IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received March 18, 2019, accepted March 22, 2019, date of publication April 11, 2019, date of current version April 29, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2910226

Pricing Mechanism for Natural Gas Distributed Generation Based on Classified Benchmark Price

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ABSTRACT Natural gas distributed generation (NGDG) has been widely concerned, promoted, and applied all over the world because it has advantages such as high comprehensive energy efficiency, environmental protection, sustainable and stable power supply, and so on. It also has become an important part of the energy strategy in China. Unfortunately, most NGDG projects on production in China do not operate very well due to several reasons such as high investment and operation cost, long load cultivation period, and so on. Thus it is quite urgent to design one pricing mechanism suitable for NGDG to meet the need in the transition stage before fully power marketization and rationalize and standardize the feed-in tariff of NGDG. This paper proposes a one-part tariff mechanism for NGDG based on classified benchmark price, which solves the problem that most NGDG projects have to refer to the benchmark tariff of local coal power plants due to the absence of NGDG pricing benchmark. Meanwhile, according to the characteristics of energy projects and regions, the mechanism establishes a two-dimensional classification scheme for NGDG, sets up the benchmark data and the method to determine the values, and then put forward the benchmark tariff of NGDG. It also changes the ''one plant one price'' approach in some areas. Finally, using the tariff mechanism and operating period price model, we calculate the benchmark tariff of all kinds of NGDG in several typical regions. The results can be referenced for research and NGDG tariff mechanism establishment in various countries.

INDEX TERMS Natural gas, distributed energy resource, one-part, pricing mechanism, benchmark price.

I. INTRODUCTION

Natural gas distributed generation (NGDG) can realize the stepped utilization of energy through combined cooling heating and power system (CCHP), which makes the comprehensive energy utilization efficiency over 70% [1]–[3]. It has been widely concerned, promoted and applied all over the world because it has advantages like high comprehensive energy efficiency, environmental protection, sustainable and stable power supply, etc [4]–[8]. As of 2016, more than 6,000 distributed generation (DG) projects have been built in the United States, most of which are NGDG projects [9], [10]. Japan, which regards resource utilization efficiency improvement as an important principle to develop energy industry, is one of the fastest growing countries in NGDG. NGDG in the UK is growing rapidly now and is mainly applied to commercial and public buildings, generating more than 7% of total power generation. Among the EU countries, Denmark has the highest utilization rate of NGDG in the world. More than 80% of regional heating energy is generated by combined heating and power system (CHP), and over 50% of total power generation is from DG; Germany expects that NGDG's generation will reach 25% of the total power generation by 2020.

In China, along with the increasing environmental pressures [11], power structure adjustment, and supply side reform in energy and power, NGDG has become a common development demand of the government and society, especially in economically developed regions lacking environmental capacity like Pearl River Delta, Yangtze River Delta and Beijing-Tianjin-Hebei [12]. Promoting NGDG projects is an effective measures for local governments to achieve energy conservation, emission reduction and energy structure improvement [13]–[14].

However, compared to the countries like US and Japan etc. which have advantages e.g. gas price [15], advanced

The associate editor coordinating the review of this manuscript and approving it for publication was Salvatore Favuzza.

technologies [16], and relatively high acceptance rate of NGDG in the markets, NGDG is still in initial development stage in China. Most NGDG projects on production don't operate very well due to several reasons like high investment and operating cost, long load cultivation period [17]–[19], etc. In order to support the promotion and development of NGDG, it becomes quite urgent to rationalize the price of NGDG products. Considering the limited price adjusting room due to the close linkage between people's daily life with cooling and heating prices, and the immature development of NGDG as power market in China is just in the early stage, it's inappropriate for NGDG to participate in market-oriented trading yet [20]. During such a transitional period, establishing a scientific and rational tariff mechanism is crucial to the healthy and orderly development of NGDG.

Most countries utilize fixed feed-in tariff of NGDG in their early development stages [21]. In US [22] and Japan, lower feed-in tariffs were utilized in order to promote the comprehensive utilization of DG. UK has set up corresponding prices according to different technology types and installed capacities [23]. Japan also establishes a complete policy system that covers laws, regulations, subsidies and tax incentives etc. [24]. In China, on the contrary, there is still no uniform pricing policy for NGDG. In some areas, price of conventional gas generation is simply referenced to when determining the price of NGDG in practice. Usually, the electricity price of NGDG is set to be lower than the benchmark price of regional coal-fired power generation, or be the average purchase price of local power grid enterprise plus 0.35 CNY. This pricing mechanism cannot reflect the permitted costs and reasonable benefits of NGDG, and it also brings negative impact on the healthy development of NGDG industry. In some areas, on the other hand, electricity price of NGDG varies from plant to plant. This approach, which has very complicated process to work out and get approval, cannot guide energy projects to improve techniques and reduce costs effectively as well.

