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Application Status and Problem Investigation of Distributed Generation in China: The Case of Natural Gas, Solar and Wind Resources

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Abstract: The development of distributed energy systems in China is one of the important measures to promote the revolution for energy production and its utilization patterns. First of all, we analyze the present application status of China's distributed generation from three major types: natural gas, photovoltaic, and distributed wind. Secondly, based on the analysis of the project overview, project scale, and project effect in three patterns of distributed generation, we summarize the policy deficiencies and development obstacles. Finally, aiming to promote the development of distributed energy in China, we propose some relevant policies corresponding to countermeasures on the problems existing in the development process of China's distributed generation of natural gas, photovoltaic, and wind power.

Keywords: distributed generation; clean energy; application status; problem investigation

1. Introduction

At present, we will energetically develop the distributed energy which is a significant way to promote the revolution of energy production and consumption. Facing the pressures of economic growth, energy crisis, and environmental protection, China carries out distributed generation (Distributed Generation-DG) and it will contribute to make full use of clean energy and renewable energy and to provide consumers with “green power” in order to achieve the target of energy conservation and emissions reduction, as well as engage in the sustainable development road for energy [1–4]. Distributed generation was defined and formally popularized in 1978 by the policy of the public service administration in the United States. Multi-generation facilities are installed in users' sites or nearby mainly for the private use, and the surplus electricity could be transmitted to the grid in order to earn extra money and achieve the energy cascade utilization.

In January 2013, the Chinese government issued the “12th Five-year Plan of the Development of Energy”, in which “promoting the revolution of energy production and utilization pattern” was listed as one of the main tasks in energy works, specifically including three fields: distributed energy, smart grid, and energy supply facilities of new energy vehicles [5–7]. According to the plan of the National Energy Administration, China will expand the development in cities that have resource conditions of different patterns of distributed energy, such as cooling-heating-power poly generation supplied by natural gas, urban buildings' photovoltaic supply, and gas-turbine cogeneration supply heat for

medium and small towns. At the same time, the National Development and Reform Commission (NDRC) issued the 'The interim measures for the distributed generation management', which proposes to exempt business licenses and encourages enterprises (including state-owned enterprises, private enterprises, and foreign capital enterprises), professional energy service companies, and all kinds of power users to invest, construct, and operate distributed generation projects. By 2020, the total installed capacity of all kinds of distributed energy is expected to reach 130 million kW, including small hydropower stations with 75 million kW, multi-generation of natural gas with 50 million kW, small wind power with 3 million kW, and urban buildings photovoltaic sources with 1 million kW [8,9].

Due to the influence of the international financial crisis and the actions of antidumping and countervailing from Europe and the United States, the development of the new energy industry of China, especially wind power and photovoltaic areas, has fallen to its lowest point since 2012. From 2013 to 2016, the State Council, the National Development and Reform Commission (NDRC), the National Energy Administration, and the Ministry of Finance have issued several policies consecutively, aiming to promote the development of distributed generation. Therefore, China needs to develop dual functions of market mechanisms and policy support to form the situation for the overall construction of a distributed energy system as soon as possible. At present, the studies of distributed generation at home and abroad are mainly focused on three aspects. ① The technology of the distributed generation system. It includes different kinds of distributed power generation technology, energy storage technology, distributed grid synchronization access technology, and distributed operation and management technology. ② The power generation management model and benefit evaluation of distributed generation. It contains the integration of distributed generation and the micro-grid, the compatibility of distributed generation with the smart grid, the benefits of the economy, society, and the environment of distributed generation projects. ③ The impacts of distributed generation on the power grid system are considered as a whole, which include the effects on tidal current, voltage, network loss, power quality and lay protection in the distribution side market, and the effects on the plan, operation, control and dispatching of the power grid. However, the studies on the application situation, actual projects, cases analysis, and development issues of different kinds of distributed generation in China are still relatively less. The main purpose of this paper is to explore the existing problems in the process of construction and operation of mainstream distributed generation projects, and then determine and analyze the reasons from the actual project perspective, and finally propose feasible countermeasures and suggestions. There are three main parts as follows. Section 1 introduces the application status of distributed generation in China. Section 2 analyzes the problem investigation of distributed generation development. Section 3 proposes some recommendations on policies. This paper will analyze the three different types of distributed generation including natural gas, photovoltaic, and distributed wind, pointing out the application status in China and summarizing the general situation, scale, and effect of the three kinds of distributed generation projects. The practical implications of this paper are to analyze the implementation and application of actual distributed generation projects, and further dissect the barriers of technology, grid access, and support policies, hoping to provide experience reference for the construction of different distributed generation demonstration projects in China as well as to propose the effective suggestions and measures for future development of distributed generation.

2. Application Status of Distributed Generation

2.1. Natural Gas Distributed Generation

Natural gas, as a high quality, efficient, green, and clean fossil energy, is the realistic choice for controlling environment problems such as governing atmospheric pollution effectively, coping with climate change, etc. In recent years, in order to cooperate with the improvement of air pollution as well as the further development of the low-carbon economy, the development of natural gas resources in China shows a steady rising tendency for the development of natural gas resources. In 2014, the proved reserves of natural gas have been increased by 2.48 times compared to 2002. The production

of natural gas has been increased by 3.9 times as compared with 2002. Meanwhile, for the increasing consumption, domestic natural gas is far from able to fill the huge gap between demand and supply. Therefore, as a net importer of natural gas, China has presented an explosive growth in import volume in recent years, and energy security is also starting to attract attention.

The main indexes of natural gas in China in recent years are shown in Table 1. It shows that in 2014, the natural gas resources reserves in China had reached 3.5 trillion cubic meters, ranking 13th in the world. The production of natural gas was 134.5 billion cubic meters, ranking sixth in the world. The imports of natural gas reached 58.4 billion cubic meters (main pipeline natural gas importers: Turkmenistan, Uzbekistan; main liquid natural gas (LNG) importers: Qatar, Australia, Malaysia, Indonesia), which were increased by 12.5% as compared with 2013. The natural gas dependency had already broken through the 30% warning line in 2014 for the first time. The consumption of natural gas had also reached 185.5 billion cubic meters, and had become the third largest consumer in the world. In China, utilization fields of natural gas mainly include urban gas, industrial fuels, gas power generation, and natural gas chemical industry. Currently, the natural gas consumption for power generation accounts for only 15%, existing as a certain development space. According to the ‘Thirteen-Five (2015–2020) development planning of natural gas in China’, the natural gas supply will be more than 360 billion cubic meters in 2020. Natural gas consumption will reach 300–330 billion cubic meters, and the natural gas market will be eased. Industrial fuels ‘replacing coal with gas’ and natural gas power generation will be vigorously developed, but the natural gas chemical industry will be limited.

