insufficient output of power plants, and others. It is urgent to carry out exploration work of deep reservoir in a north area the field to realize resource replacement. The old units should be replaced and renewed to improve the power plant based on the basis of basically completing exploration work for a deep reservoir. The goal is to expand the capacity, to increase the power generation efficiency and its output.

3.2 Yangyi Geothermal Power Plant in Tibet

The prospecting works of the Yangyi geothermal field were carried out from 1981 to 1990. The exploration report was submitted in 1991. The exploration results show that the highest temperature of the reservoir was 207℃, the potential was 30MW, and the potential of the long-range perspective forecast was 50MW. The plan report of the Yangyi geothermal power plant was completed very soon. Two pilot units of 400 kW and 500 kW were built in 2011 and 2012 through various efforts. In October 2018, one 16 MW OMART ORC units successfully generated electricity and were connected to the grid (Fig. 6). This unit is using geothermal fluids from two production wells. The initial load reached 13 MW. The output capacity of the power plant could reach 18 MW in the wintertime while the environment temperature was -5 ℃. This result shows that the output of the unit is higher than it's designed under the environment of low temperature and low pressure on the Tibet plateau.

Figure 6: The Yangyi 16MW ORMAT unit (photographer, 2018)

It took 20 years, for the Yangyi geothermal field, from completing the exploration work to the pilot units. It took another seven years for the successful installation of the unit and to be grid-connected. Due to the lack of maintenance of wellhead equipment, vast geothermal fluids were discharging from the rusted wellhead during the wasted years. It is a waste of resources. This is the mistake of the development concept and policy decision.

4 HIGH-TEMPERATURE GEOTHERMAL POWER GENERATION POTENTIAL

According to the evaluation results of the Ministry of Land and Resources in November 2014, there are 2307 hot springs in China (Wang J.Y., 2015). The high-temperature geothermal resources are mainly distributed in southern Tibet, western Yunnan, western Sichuan, and Taiwan. Meanwhile, the medium-low temperature geothermal resources are mainly distributed in large-scale sedimentary basins and mountain fault zones (Fig. 7).

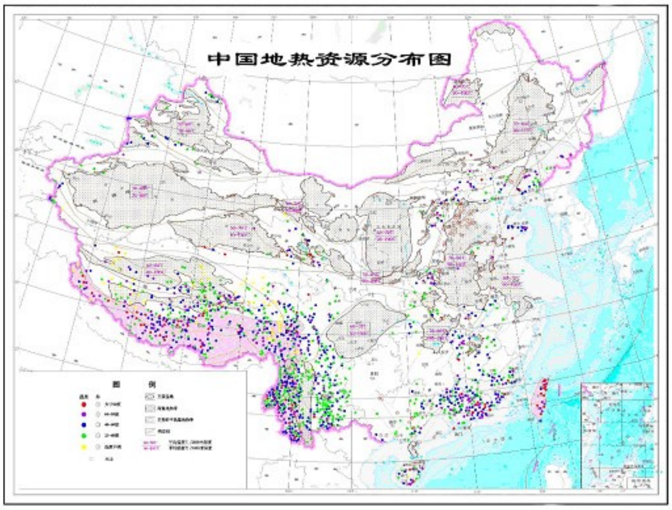

Figure 7: Sketch of geothermal resource distribution

The Yunnan-Tibet geothermal belt (Tibet, western Yunnan and Western Sichuan) is located in the eastern part of the Mediterranean-Himalayan geothermal zone, which distributes about 1750 hydrothermal active areas. The geochemical thermometers are used to estimate the reservoir temperature. Sixty-one high-temperature geothermal systems are identified, as well as 194 quasi-high-temperature geothermal systems. The total potential of power generation is estimated to be 5817MW$_{30a}$ (Liao Z.J., 1999).

Taiwan sits on the west of the circum-Pacific geothermal belt. There are more than 80 hydrothermal active areas mainly distributed in the Datun volcanic area at the northern island, the metamorphic rock area along the central mountains area, and the longitudinal valley at eastern Taiwan. Geothermal exploration works have been carried out in Taiwan since 1972. The potential of power generation is estimated to be around 500-700 MW in all Taiwan, and 80-200 MW in the Datun volcanic area.

5. ROUTE MAP OF GEOTHERMAL POWER GENERATION

On the basis of comprehensive research, it has been planned for the short-term programme on the development and utilization of geothermal resources, as well as medium-long term programmes in recent years (Table 5). The prediction models given by various researchers (research institutions) are different or even quite different.

Table 5: Geothermal power generation forecast

Year	***A***（Geothermal power generation，MWe）	***B***（Geothermal power generation，MWe）
2020	150	50
2030	450	500
2050	1200	5000

A: Strategic Study on Development and Utilization of Geothermal Resources in China （Duo J., 2015）

B: Renewable Energy Research Group（2014）

The National Development and Reform Commission, the National Energy Administration, and the Ministry of Land and Resources released the 13th Five-Year Plan (2016-2020) for the Development and Utilization of Geothermal Energy in January 2017. This plan announced the guidelines and objectives, key tasks, major layout and safeguards for the implementation of the plan. The goal of this plan is to increase the capacity of geothermal power generation by 500 MW by the end of 2020, with the total installed capacity reaching 527.28 MW. The plan calls for the construction of high-temperature geothermal power generation projects in Tibet, western Sichuan, and other high-temperature geothermal resource areas. It also considers a number of medium-low temperature geothermal power generation projects in North China, Jiangsu, Fujian, and Guangdong and other districts. It also calls for the establishment and improvement of the mechanism to support geothermal power generation, and the establishment of a policy system for grid-connected of geothermal power generation, grid peak regulation, and on-grid price. It is clear of orderly starting for planning or construction of 400 MW in eleven high-temperature geothermal fields in Tibet. However, it would be very difficult to break through 50MW by the end of 2020 according to the current development situation.