In recent years, some researches have been done on the price model of natural gas power generation in China. Reference [25] studied the relationship between gas price and electricity price in the US, Beijing and Shanghai, and proposed that the result was quite unreasonable when comparing the two cities', e.g. Beijing and Shanghai, electricity price ratio with the gas price ratio. The electricity price was relatively lower than gas price. References [26], [27] analyzed interrelation between gas and electricity, and further proposed a natural gas power generation pricing method coupled with gas price. Reference [28] pointed out that the prices of natural gas fired generation should be determined according to the categories of different regions' practices and project characteristics [28]. Reference [29] found that the problem that peak load compensation and electricity price mechanism could not cover the costs. This paper also clarified the boundary between paid and unpaid peak-load regulation, proposed a two-part tariff model accordingly. References [30], [31] investigated the challenges that DG industry is facing, and proposed some advice of the policies including how to work out proper electricity price and provide necessary subsidies. References [32] and [33] summarized the economics of natural gas power generation, proposed the principles and approaches of pricing model. The two papers pointed out the comprehensive pricing mechanism should consider in terms of environmental protection and auxiliary services. Reference [34] proposed that pricing mechanism of NGDG should consider the cost allocation among cold, hot and electricity. Unfortunately, the proposed mechanism is just for 'one plant with one price' model and has limitations in the promotion and application of the tariff mechanism.

According to our investigations on current policies and researches, there are few researches related to pricing mechanism for NGDG in China, and most of them only studied gas electricity price and peak load price. Although a few researches adopted the approach of 'one plant with one price', there is still no uniform regulations and standards. This will bring negative impacts on the development of NGDG, and cannot fully utilize the characteristics of NGDG like high comprehensive energy efficiency and continuous power supply etc. Therefore, we propose a one-part Tariff mechanism for NGDG based on classified benchmark price in this paper. First, we establish a two-dimensional classification scheme for NGDG, and classify it by projects and regions. Then, considering national policies and regional characteristics, we propose a benchmark pricing mechanism for various types of NGDG with benchmark data and the method to finalize the data. Finally, we use the model to calculate the feed-in tariff of NGDG projects in several typical regions, and compare the income level with which under the current pricing mechanism.

II. PRICING MECHANISM DESIGN FOR NGDG

A. FUNDAMENTAL PRINCIPLES OF PRICING MECHANISM DESIGH

According to the development laws of market economy and current status of NGDG industry, below basic principles need to be considered when design pricing mechanism [35].

i) According to clause 36, China Electric Power Law, electricity pricing should properly compensate for the costs, get the reasonable income, and include the taxes. So feed-in tariff of NGDG should consist of three parts, the permitted cost, reasonable income and taxes.

ii) In principle, pricing mechanism should be consistent with the current feed-in tariff mechanism for other types of generator sets in terms of price patterns, defining method, adjustment mechanism and allowed return on investment (ROI).

iii) The pricing mechanism should be easy to understand and work out, and regulatory costs of the mechanism should be as low as possible.

B. PRICING MECHANISM FOR NGDG

Target to solve the current problems of NGDG like bad profitability and immature power market, we propose a one-part pricing mechanism for NGDG based on classified benchmark.

1) ONE-PART PRICING MECHANISM

One-part pricing mechanism is adopted due to the following reasons:

i) One-part price is more clear and transparent. Rather than calculating capacity price and energy price separately based on fixed costs and variable costs, it only has one price that comprehensively reflects generating cost including permitted income. And it is more convenient for pricing administration to supervise.

ii) Adopting one-part price can keep pace with other types of generator sets in pricing mechanism. One-part pricing mechanism is the most widely used pricing mechanism in China, which facilitates the transaction and settlement between supply and requisitioning parties.

iii) It is easy to operate in practice. As the cost of NGDG projects will gradually reduce along with the nationalization of related technologies and the promotion of gas price reform, it is much easier to adjust one-part tariff than two-part tariff.

2) TWO-DEMENSIONAL CLASSIFICATION SCHEME

In the Chinese power industry, NGDG projects are divided into building-type gas distributed systems (BGDS) and regional-type gas distributed systems (RGDS) by supply range. Power of BGDS is generally provided by gas engines, while the power source of RGDS can be selected between internal combustion engine and aero-derivative gas turbine. The equipment, operation and maintenance cost of distributed energy projects depends on the type of prime motor.