Natural gas distributed energy refers to using natural gas as fuel to realize the cascaded utilization of energy by means of combining cooling, heating, and power generation. The comprehensive energy utilization efficiency is above 70%, and the energy supply should be near to the load center, which is an important way of using natural gas efficiently. Compared with the traditional way of centralized energy supply, natural gas distributed energy has a good stability, high efficiency, clean environmental protection, good safety, peak load shaving, as well as good economic benefits, especially for the energy-starved cities. For example, Changsha is the capital city of Hunan province in China with no oil, no gas, and less coal and electricity. Its external dependence degree for energy has reached over 80%, which has become the bottleneck of restricting economic and social development. However, the development of natural gas distributed energy will play an important role in the dual peak load shifting of both the power grid and the natural gas network, and will finally increase the energy supply security and solve the economic development bottleneck.

Table 1. Main indexes of natural gas in China in recent years.

Natural Gas	Unit	2012	2013	2014
Reserves	100 million cubic meters	31,000	35,000	35,000
Production	100 million cubic meters	1143	1249	1345
Consumption	100 million cubic meters	1512	1708	1855
Pipeline natural gas imports	100 million cubic meters	214	274	313
Pipeline natural gas exports	100 million cubic meters	29	27	26
Liquefied Natural Gas (LNG) imports	100 million cubic meters	200	245	271
LNG exports	100 million cubic meters	—	—	—
External depending degree	—	27%	30%	31%

Data source: National Bureau of Statistics of the People’s Republic of China.

Natural gas distributed generation has been developing abroad for more than 30 years, which has been vigorously promoted in many countries such as America, Japan, Denmark, and The Netherlands [10,11]. In China it also has a history of nearly 20 years. However for a variety of reasons, only half is under operation among the more than 40 projects that have been built-up, and the other half was shut down because of problems like grid-connection, benefits, or techniques. The natural gas distributed generation in China still has a long way to go [12]. Gas, as a kind of distributed energy,

is applied widely and is still in the exploration phase, which arouses the government's eagerness for promoting pilot and demonstration projects. According to the "Guidance on developing natural gas distributed energy" promulgated in October 2011, China will build 1000 gas DG projects and has proposed constructing 10 kinds of distributed energy demonstration areas with typical characteristics during "the twelfth five-year" period. By 2020, large scale cities will widely extend and use the distributed energy system and the installed scale will reach 50 million kW, preliminary realizing the industrialization of distributed energy, which provides a favorable opportunity for the development of natural gas distributed generation [13,14].

In view of natural gas distributed generation, it is an effective way to alleviate regional energy shortages, and reduce the proportion of coal-fired power generation and environmental pollution. It is estimated that the sulfur dioxide gas emission from natural gas power generation is less than one thousandth of coal-fired power plants. The nitrogen oxide emissions from natural gas power generation is half that of the coal-fired power plants. Additionally, the water use and land use of natural gas power generation respectively account for 33% and 54% of coal-fired power plants, with basically no ash. The operation experience of the power plants at home and abroad shows that when the power grid accident appears or even under the condition of a large area blackout, gas turbines can guarantee the regional power supply because the startup performance is superior to the conventional steam turbine with a compact structure and good start-stop performance. According to the current development of the electric power industry in China, in order to improve the maneuverability and safety of the power grid operation in the load center, it is necessary to utilize gas turbines as an emergency and peak load shifting generator set, which account for 15% to 20% of the total power grid capacity. In addition, 'The natural gas utilization policy in China which was released in 2007 proposes that the first priority of natural gas utilization is distributed combined heat and power generation and combined cooling, heating, and power (CCHP). In December 2016, the National Energy Administration in China issued 'The opinions about accelerating natural gas utilization'. It put forward some suggestions, such as developing natural gas as the main energy of the modern energy system in the future, carrying out natural gas system reform pilots, replacing coal with gas, quickly raising the level of urban residents' gasification, vigorously developing natural gas distributed energy projects, encouraging the construction of natural gas peak load shifting plants and CCHP plants, while encouraging the integration development of natural gas and renewable energy such as wind and solar power. China's natural gas development report of 2016 also points out that the natural gas power generation installed capacity will account for over 5% of the total power supply in China by 2020 through the development of natural gas peak load shifting plants, CCHP plants, and distributed energy, and up to 10% in 2030.

According to preliminary statistics, the capacity of natural gas distributed generation having been built in China reached more than 800,000 kW, and the distributed plant in Guangzhou University Town is the largest, which has the capacity of 156,000 kW. The application of natural gas distributed generation is mainly divided into four categories, including large-scale building (building combined heating and power, BCHP), public facilities construction (combined cooling heating and power, CCHP), independent community (CCHP), and new town construction (energy integration system). The specific content is shown in Table 2.

Table 2. Project pattern and application status of natural gas distributed generation in China.

Application	General Situation	Project Scale	Project Effect
Large-scale Building—BCHP	Wuhan Creative Land Distributed Energy Station is a national demonstration building distributed generation (DG) project, rarely located in center of the city. This project is located in the basement of Wuhan Creative Land industry Park, covering an area of 4400 m ² .	The project is composed of 5 × 4 MW gas combustion units, matching 5 gas and hot water lithium bromide units with a refrigerating capacity of 3.93 MW and 3 centrifugal chillers with a refrigerating capacity of 1.758 MW as peak shaving devices.	After construction, the project has an annual output of 100 million kWh, heating supply of 130,000 GJ, cooling supply of 210,000 GJ, saving 21,800 tons of standard coal. The project has great economic and environmental benefits.
Public Facilities Construction—CCHP	Changsha Huanghua International Airport Multi-generation Station completed in July 2011, to provide cooling and heating and some electricity for the new-constructed terminal buildings, which cover 154,000 m ² .	The project has a refrigerating capacity of 27 MW, heating capacity of 18 MW, generating capacity of 2320 KW, and the total investment is about 82 million RMB.	The project adopts an advanced gas turbine generator, greatly reduces the pollutants such as nitrogen, SO ₂ , and dust emissions.
	Energy center project in Beijing South Railway Station uses the technology combined cooling, heating, and power, and the sewage source heat pump system.	There are 2 internal combustion generating units and 2 gas and hot water lithium bromine refrigeration units that have a heating capacity of 2221 kW and a refrigerating capacity of 1622 kW.	After construction, the project would save 70,000 tons of water, and save 4.2 million kWh of energy each year. The energy saving is equal to standard coal 1600 tce, reducing CO ₂ emission by 4000 tce and SO ₂ emission by 37 tce.
Independent community—CCHP	Distributed energy station in Guangzhou University Town is currently the largest DG project put into operation in China, with both sets of gas generator running from October 2009.	The project is composed of 2 gas units of 78 MW to provide electricity, hot water, and refrigeration for 10 universities and 200,000 users nearby. The project realizes energy step utilization: the generating efficiency is about 58%, and the cooling and heating efficiency is about 20% by waste heat utilization, promoting the comprehensive efficiency up to 78%.	After construction, the emission of nitrogen oxides is reduced by 80%; emission of SO ₂ and dust are almost zero; CO ₂ emissions are decreased by 70%; boiler make-up water uses an electrode ionization system, achieving the zero discharge for wastewater.
New town construction—energy integration system	Tianjin Eco-city is a strategic cooperation project between China and the Singapore government, a new highlight of cooperation after Suzhou Industry Park, and it is a national exploration of a building demonstration area for constructing a resource-conserving and environmentally friendly city.	Target: the Park is committed to promote the new energy technology, strengthen the energy step utilization, and improve the efficiency of energy utilization.	Method: priority to the development of geothermal, solar, wind, biomass, and other renewable energy resources and construction of first smart grid demonstration area. The renewable energy utilization rate will reach 20% by 2020.