6. CONCLUSIONS

There are two wrong development concepts in the development and utilization of geothermal resources, especially in the field of geothermal power generation. One is "radical", and the other is "conservative". "Radical" means that the expectations are too high and ahead of schedule. The geothermal power plant is constructed blindly according to the artificial wills without completing the geothermal exploration and making a thorough investigation of the reserves of geothermal resources. Such as the Langju geothermal power plant, the obtained resources reserves cannot satisfy the requirements of the geothermal power plant. "Conservative" means that it is stopped or abandoned of research and development when geothermal power generation is not economically viable, or individual projects fail. Such as the Yangyi geothermal field and the research of medium-low temperature geothermal power generation in China. More than twenty years were wasted in the Yangyi geothermal field. The technique on medium-low temperature geothermal power generation was comparable to the international level in the 1970s. It was abandoned by technology research and development because of "feasible technology and diseconomy".

As we know, geothermal resources have many advantages, but it also has the characteristics of uneven distribution. Different thermal fields have their own characteristics in terms of reservoir temperature, reserves, and its water quality. Geothermal exploration is a high-risk industry also. Therefore, in terms of policy-making and planning, judging the benefit of development and utilization of geothermal resources cannot be only based on the economic indicators, but also the factors of renewability and advantages of environmental protection. There is a vast amount of high-temperature geothermal resources in China. The distribution of these is extremely uneven. Most of them are distributed in the southern Tibet, western Yunnan, western Sichuan, and Taiwan. Therefore, we should follow the principles of the exploration ahead and construct a capacity based on the reserves detected in line with local conditions, steadily progress, and moderately advancing.

ACKNOWLEDGEMENT

I would like to express my heartfelt thanks to Professor Zheng Keyan for his reviewing and revising of this paper carefully.

REFERENCES

Duo J.: Typical High Temperature Geothermal System - Basic Characteristics of Yangbajain Thermal Field, *Engineering*, 5(1), (2003), 42-47

Duo J.: Suggestions on Exploitation and Utilization of High Temperature Geothermal Resources in Tibet, *Abstracts of Proceedings on Seminar on Development and Utilization of Geothermal Energy and Low Carbon Economy* - 14th Branch of the 13th Annual Conference of the Chinese Association of Science and Technology, China Association for Science and Technology, Tianjin Municipal People's Government, Geological Society of China, 3, (2011), 11-13.

Duo Ji and Fan.

Duo J., and Fan X.P.: Strengthening the Policy Guarantee of Geothermal Exploitation, Ensuring the Sustainable Development of Geothermal Exploitation, *Proceedings of the Symposium of the 40th Anniversary of Li Siguang's Advocacy for the Development and Utilization of Geothermal Energy in China and the Geothermal Development in China,* Department of Geological Environment, Ministry of Land and Resources, 3, (2010), 24-26.

Duo J., Wang G.L., and Zheng K.Y. et al.: Strategic Study on Development and Utilization of Geothermal Resources in China, *Science Press,* Beijing (2018).

Duo J., Zeng Y., and Jiao X.Y. et al.: Review and thinking of geothermal power generation in Tibet. Development and protection of geothermal resources in China——Proceedings on exploitation, utilization and protection of geothermal resources in China, *Geological Publishing House,* Beijing (2007), 36-39.

Duo J., and Zheng K.Y.: Current situation and prospect analysis of geothermal power generation in China. Scientific development of geothermal resources in China——Proceedings on high-level Symposium on scientific development of geothermal resources in China. Geothermal China Energy Society, Sinopec Xinxing Petroleum Co., Ltd., Shaanxi Xianyang Geothermal Association, 5, (2008), 110-114.

Liao Z.J.: A brief history of geothermal development in Taiwan province, *Geological Review*, 31(3), (1985), 285-288.

Liao Z.J.: Recent Developments of Geothermal Resources in Taiwan Province, *Geothermal Energy*, 4, (2003), 22-26.

Liao Z.J., and Zhao P. et al.: Yunnan-Tibet Geothermal Belt—Geothermal Resources and Case Histories, *Science Press,* Beijing (1999).

Tong W., Liao Z.J., Liu S.B., Zhang Z.F., You M.Z., and Zhang M.T.: Thermal Springs in Tibet, *Science Press,* Beijing (2000).

Tong W., Zhang M.T., Zhang Z.F., Liao Z.J., You M.Z., Zhu M.X., Guo G.Y., and Liu S.B.: Geothermals beneath Xizang (Tibetan) Plateau, *Science Press,* Beijing (1981).

Wang J.Y. et al: Geothermics and Its Applications, *Science Press,* Beijing (2015).

Xin S.L., and Liang H.B. et al.: Electrical Power Generation from Low Temperature Co-produced Geothermal Resources at Huabei Oilfield, *Proceedings,* 37 Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2012).

Zheng K.Y., Pan X.P.: The 100 Cases of Geothermal Exploration and Development in China, *Geological Publishing House,* Beijing (2005).

Zheng K.Y., Pan X.P.: Current Situation and Prospect of Geothermal Power Generation Development in China, *Sino-Global Energy*, 14(2), (2009), 45-48.