To summarize, there are large differences among NGDG projects. It is necessary to work out the prices according to the type of project and regional characteristics.

3) BENCHMARK FEED-IN TARIFF

At present, benchmark feed-in tariff has been applied to coal-fired power, hydropower, wind power and photovoltaic power generation. Benchmark price promotes the optimal distribution of resources and rational flow of capital [36], pushes generation enterprises to enhance internal management, ensures fair competition among companies, and lays the foundation for the power market. However, in China, due to the large differences of gas power generation enterprises, the benchmark price has not been applied to gas power generation yet.

With two-dimensional classification, the differences among the same type NGDG projects become relatively small. This makes the application of benchmark feed-in tariff feasible. Based on operating period price, provincial benchmark price can be set up combining state related standards, policies and regional average levels.

III. BENCHMARK TARIFF FOR NGDG BASED ON TWO-DIMENSIONAL CLASSIFICATION

A. TWO-DIMENSIONAL CLASSIFICATION

The two-dimensional classification scheme of NGDG projects is shown in Figure 1.

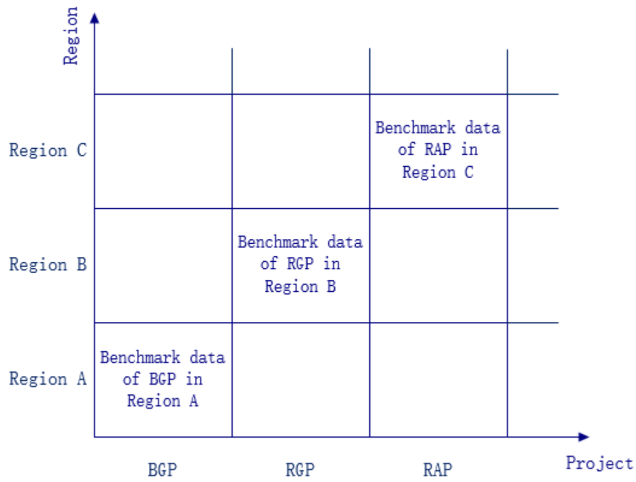

FIGURE 1. The two-dimensional classification scheme of NGDG.

1) ENERGY PROJECT DIMENSION

According to the costs of the projects' construction and operation, energy projects can be classified by the type of power supply and prime mover.

Following the industry classification habits, we divide the projects into building-type projects and regional-type projects according to the type of power supply. Because of different load scenario and supply radius, the costs of building-type projects and regional-type projects vary largely. Gas engine project is usually small and often has the capacity within 20MW. While the aero-derivative gas turbine project, on the contrary, normally has larger capacity that exceeds 100MW. When investing a NGDG project, besides generator set, we need to choose suitable waste-heat recovery equipment, cooling and heating equipment according to cold and heat load requirements. Meanwhile, it is also necessary to set up complete control system and supporting equipment. Therefore, the smaller installed capacity a project has, the higher unit cost it has. In addition, price of prime mover is also an important factor affecting the project unit cost. Now in China, gas engine costs about 3.5-4.5 million yuan/MW, while aero-derivative gas turbine costs 2.5-3 million yuan/MW.

As NGDG projects in China heavily rely on imports on the procurement of major equipment, the operation and maintenance cost is always expensive. Now the operation and maintenance cost of gas engine is normally determined according to the repair times of major, medium and minor repair, while aero-derivative gas turbine projects are more likely to sign a long-term agreement and pay annual fixed fees as specified in agreements.

In summary, NGDG projects are divided into three types according to energy project dimension: Building-type Gas engine Projects (BGP), Regional-type Gas engine Projects (RGP) and Regional-type Aero-derivative gas turbine Projects (RAP). The costs of equipment, operation and maintenance are shown respectively in Table 1.

TABLE 1. Equipment, operation and maintenance cost of NGDG project.

Type	Equipment cost/ (thousand yuan /kW)	Operation and maintenance cost / (million yuan/set/year)	
		Maintenance cost of prime mover	Annual maintenance cost for other power equipment and systems
BGP	Above 20	1. 5 to 1.8	1 to 2
RGP	Above 15	1.5 to 1.8	1to 2
RAP	6 to 8	5 to 8	2 to 4

2) REGION DIMENSION

From region dimension, this paper has mainly considered the regional differences.

Different regions have different gas sources and economic development status. There are also differences in the factors of gas price, lower calorific value of gas, users' affordability to cold and heat price, payment level of employees, additional tax rate etc. So when calculating benchmark price, we need to consider the actual conditions of different regions, and set up benchmark price and calculating method suitable for the regions.