In view of the distributed projects which are ongoing or upcoming in China, they are mainly located in developed cities such as Shanghai, Guangzhou, and Beijing.

- Shanghai has built several natural gas distributed projects, including the Huangpu Central hospital, Minhang hospital, Pudong airport, Shuya Health Center, and Tianting Hotel. In addition, some campus designing projects including Shanghai Science and Technology University are at the beginning of negotiation and research.
- In Guangzhou, besides University Town, the Dongguan shoe factory and aluminum company also have gas DG projects operating. Moreover, projects for a Guangzhou pharmaceutical company, Shenzhen Guangming Technology Park, and others are in planning.
- As for Beijing, according to the previous experience and foreign development modes, the experts suggest that Beijing change the utilization patterns of boilers, study the CCHP technology of medium and small scale gas-turbines, rebuild the boiler room, and supply electricity for consumers directly. Electricity can be directly supplied for users, which will achieve obvious economic benefits as well as social and environmental benefits. The development of CCHP technology is likely to be a new tendency of city heating. The Beijing Gas Co. monitoring center and Beijing Ciqu Station Building has been put into operation. Beijing University of Posts and Telecommunications has finished its feasibility study. From the situation above, China is gradually exploring a new mode of natural gas distributed energy utilization, using policy and economic measures to encourage the development of the DG industry, and accelerating the promotion and application of the industry through demonstration projects.

2.2. Photovoltaic Distributed Generation

During the 12th Five-Year Plan period, China strengthened the development of solar energy, particularly the solar PV industry development, with a focus on conquering solar distributed generation technology challenges; it gave priority to using buildings' roofs to construct the distributed PV system; and it sped up the promotion of distributed grid-connected photovoltaic systems on the user side. Meanwhile, the government in China published more targeted policies, such as "The 12th Five-Year Plan of the development of solar PV industry", "The notice of using price leverage to promote the healthy development of PV industry", "The notice of declaration distributed PV generation large-scale application demonstration areas", "The related comments on distributed PV on-grid", etc. With an additional total commitment of 250 billion yuan (36.32 billion dollars), the national total installed capacity of distributed PV has reached 6.06 million kilowatts by the end of 2015. However, the '13th Five-Year Plan for electric power development' proposes that the solar power installed capacity in China will reach more than 110 million kilowatts by 2020, of which more than 60 million-kilowatts are distributed PV (Data source: the 13th Five-Year Plan for electric power development in China). It means that there is a big gap of 54 million kilowatts in the distributed PV installed capacity during the 13th five-year period. The distributed PV industry will face great opportunities, greatly promoting the development of distributed PV generation [15–17].

The State Grid Corporation's service milestones on photovoltaic distributed generation are shown in Table 3.

After two years of implementation of the "Golden Sun" project, with respect to the application and development of photovoltaic distributed generation, there was about a total of 1.1 million-kilowatt capacity granted for user-side solar power photovoltaic generation. Table 3 shows that on 21 December 2012, the first residential customer solar energy power station was incorporated into the national power grid in Qingdao, Shandong province. The total installed capacity of the project is 2 kilowatts, and the grid voltage is 220 volts, using the means of generating power mainly for private use, and the rest is connected to the grid. By 26 February, 2013, the project cumulative generation had reached 337.04, which not only met the electricity demand of households, but also sold 212.86 kilowatt-hours of electricity to the grid. According to the 2300 h of sunshine per year, 1300 h of sunshine peak time in the Qingdao area, the PV power plant with a total investment of more than 20,000 yuan (2905.5 dollars)

is expected to recover its costs after 15 years, taking into account that the PV modules have a life cycle of 25 years, in which there will be 10 years of profits.

Table 3. State Grid Corporation’s service milestones on photovoltaic distributed generation.

Time	Milestones
26 October 2012	State Grid Corporation released “The views on doing well the work of distributed PV on-grid services”, prepared to optimize the incorporation process, simplified the incorporation procedures, improved service levels, and promoted the sustained and healthy development of photovoltaic power generation. The views triggered strong repercussions in the community.
21 December 2012	The first residential customer solar energy power station in Qingdao, Shandong province was incorporated into the national power grid, causing widespread concern. The total installed capacity of the project has reached 2 kilowatt, and the grid voltage is 220 volt. The generating power is mainly for the private use and the excess electricity is transmitted to the power grid system.
The end of 2012	China’s launched grid-connected distributed generation sources reached 15,600; the installed capacity reached 34.36 million-kilowatt, in which distributed hydroelectricity was 23.76 million-kilowatt, ranking first in the world.
25 January 2013	The second national residential customer’s solar energy power station in Beijing was connected with the national grid, which was paid attention to by the media. The mode selected by customers is electricity on-grid with full power generation.
In late January 2013	State Grid Company accepted 850 consulting items related distributed PV on-grid, 119 applications for incorporation into the grid, and the total installed capacity was 3.382 million kW.
27 February 2013	State Grid Company released “Views on a distributed power grid services” in Beijing.
2015	1000 natural gas distributed energy projects, 10 natural gas distributed energy demonstration regions have been built in China; distributed solar power generation reached 10 million-kilowatt, and 100 new demonstration cities mainly using distributed renewable energy were built.

Notes: The State Grid Newspaper.

On 25 January 2013, the second inhabitant customer’s photovoltaic power station in Beijing Shunyi was incorporated into the national power grid. The total installed capacity of the project is 3 kilowatts, sending all generated electricity to the grid while normal families still use municipal electricity. Under good weather conditions, the project can generate around 8–9 kWh one day. By 28 February 2013, the project cumulative electricity had reached 230-kilowatt kWh/month, 7-kilowatt kWh/day on average. On 7 February 2013, the first distributed generation project in Jiangsu Province, Changzhou JiaXun Optoelectronics Industry Development Limited Company’s independent solar power source, was incorporated into the grid. The installed capacity of the project is 1573-kilowatt, mainly for the private use and the excess electricity is transmitted to the grid. Until 27 February 2013, the on-grid electricity of the project has generated up to 1740 kilowatt hours. Meanwhile, the company also plans to invest in 25 similar projects, involving a total of 33 on-grid outlets whose investments are valued at 160 million dollars. By the end of January 2013, the State Grid Company accepted 850 consulting items related to distributed PV on-grid, 119 applications for incorporation into the grid, including the total installed capacity of 3.382 million kW. By the end of 2013, the accumulated total distributed PV installed capacity reached about 2 million kilowatts, in which was the new distributed PV installed capacity was 1 million kilowatts during 2013. From all the situations above, it is obvious that photovoltaic distributed generation projects encouraged by the State’s policies have already achieved some measures of success and photovoltaic power generation projects are developing step by step, shifting from the large centralized power generation side to small distributed user side. In the next development stage of distributed PV, the country will focus on the on-grid technology, pricing mechanisms and subsidy policies.