B. CLASSIFICATION AND EVALUATION OF BENCHMARK DATA

Benchmark data include common fundamental data, project data and regional data.

1) COMMON FUNDAMENTAL DATA

Common fundamental data is the common benchmark data used in the national NGDG benchmark price measurement and calculation, whose values are shown in Table 2.

2) PROJECT TYPE DATA

According to the classification, benchmark values of project type data are shown in Table 3.

3) REGIONAL DATA

During the benchmark price measurement process of NGDG, partial benchmark data will be different due to regional diversity.

i) Gas price

If the region has already unified the gas price for natural gas power generation, gas price benchmark can take this uniform price. For regions where there is no uniform gas price for gas power generation, the gas price benchmark can take the average gas price of regional gas companies.

ii) Heat and cold price

It can be finalized by the type of prime mover, and be valued as the average price in the region. The benchmark values of BGP and RGP are usually higher than those of RAP.

iii) Lower calorific value of gas

The benchmark value equals the local mean level.

TABLE 2. Benchmark values of common fundamental data.

Data	Benchmark values and corresponding selection method
Operating period	20 years
IRR (Internal rate of return)	0%、3%、5%
Parameters of construction period	The construction period is 2 years, 55% of annual capital will be used each year, capital ratio is 20% and the capital will be invested in the first year.
Repayment period and method	Repayment period is 13 years，linear repayment.
Generation utilization design value	6000 hours
Load parameters of cultivation and maturity period	Cultivation period is 4 years. During the cultivation period, the comprehensive energy efficiency is 50%, the generating equipment availability hour is 55% of the design value. During the maturity period, the comprehensive energy efficiency is 70%, taking 70% of the design value in the first year to second year, 90% in the third to fourth year, 100% in the fifth year and after.
Production ratio between heat and cold	1:1
Cold and heat loss	5%
Depreciation way and residual rate of fixed asset	The fixed asset accounts for 60% of the total investment, Depreciation period is 15 years，linear depreciation, residual rate of fixed asset is 5%.
Staff quota	1 person/MW
Material costs	20 yuan/kW
Other expenses	30 yuan/kW

TABLE 3. Benchmark values of project type data.

Data	Benchmark value		
	BGP	RGP	RAP
Installed capacity	4×4.4MW	4×4.4MW	2×60MW
Unit cost	22 million yuan/MW	18 million yuan/MW	8 million yuan/MW
Recondition cost	**Gas engine:** Minor repair(2000 hours) : 0.3 million yuan/set Medium repair(6000 hours): 0.5 million yuan/set Overhaul(10,000 hours): 0.8 million yuan/set **Other power equipment and system**: 1~2 million yuan/set/year		**aero-derivative gas turbine :** 8 million yuan/set/year **Other power equipment and system**: 4 million yuan/set/year
Service power rate	10%	10%	5%
Gas consumption rate	$0.255Nm^3/kWh$	$0.255Nm^3/kWh$	$0.22\ Nm^3/kWh$

iv) Payment level

It includes employee wages, welfare, labor union funds, social insurance, etc. The value can take the average level of payment of local power industry.

v) Interest rate in construction and operating period

We can take the mean interest rate of local thermal power projects.

vi) Water

The water consumption is about 500 kilograms/MWh, and we will take the regional industrial comprehensive water price as the unit price.

vii) Tax rate

Taxes include Value-Added Tax (VAT), income tax, business tax and surcharge, whose rates are valued in accordance with the local policies.

IV. A ONE-PART TARIFF CALCULATION MODEL

A. OPERATING PERIOD PRICING MODEL

Symbols used in the model and their meanings are detailed in the appendix.

i) Product income

$$I = IE + IH + IC \tag{1}$$

$$\times \begin{cases} IE = Q_e \times P_e \\ IH = Q_h \times P_h \\ IC = Q_c \times P_c \\ Q_h + Q_c = \\ \quad \left[\eta\left(GEC \times V_f \times T \times V_{ca}\right) - 3600Q_e\right]10^{-6} \end{cases} \tag{2}$$

ii) Operating cost

$$TC = CF + CP + CR + CO + CM \tag{3}$$

$$\times \begin{cases} CF = GEC \times V_f \times P_f \times T \\ CP = GEC \times \beta_p \times P_p \\ CR = P_1 \times n_1 + P_2 \times n_2 + P_3 \times n_3 \\ CM = GEC \times P_m \\ CO = GEC \times P_o \end{cases} \tag{4}$$