2.3. Distributed Wind Power Generation

In recent years, centralized wind power generation projects have developed rapidly with a dramatic increase in the total amount of installed capacity. By the end of June 2013, China's wind power cumulative installed capacity had reached 80.82 million-kilowatt, ranking first in the world, and it has also grown as the third source for electricity after coal electricity and water electricity [18]. However in recent years, it is obvious that China's wind power capacity has grown less rapidly, and even negative growth appeared in 2011 for the first time because of the inherent defects of centralized wind power:

- Grid connection is difficult, the current grid is relatively backward, and large wind farms are in high demand of grid connection, so there is a large grid-connected risk.
- With strong demand for wind resources, centralized wind power currently focuses on the areas of rich wind resources (named first-level and second-level wind areas) and ignores other wind areas (named third-level and forth-level wind areas with insufficient resources), which will cause the phenomena of severely abandoning wind resources. Aimed at the problems in centralized wind power, China proposed a distributed wind power development strategy. Decentralized access of the wind power project is the project located near the load centers, not intended for large-scale long-distance transmission of electricity and the generated electricity is to be absorbed by the nearest local power grid [19–22].

Characteristics of wind power decentralized access: (1) being near the load, reducing the capital investment and line loss; (2) no requirement of centralized transformers; decreasing overall investment, low occupation of land, and short construction periods; (3) being able to work as a black start power supplier to the grid in order to cope with widespread blackouts [23–25].

In 2011, the National Energy Council issued a series of files, mainly including the “Notification of the guide view issued by National Energy Council on development and construction of wind power decentralized access project” and “Notification on the development about dispersed access of wind electricity”, which all clearly showed the national encouraged attitude towards the development of dispersed wind electricity, while it also defined wind electricity dispersed access, conditions for grid connection, preliminary work and verification of the project location, technology requirements in the access system, and operation management and engineering construction acceptance [26]. Later, in July 2013, the State promulgated the “Interim measures for the administration of distributed generation”, which stipulates the power grid's responsibility for acquiring distributed power and encourages enterprises and individuals to invest in decentralized power generation projects [27]. However, in the past two years, the local distributed wind power generation development process is still slow, with only a handful of firms carrying out and exploring distributed wind power development and demonstration projects.

As for the application and implementation situation of dispersed wind power generation, on 9 August 2012, China Guangdong Nuclear Power Group's wind electricity dispersed access project in Hami was approved by the Xinjiang Autonomous Regions' Development Reform Board which is the first national distributed wind power demonstration project. The project plans to construct four wind farms, including Balikun County West Mine Black Eye Springs totaling 24,000 kW, Yellow Shandong in the Hami Southeast wind district totaling 9000 kW, Sand Springs totaling 9000 kW, and Yamansu totaling 27,000 kW. The project's total installed capacity is 69,000 kW, and after a year of building and grid-connected operation, the annual on-grid capacity reached 146.99 million kWh. According to the thermal power consumption (coal equivalent) per unit energy consumption of 350 g, the project's construction and operation can save about 51,400 tons of standard coal per year, and can reduce CO₂ emissions by about 146,000 tons annually. Other typical distributed wind power projects are shown in Table 4. Table 4 shows that there are not many distributed wind power projects in China at present. On the premise of success examples, there are follow-up wind energy plans such as Yunnan, Hunan, Zhejiang, and other provinces' developing plans for distributed wind power, but government

departments, enterprises, and power grid enterprises still need interaction and cooperation, as well as to form composition forces to achieve a win-win situation.

Table 4. Typical distributed wind power projects' general situation.

Time	Event	Project's General Situation
December 2010	HuaNeng Wolf Ditch distributed wind project completed project approval	The project including 6 wind turbines began on 15 March 2011; grid synchronization and debugging on 10 December 2011, to which the start and connection into the grid as well as 240 h grid hanging trial operation. As of 31 July 2012, the Wolf Ditch wind power farm generated electricity totaling 3.63 million-kilowatt.
October 2013	China Shipbuilding (Chongqing) Sea-Put Wind Power Equipment Company invested a wind power distributed access project in Wulong county, and signed a contract with government officials.	The project's total size is 80,000-kilowatt, with a total investment of 800 million Yuan, with an annual output value of more than 100 million Yuan after its completion. The project was implemented according to the phase, including 12,000 kW capacity for first phase and 68,000 kW capacity for secondary phase.
July 2013	Huizhou province, established "Guizhou province program for the development of wind power decentralized access", and got the National Energy Board's reply. It is the first development program of provincial-level wind power decentralized access that has the National Energy Board's approval.	The wind power decentralized access development project in Guizhou province totals 1.2 million-kilowatt, to be implemented by stages and in groups, of which the first phase projects total 500,000-kilowatt, developed time confined to 2013–2015 ;the second phase 700,000-kilowatt, developed time 2016–2020.

3. Problem Investigation of Distributed Generation Development

3.1. Natural Gas Distributed Generation

Natural gas generation has the characteristics of high energy conversion efficiency, less pollutant emissions, quick start and stop, flexible operation, and so on [28]. To strengthen safety supervision and management of natural gas generation, improve the level of safe and reliable operation of the unit, and promote healthy development of the natural gas industry, the National Energy Board has carried out specific regulatory actions for natural gas generators running safely, and has revealed current problems in gas-fired generation including natural gas distributed generation. As shown in Figure 1, there are several aspects:

- (1) The core technology of natural gas generation has not been fully mastered, which restricts the development of natural gas in the power generation industry [29]. At present, compared to the foreign enterprises, although domestic enterprises are capable of manufacturing and assembling gas generators, as to the overall design and key technologies such as thermal materials manufacturing, there is no substantive breakthrough. Gas turbine burner and other hot parts can only be imported, so when parts fail, depot maintenance is unavoidable, which always causes higher expenses for repair and maintenance and boosts the operating cost.
- (2) The problems of gas equipment design and manufacturing quality affect the reliability of the unit. In recent years, there are problems in the quality of domestic natural gas generator design and manufacturing. For example, the frequent failures in compressors, burners, and thermal path parts, generators, natural gas systems resulted in a shortened actual running time and less efficiency [30].
- (3) The units failing to meet operational requirements and environmental conditions affect the equipment life. Most of the domestic natural gas generating electricity units needs to introduce foreign technology and cannot meet the domestic operating mode and operating environment [31]. For the reasons of peak load shaving or the difference in gas supply types, domestic combustion engines have to start and stop frequently leading to problems in unit parts, and shortens the maintenance periods and service life, which greatly reduces the operating efficiency.

- (4) There are weaknesses in natural gas grid-connection operation, affecting safety in production [32]. At present, domestic natural gas distributed generation model is still in its preliminary demonstration stage with the manufacturing immaturity of key parts and system integration. There still are lots of work to be done, such as the analysis and conclusion for organizational design, construction installation, operation, maintenance, safety management, etc.
- (5) Supporting policies and standards need to be further improved. The price of natural gas is the decisive factor influencing the economy of natural gas power generation projects. However the unified feed-in tariff mechanism of natural gas power has not been formed yet. The natural gas price is still in the status of ‘one price for one plant’ or ‘one price for one generator set’, and the price is generally higher than the feed-in tariff of coal. Due to the high natural gas price (3–4 yuan/M³ = 0.43–0.58 dollars/M³), the feed-in tariff of natural gas units runs up to 0.7 yuan/kWh (0.101 dollars/kWh), while the feed-in tariff of coal-fired units is 0.3 to 0.4 yuan/kWh (0.043–0.058 dollars/kWh). In addition, natural gas transportation needs the arrangement of pipelines, and the cost will increase greatly. Therefore, a lot of power generation enterprises rely on government subsidies to keep running. After the price reform in 2013, the market growth of natural gas power generation in China slowed significantly without any increase in government subsidies. However, based on the current standard of subsidies, natural gas power generation is facing pressures from continuous increases of the gas price, and pipeline natural gas and electricity are administrative pricing by the government, which would affect enterprises’ production [33]. In addition, natural gas generators are always used as peak adjusters, and the natural gas power generation peak-shaving compensation mechanism has not been established. Meanwhile, the technical standard system has not been improved, including natural gas power plants’ construction, equipment installation and construction specification, and operation and management specification, which will affect the further development of the natural gas distributed generation industry.

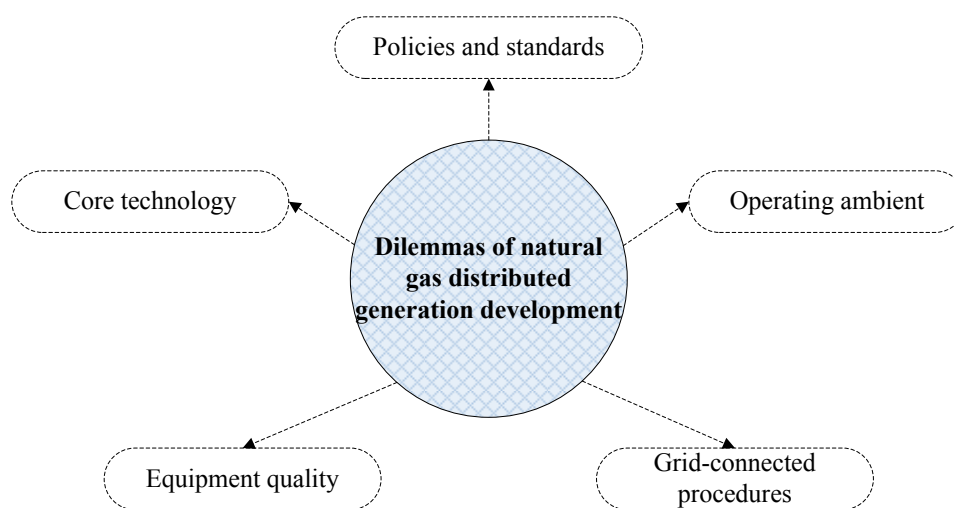


Figure 1. Dilemmas of natural gas distributed generation development.

3.2. Photovoltaic Distributed Generation

In 2014, Solarbe Photovoltaic Network and Shine Magazine hosted a forum on photovoltaic cell modules’ innovative technology and power plant application technology in Shanghai. In the forum, the first batch of demonstration projects established in late 2013 and early 2014 were investigated thoroughly. It was found that there were several problems in photovoltaic distributed generation, mainly including the following aspects:

- High economic uncertainty. Roof space resource is affected by the Golden Sun demonstration project and local subsidies have not been implemented completely (or have not even been introduced). Moreover, the costs (including the time cost and capital cost) over the whole period remain uncertain.
- Lack of funds. Most commercial banks adopt a wait-and-see policy. “Comments on Financial Services Supporting the Photovoltaic Distributed Generation” (NEA File [312]) has not been carried out.
- Defective construction. Affected by the Golden Sun demonstration project, domestic PV distributed generation projects have not been implemented perfectly at the beginning. For example, roof space resources are abused, the actual generation effect is not good, quality assurance and risk transfer mechanisms are not established, and related standards and effective surveillance measures are lacking. In addition to the above questions, there is no clear functional distribution responsibilities and technical support for each service party.
- Unable to be completed. It was planned to build 18 demonstration parks, but until now, none of them have been started yet.
- Lack of sustainability. Since the local governments have poor predictive knowledge of the sustainable development within the area under their jurisdiction, they cannot deal with the challenges of PV distributed generation.

In addition to the above problems, there are still other problems related to the elements of PV distributed generation, as shown in Figure 2. The following will be a detailed analysis.

- (1) The generation cost: Distributed generation is characterized by small capacity. The smaller the capacity of each project is, the higher the unit cost will be. Even for a megawatt-class distributed generation project, its unit cost is around 0.8 yuan/kwh (0.116 dollars/kwh) generally. Considering the PV generation period (from 8 a.m to 4 p.m), the weighted average price of electricity consumption for industry and commerce is 0.7–0.9 yuan/kwh (0.102–0.131 dollars/kwh), so the price advantage of PV distributed generation is not obvious. Even with the subsidy of 0.42 yuan/kwh (0.061 dollars/kwh) granted by the national government, the return on investment is still not very high, and the payback period is usually 6–8 years [34,35].
- (2) The ratio of electricity for the private use: According to the principle that the electricity generated is mainly for private use and the rest is connected to the grid, users who sell electricity generated to grid companies can only get the benchmark feed-in tariff of coal desulfurization of 0.25–0.52 yuan/kwh (0.036–0.075 dollars/kwh). Even with the subsidies of 0.42 yuan/kwh (0.061 dollars/kwh), it is still much lower than the electricity price for the private use. Therefore, to get the highest rate of return, a higher ratio of electricity for the private use is better. Generally, the minimum ratio is not lower than 70%.
- (3) The tariff settlement: To maximum the benefits of PV distributed generation projects, it is important to insist on the principle above [36]. If the project is invested in by a third party and operated through the EMC (Energy Management Contracting) model, the benefits will be shared with the owner of the roof, which means that the owner of the roof should settle the current electricity bill according to the EMC agreement monthly. However, in China’s peculiar business environment, EMC agreements are not enough to control the tariff settlement risks. Thus, how we control the tariff settlement risks becomes a major concern of investors of PV distributed generation projects.
- (4) Filing, application of access to the grid, subsidy payment, and so forth: Because of the introduction of the “Provisional Rules on PV Distributed Generation Projects”, local related departments have rules to follow and current policy risks are relatively low. In terms of the subsidy payment of the grid, if the project is invested in by a corporate juridical person, then there will be no need to invoice, but the value added tax (VAT) should be reduced by half [31]. Although the VAT policy has been laid out by the State Administration of Taxation, the implementation situations vary from

area to area. Therefore, the local taxation departments should reach a common understanding and implement the policy properly. In addition, if the project (such as a household PV distributed generation project) is invested in by natural persons, there are complicated invoice procedures for the issued invoice, which is the key issue of the subsidy payment.