iii) Financial cos

$$A = L \times C_r \times K \tag{5}$$

$$\times \begin{cases} C_r = \dfrac{r_1 \times (r_1 + 1)^{N_2}}{(r_1 + 1)^{N_2} - 1} \\ K = \sum\limits_{i=1}^{N_3} l_i (1 + r_2)^{N_3 - i} \end{cases} \tag{6}$$

iv) Taxes

$$R_\sigma = \left[IE \times \sigma_e + IH \times \sigma_h + IC \times \sigma_c - CF_i \times \sigma_f\right] \times \omega \tag{7}$$

$$R_{\delta i} = [I - TC - A \times r_1 / (1 + r_1) - Z] \times \delta \tag{8}$$

B. OPERATING PERIOD TARIFF CALCULATION MODEL

The electricity price satisfying (9) is the pre-tax benchmark price. This price plus VAT is the benchmark price we get.

$$NPV = \sum_{i=1}^{N_1} \frac{I_i + d_i - TC_i - A_i + R_{\sigma i} - R_{\delta i}}{(1 + IRR)^i} = 0 \tag{9}$$

$$d_i = \begin{cases} 0 & i \neq N_1 \\ \lambda \times D & i = N_1 \end{cases} \tag{10}$$

V. CASE STUDIES

The pricing mechanism proposed in this paper can be applied to all regions in China. When considering the regional dimension, only the regional data needs to be provided. After completing the region data and substituting all benchmark data into the model, we can calculate the classified benchmark tariff of NGDG.

NGDG in Shanghai has been growing rapidly and this makes Shanghai be in the leading position in China. Compared with many other regions, Shanghai has already approved the feed-in tariff of NGDG projects, and the price is relatively high among all provinces. For the purpose of easy comparison, we take Shanghai's NGDG as an example for further analysis.

Regional data need to be changed when considering the region dimension. As the calculation process of other region's NGDG is the same as which of Shanghai's NGDG, only the calculation result of benchmark tariff will be shown here.

A. CLASSIFIED BENCHMARK PRICE CALCULATION

Benchmark values of region data are as Table 4, while other values are shown in Table 2 and 3 above.

TABLE 4. Benchmark values of regional data in shanghai.

Region data	value
Gas price	2.628 yuan/Nm^3
Heat price of BGP and RGP	167 yuan/GJ
Heat price of RAP	100 yuan/GJ
Cold price of BGP and RGP	164 yuan/GJ
Cold price of RAP	141 yuan/GJ
Lower calorific value of gas	340000 KJ/Nm3
Salary cost	120 thousand/person
Interest rate in construction period and operating period	4.41%
Water price	3.65 yuan/t
Value-added tax rate of electricity	16%
Value-added tax rate of gas, heat and cold	10%
Income tax	25%
Business tax and surcharges	11%

1) ANNUAL COST IN OPERATING PERIOD

According to benchmark data setting and the operation period pricing model, annual cost of three types of NGDG projects can be calculated. When Internal Rate of Return (IRR) reaches 5%, cost in operating period are shown in Table 5-7.

2) BENCHMARK PRICE CALCULATION

According to operating period cost and formula (9)-(10), benchmark price with the target IRR 0%, 3% and 5% (assuming operating period is 20 years) can be calculated. Results are shown in Table 8.

3) SENSITIVITY ANALYSIS OF BENCHMARK TARIFF

Gas cost, accounting for about 70%-80% of the operating cost of conventional natural gas distributed energy projects, plays

TABLE 5. Operating Period Cost of BGP (IRR = 5%).

Year	1	…	6	7	…	20
Production						
Electricity (million kWh)	5.280		7.392	9.504		10.560
Heat (GJ)	30848		91254	117327		130363
Cold (GJ)	30848		91254	117327		130363
Auxiliary power rate (%)	10		10	10		10
Ratio of cooling and heat consumption (%)	5		5	5		5
Cost(million yuan)						
Furl cost	3.217		4.504	5.791		6.434
Water cost	0.010		0.013	0.017		0.019
Material cost	0.035		0.035	0.035		0.035
Salary cost	0.216		0.216	0.216		0.216
Maintenance cost	1.068		1.068	1.068		1.068
Business tax and surcharges	0.056		0.093	0.119		0.133
Amortization of construction cost	3.098		0	0		0
Other cost	0.053		0.053	0.053		0.053
Depreciation expense	1.549		1.549	1.549		0
Interest	1.423		0.876	0.766		0

TABLE 6. Operating period cost of RGP (IRR = 5%).