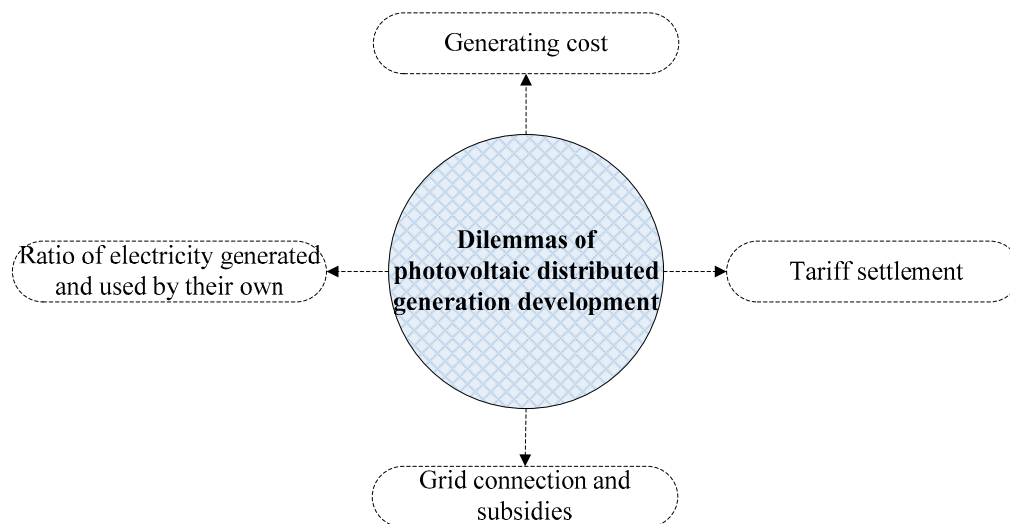


Figure 2. Dilemmas of photovoltaic distributed generation development.

3.3. Distributed Wind Power Generation

In the “Notice on Printing and Issuing Guidance on Development and Construction of Distributed Wind Power Generation Projects” published by the NEA, the definition of distributed wind power generation, the conditions of access to the grid, and the operational management of projects are given clearly. In July 2012, the NDRC (National Development and Reform Commission) published the 12th Five-year Plan of Renewable Energy, which puts forward that centralized and distributed projects should be developed and that distributed wind power generation connected to the grid should be supported. In July 2013, the “Provisional Rules on Distributed Generation” was published, which gives specific measures of construction management, access to the grid, and operational management of the distributed generation projects. Also, it imposes a liability for the grid to purchase the distributed generation. However, the details of these policies are not perfect, and some related regulations have not been established yet. As shown in Figure 3, they mainly including the following aspects:

- (1) The technical standards of distributed generation are imperfect. Currently, the standards of testing and access of distributed generation to the grid are relatively completed, while the technical standards for distributed wind power to the grid has only one drafted edition for approval, in which the technical standards mainly involving the grid synchronization test of wind turbines was stipulated and needs to be perfected.
- (2) The influences of the access of distributed generation to the grid [37]:
 - Flow changes: Traditional large-scale centralized power is transmitted by high voltage over long distances, while distributed wind power generation is fed into the grid directly which turns the tideway from two-way to one-way.
 - Relay protection: The access of distributed generation turns the distribution network to a multi-power network, which will have an impact on some of the existing protection systems, fault current, traditional current protection with three stages, and automatic reclosing.
 - Islanding effect: The islanding problem is defined as a continuation of operation of a grid-connected inverter after the grid has been turned off. Under the fault condition, an

island condition with power generation and consumption is undesirable for a number of reasons including safety hazards to utility personnel, and potential damage to the equipment.

At present, there is an absence of a perfect response mechanism to the above problems. Therefore, China should further strengthen defense and response measures, establish a risk prevention mechanism, and make detailed relevant standards and regulations of distributed wind power generation.

- (3) The subsidies and purchasing policy are inadequate. After the implementation of the ‘Renewable Energy Law’ in China, the “Provisional Rules on Special Funds of Renewable Energy Development” was published by the Ministry of Finance in May 2006, which makes relative general provisions on the focus of support enterprises, application and approval of the special funds, financial management, system of the appraisal and supervision, and so on. However, these Provisional Rules do not specify the fund’s size, the application procedures, and the use details of the funds. As a result, too many unclear factors with poor operability prevent the implementation of the Provisional Rules. Additionally, the government will reduce the subsidies for wind power in the future. In order to make distributed wind power generation participate in the market competition, it is crucial to control the investment and reduce the equipment price [38].

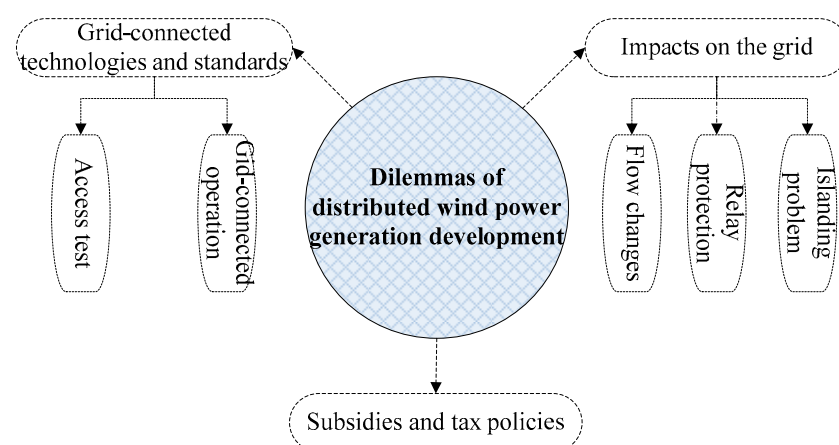


Figure 3. Dilemmas of distributed wind power generation development.