Year	1	…	6	7	…	20
Production						
Electricity (million kWh)	5.280		7.392	9.504		10.560
Heat(GJ)	30848		91254	117327		130363
Cold(GJ)	30848		91254	117327		130363
Auxiliary power rate (%)	10		10	10		10
Ratio of cooling and heat consumption (%)	5		5	5		5
Cost(million yuan)						
Furl cost	3.217		4.504	5.791		6.434
Water cost	0.010		0.013	0.017		0.019
Material cost	0.035		0.035	0.035		0.035
Salary cost	0.216		0.216	0.216		0.216
Maintenance cost	1.068		1.068	1.068		1.068
Business tax and surcharges	0.049		0.083	0.107		0.119
Amortization of construction cost	2.534		0	0		0
Other cost	0.053		0.053	0.053		0.053
Depreciation expense	1.267		1.267	1.267		0
Interest	1.164		0.717	0.627		0

TABLE 7. Operating period cost of RAP (IRR = 5%).

Year	1	…	6	7	…	20
Production						
Electricity (million kWh)	36.000		50.400	64.800		72.000
Heat (GJ)	92520		412272	530064		588960
Cold (GJ)	92520		412272	530064		588960
Auxiliary power rate (%)	5		5	5		5
Ratio of cooling and heat consumption (%)	5		5	5		5
Cost (million yuan)						
Furl cost	18.924		26.493	34.063		37.848
Water cost	0.066		0.092	0.118		0.131
Material cost	0.240		0.240	0.240		0.240
Salary cost	1.440		1.440	1.440		1.440
Maintenance cost	2.400		2.400	2.400		2.400
Business tax and surcharges	0.201		0.346	0.444		0.494
Amortization of construction cost	7.680		0	0		0
Other cost	0.360		0.360	0.360		0.360
Depreciation expense	3.840		3.840	3.840		0
Interest	3.528		2.171	1.900		0

TABLE 8. Benchmark tariff of NGDG in shanghai.

yuan/kWh		BGP	RGP	RAP
IRR=0%	Pre-tax	0.8320	0.7702	0.5909
	After-tax	0.9651	0.8934	0.6855
IRR=3%	Pre-tax	0.9136	0.8395	0.6216
	After-tax	1.0598	0.9738	0.7211
IRR=5%	Pre-tax	0.9716	0.8891	0.6438
	After-tax	1.1270	1.0314	0.7468

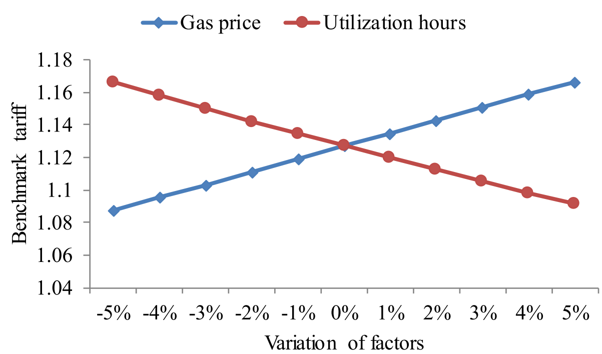

FIGURE 2. Sensitivity of benchmark tariff for BGP when IRR= 5%.

a crucial role in the economic benefits of energy projects. In the meantime, the utilization hours can reflect the overall utilization efficiency of NGDG project, and affect the benefit directly. Therefore, we take gas price and utilization hours as the two top factors to analyze the sensitivity of benchmark tariff. The sensitivity analysis results of the benchmark tariff for the three types of NGDG when IRR=5% (after tax) are listed below, as shown in Figures 2 to 4.

B. COMPARATIVE ANALYSIS WITH CURRENT TARIFF

IRRs of BGP, RGP and RAP under current tariff and calculated benchmark tariff are shown in Figure 5.

At present, tariff of NGDG in Shanghai is 0.759 yuan/kWh, which is very high among all provinces in China. However, the current tariff is not categorized by project type. Under this unified tariff, IRR of BGP is −7.7%, IRR of RGP is −5.69%, and IRR of RAP is 5.92%. If the subsidy is taken into account, the investment will be RMB 50 million according to the

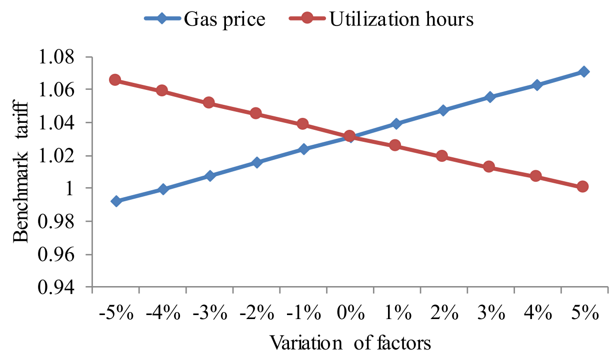

FIGURE 3. Sensitivity of benchmark tariff for RGP when IRR = 5%.

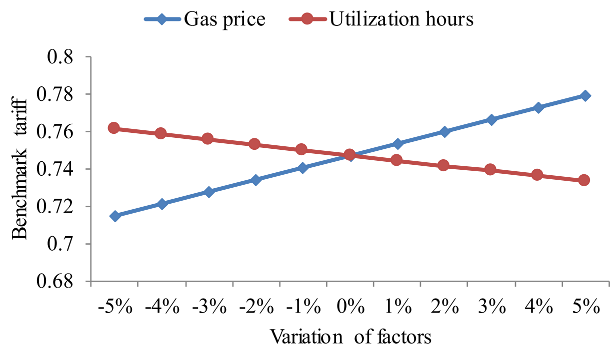

FIGURE 4. Sensitivity of benchmark tariff for RAP when IRR = 5%.

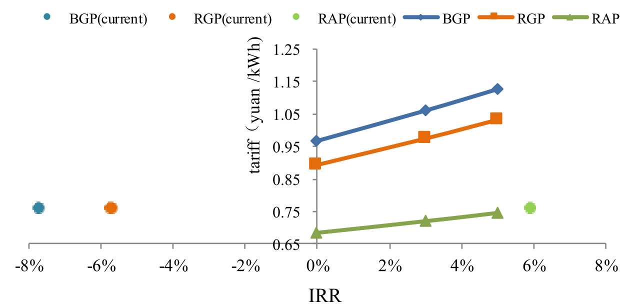

FIGURE 5. Comparison between benchmark tariff and current tariff.

highest standard of Shanghai NGDG subsidy, which will be included in the first year after production. In this case, IRR of BGP is −6.86%, IRR of RGP is −4.49%, and IRR of RAP is 6.74%. From the perspective of income, RAP can guarantee their basic income, but BGP and RGP are suffering heavy losses even if the subsidy is considered. These results demonstrates that the existing pricing mechanism has impacted the healthy development of NGDG, and needs to be adjusted urgently.

In contrast, benchmark tariff proposed in this paper has been classified by project type, i.e. BGP, RGP and RAP. Tariffs of these three NGDG types are calculated with the condition of IRR = 0%, 3% and 5%. Without considering the capital time value, we not only calculate the bottom line of price standard to avoid loss for NGDG projects, but also find the relationship between tariff and IRR, which provides supporting data for regions with high price tolerance to calculate tariff of NGDG.

TABLE 9. Cost and profit per kilowatt hour.

	Unit: yuan /kWh		
	BGP	RGP	RAP
Cost per kilowatt hour	1.1663	1.1093	0.7431
Gas cost	0.6770	0.6770	0.5533
Investment cost	0.3057	0.2501	0.1053
Salary cost	0.0264	0.0264	0.0245
Maintenance cost	0.1307	0.1307	0.0408
Water cost	0.0020	0.0020	0.0019
Material cost	0.0043	0.0043	0.0041
Other cost	0.0065	0.0065	0.0061
Business tax and surcharges	0.0137	0.0123	0.0071
Taxes per kilowatt hour	0.0644	0.0551	0.0246
Heat and cold profits per kilowatt hour	0.3681	0.3681	0.1652

TABLE 10. Gas source data in Beijing and Hubei.

Region	Beijing	Hubei
Gas price(yuan/Nm^3)	2.62	2.641
Lower calorific value of gas(KJ/ Nm^3)	35000	33500

TABLE 11. Benchmark tariff of NGDG in Beijing.

yuan/kWh		BGP	RGP	RAP
IRR=0%	Pre-tax	0.8023	0.7404	0.5727
	After-tax	0.9306	0.8589	0.6644
IRR=3%	Pre-tax	0.8840	0.8100	0.6035
	After-tax	1.0255	0.9396	0.7001
IRR=5%	Pre-tax	0.9422	0.8598	0.6258
	After-tax	1.0930	0.9973	0.7260

TABLE 12. Benchmark tariff of NGDG in Hubei.

yuan/kWh		BGP	RGP	RAP
IRR=0%	Pre-tax	0.8492	0.7874	0.6019
	After-tax	0.9851	0.9134	0.6983
IRR=3%	Pre-tax	0.9307	0.8566	0.6325
	After-tax	1.0796	0.9937	0.7337
IRR=5%	Pre-tax	0.9886	0.9061	0.6547
	After-tax	1.1468	1.0511	0.7594

C. PROFIT AND LOSS ANALYSIS

Cost and profit per kilowatt hour of NGDG projects in Shanghai is shown in Table 9.