4. Recommendations on Policies

4.1. Practical Implications

(1) Natural Gas Distributed Generation

From Section 3.1, we can see that currently, the main problems of natural gas distributed generation are focused on the technology and subsidies, in which the former is more serious. To solve the above problems, the corresponding recommendations are proposed as follows (Figure 4):

- The natural gas market in China is in a rapid development period. Along with the advancement of marketization and the perfection of relevant laws, regulations, and policies, the market will be gradually open to all kinds of capital in society. Foreign enterprises have natural gas sources, technologies, and capital, all of which are important for the natural gas market in China. Using these advantages, foreign enterprises could cooperate with old brand central enterprises and private enterprises with strong economic strength, and could gradually penetrate into the natural gas downstream market in China. This could be the main strategy for foreign investments recently. From the national side in China, there must be unified planning and massive capital

investment (allowing for joint ventures and cooperation) to strengthen technology development. This industry should master key technology to produce natural gas generating sets suitable for the Chinese power network and other external environments, which can reduce maintenance costs while increasing the efficiency of the sets.

- Learn from foreign experience of natural gas distributed generation, make a natural gas distributed generation plan, and establish a standards system suitable for China's conditions.
- Improve related policies and regulations. Distinguish between different types and scales of users at different times of the day to apply differential pricing. Provide a supporting compensation mechanism for the natural gas power price, and adjust the compensation according to the natural gas price, operation period (such as peak shaving) of the natural gas generating sets, and other costs.

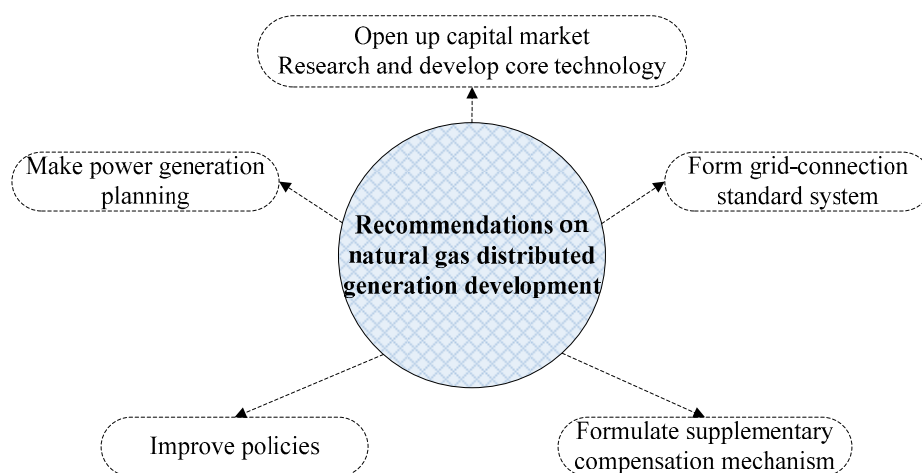


Figure 4. Recommendations on natural gas distributed generation development.

(2) Photovoltaic Distributed Generation

For the problems of photovoltaic distributed generation such as high economic uncertainty, defective construction, and the lack of sustainability mentioned in Section 3.2, some corresponding recommendations are proposed as follows:

- The local governments should issue detailed rules and regulations on photovoltaic distributed generation, in order to ensure the operation of the 2014 to 2015 Plan and have the sustainability of the 2016 to 2020 Plan.
- The local governments should maintain the rules and regulations in an open, fair, and impartial manner.
- China should start photovoltaic funds and P2P lending platforms.
- Control the quality and risks during the construction and operation of the projects, in order to increase the commercial certainty.
- The local governments should achieve harmonization with the parks, in order to ensure the efficient implementation of policies.

For the problems mentioned above relating to the elements of PV distributed generation, the corresponding recommendations are proposed as follows (Figure 5):

- To reduce the generation cost, upstream and downstream firms of crystalline silicon are required to make joint efforts, and continuous R&D (research and development) investment is also required to reduce the manufacturing costs and improve the generation efficiency.

- Risk management of the ratio of electricity for the private use is related to the design of the system capacity and the choice of the roof owner in the initial project stage. Therefore, despite adopting contracts or credit guarantees, the investors should pay more attention to this kind of risk.
- For the risk management of the tariff settlement, the third-party investors can choose to: design appropriate insurance products with insurance companies; apply for guarantees of the projects to the parent company; unify various small projects as a whole according to the law of large numbers to spread risks; endorse projects through the local governments; set up a joint venture with the owner of the roof to ensure the safety of the benefits. These methods have both merits and demerits. Thus, it is important to find a risk control method suitable for the investors and the owner as well as the characteristics of the photovoltaic distributed generation.
- For the subsidy payment, the current practice is that local grid companies pay the coal desulfurization and subsidies of distributed generation in advance, then pay the other half of the VAT after the invoice is issued. Furthermore, a new method is expected to solve this problem.

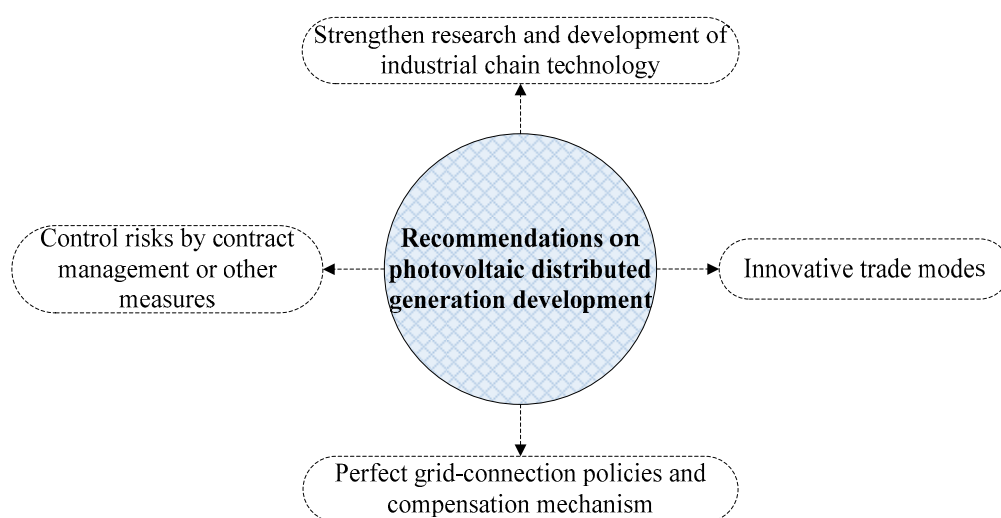


Figure 5. Recommendations on photovoltaic distributed generation development.

(3) Distributed Wind Power Generation

From Section 3.3 we can see that currently, the main problems of distributed wind power generation are focused on the technical standards of access to the grid and subsidies. To solve the problems above, recommendations are proposed as follows (Figure 6):

- For the technical standards of access to the grid, there are various requirements for wind turbines. The standard proposes that distributed wind power generation is different from traditional wind power generation, and the wind turbine design is required to meet local conditions. However, current distributed wind power generation projects in China are located in the areas with third-level and forth-level wind resources, so China has to increase R&D efforts of low-speed wind turbines and accumulate experience from practice. Technologically, there are many problems to be solved, such as site selection of wind farms, power quality, power adaptability, self-control of active power and reactive power, islanding of wind turbines, which requires R&D efforts and related technical standards.
- For the policies on distributed wind power generation, China should improve the systems of subsidies of renewable energy which adapt the development scale of wind power generation. Furthermore, it should define the responsibilities of grid companies to the development of renewable energy, implement the acquisition policy of renewable energy and development plan

of wind power generation, encourage various forms of investment, and meanwhile ensure a reasonable electricity price.

- For the construction of distributed wind power generation projects, local governments and energy authorities should provide wind data for the resource appraisal of distributed wind power generation, in order to accurately analyze the wind resource of distributed wind farms. Meanwhile, the feasibility study report should include reports of soil and water conservation, environment protection, safety assessment, and energy audit, in order to simplify the approval procedure and increase the working efficiency.

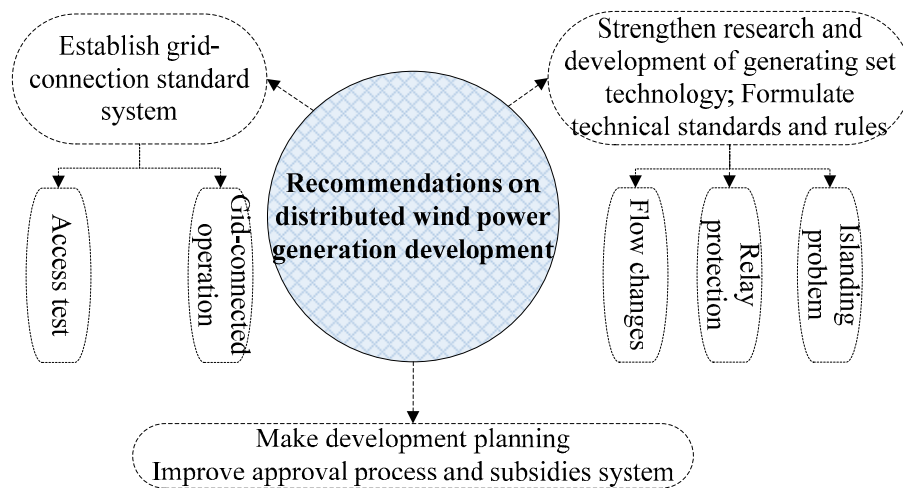


Figure 6. Recommendations on distributed wind power generation development.

4.2. Future Planning

With the development of distributed generation, both the power system structure and the operation management mode of the electric power industry will be changed. The future power system should be more similar to the modern business system. In this new system, based on the traditional or emerging online trading platforms and according to the trade and operation rules, different types of electricity generators, power grid enterprises, power suppliers, and power users could carry out the wholesale, retail, or direct power purchase transactions under the supervision of the government. Different from other business models, due to the real-time balance of electricity, it is necessary to set up independent scheduling agencies and trading platforms to process the trade application and to ensure stable operation of the power grid.

Because the distributed generation is at a small scale and scattered, it is difficult to promote its development by means of executive orders. The Chinese government should eliminate the institutional obstacles to create a good market environment for the distributed generation development, attracting different investors to participate in the investment, construction, and operation of distributed generation. Relevant measures are as follows.

(1) Perfecting Laws and Regulations

The Chinese government should revise the electric power laws and relevant regulations, supporting the development of distributed energy, clarifying its legal status, and establishing and improving the standards and specifications of grid access and grid-connection operation, allowing distributed generation operators to deal with users directly.

(2) Making Price Policy and Fiscal Policy

Firstly, it is necessary to promote the electricity market reform so as to form a good market competition environment. Secondly, the Chinese government should make reasonable fiscal and

taxation policies. Levying an environment tax and carbon tax could adjust the cost gap between fossil energy power generation with high pollution and high emissions and clean energy power generation with low pollution and low emissions, in order to improve the market competitiveness of the distributed energy. Thirdly, for distributed energy with higher costs, some targeted subsidies and support policies are needed.

(3) Encouraging Multi-Party Participation

It is significant to encourage state-owned energy enterprises, local state-owned enterprises, private enterprises, and foreign enterprises to participate in the construction of distributed energy, vigorously support the development of professional energy services companies, boost a group of third party certification bodies in the professional design and testing, in order to form a pattern of different parties involved in the development of distributed energy.

(4) Promoting the Collaborative Development among Distributed Generation, Micro-Grid Technology and Smart Grid Technology

The distributed generation technology is helpful for making full use of clean renewable energy. However, large-scale grid-connection of distributed generation will have great impacts on the operation security and stability of the power system. The micro-grid technology could provide interfaces for the grid-connection operation of various kinds of distributed power supplied by different structures, which is an effective way to solve the grid-connection problem of distributed generation. A smart distribution network could realize the flexible access of distributed power supply and the safe, reliable, and economic operation of the power system by managing the micro-grids effectively. Therefore, in the future various distributed power supplies could form different micro-grids and meanwhile it will be developed with the smart grid synergistically.

5. Conclusions

In this paper, firstly, the application situation of natural gas distributed generation, photovoltaic distributed generation, and distributed wind power generation are analyzed respectively. Then, defects of policies and obstacles to the development of distributed generation are studied through analyzing the general situation, scale, and performance of the distributed generation projects. In the end, the related recommendations are proposed.

The main conclusions are as follows:

- (1) For natural gas distributed generation, the main problems are the lack of core technology, poor quality of the equipment, unstable operating environment, weak grid connection, and imperfect policies and standards. Therefore, China should strengthen technology development, make a development plan for natural gas distributed generation, establish a standards system, and improve related policies and regulations.
- (2) For photovoltaic distributed generation, main problems are high generation cost, low ratio of electricity generated, low self-use proportion, high risk of tariff settlement, and imperfect subsidies. Therefore, China should increase investment on R&D, optimize the industry chain, strengthen risk control and credit guarantee of the projects, improve subsidies policy, and simplify working procedures.
- (3) For distributed wind power generation, the main problems are the lack of technical standards of grid connection, acquisition policies, absence of response mechanisms, and imperfect subsidies. Therefore, China should increase investment on R&D of low-speed wind turbines, find problem solutions such as site selection, power quality, power adaptability and islanding, establish technical standards of grid connection, improve the systems of subsidies, and strengthen coordination of different departments, in order to further promote the healthy development of distributed wind power generation.

The government in China launched a series of policies focused on distributed generation in 2012 and 2013. It can be seen that distributed generation in China is facing unprecedented opportunities for development. Meanwhile, there are still many institutional obstacles to be broken. Based on the actual projects of distributed generation, this paper analyzes the barriers of technology, grid access, and support policies in the process of construction and operation. In the future, some important issues need to be further researched, including the safe operation of grid-connection, cost recovery time, power generation income instability, etc. The Chinese government should draw lessons from international experience, combined with national conditions to improve the subsidy policies, guide the planning information, construct the standard system, and create the business model and operation management mechanism.

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