According to Table 8 and Table 9, we can draw some conclusions as followed.

i) Gas cost, investment cost and maintenance cost are the main components of cost per kilowatt hour of NGDG projects, accounting for about 95% of it. Moreover, these three kinds of costs will bring different effects in NGDG projects. High tax expense leads to high cost indirectly, making benchmark tariff of BGP and RGP higher than which of RAP. All types of NGDG have much higher feed-in tariff than other types of generator sets such as coal, hydropower etc.

ii) Gas cost is the main portion of unit cost. High gas cost directly leads to high benchmark tariff. According to the calculation results, gas cost of NGDG in Shanghai has already exceeded the feed-in tariff of most other generator sets.

iii) Cold and heat gain of NGDG is still unsatisfactory. Cold and heat income of BGP accounts for 32% of the cost,

TABLE 13. Symbols used in the model.

Symbol	Explanation
I	Total income
IE	Income from electricity trading
IH	Income from heat trading
IC	Income from cold trading
Q_e	On-grid energy
Q_h	Heat supply
Q_c	Cold supply
P_e	Electricity price
P_h	Heat price
P_c	Cold price
η	Comprehensive energy utilization efficiency
T	Annual utilization hours
V_{ca}	lower calorific value of gas
TC	Operating costs
CF	Fuel costs
CP	Salary costs
CP	Maintenance costs
CM	Material costs
CO	Other costs
GEC	Generation capacity
V_f	Gas consumption rate of the unit
P_f	Gas price for gas power generation
β_p	Staff quota
P_p	Average level of payment
P_1	Costs of minor repair
P_2	Costs of medium repair
P_3	Costs of overhaul
n_1	Frequency of minor repair
n_2	Frequency of medium repair
n_3	Frequency of overhaul
P_m	Percentage of material costs
P_o	Percentage of other costs
A	Repayment of principal and interest
L	Project loan
C_n	Coefficient of investment recovery
K	Adjustment coefficient
r_1	Annual loan interest rate
r_2	Interest rate in construction period
N_2	Repayment period
N_3	Construction period
$L_1, l_2, \ldots, l_{N_3}$	Annual investment flow ratio in construction period
R_σ	business tax and surcharges
σ_e	Value-added tax rate of electricity
σ_h	Value-added tax rate of heat
σ_c	Value-added tax rate of cold
σ_f	Value-added tax rate of natural gas
ω	Surtax rate
R_δ	Income tax
Z	depreciation
δ	Income tax rate
NPV	The cumulative present value of net cash flow in operating period
IRR	Financial internal rate of return
N_1	Operating period
d	Recovery of fixed asset residual values
λ	Recovery rate of fixed asset residual values
D	Original value of fixed assets

which of RAP only accounts for about 22%. This means that more costs should be covered by tariff, which leads to a high benchmark tariff indirectly.

D. RESULT OF OTHER REGIONS

In addition to Shanghai, NGDG is also growing rapidly in Beijing, Hubei, etc. The major difference between the benchmark tariff calculation of other regions and which of Shanghai is the gas source (including gas price and lower calorific value of gas). To simplify the calculation, only the gas source data in regional data is adjusted, as shown in Table 10. Then the benchmark tariff of NGDG in Beijing and Hubei can be calculated, the results are shown in Table 11 and 12.

Comparing the results shown in Table 8, 11 and 12, with the same project type and IRR, Hubei has the highest benchmark price, while Beijing has the lowest one.

VI. CONCLUSION

This paper proposes a one-part tariff mechanism for NGDG based on classified benchmark price, which can be referred in the research and establishment of NGDG tariff mechanism by the countries or regions where NGDG is still in the early stage, or has not achieved complete power marketization yet. The mechanism adopts the form of one-part tariff, which was supported by operating period pricing model. Energy projects are divided into several types through energy project dimension and regional dimension. Finally, combining with national policies and regional characteristics, benchmark data were provided to calculate benchmark tariff further.

Case study of Shanghai projects shows that feed-in tariff of BGP and RGP is higher than RAP, and all types of NGDG have much higher feed-in tariff than other types of generator sets such as coal, hydropower, etc. And gas cost is the main portion of the unit cost. If the government would promote gas price reform further in the future, the operating pressure of NGDG would be effectively relieved.

Several strategies from different aspects should be applied to support NGDG. We have studied from the perspective of pricing mechanism, and subsequent studies like subsidy mechanism [37], [38] and strategies to improve competitiveness of NGDG [39] could be promoted in the future.

APPENDIX

See Table 13.

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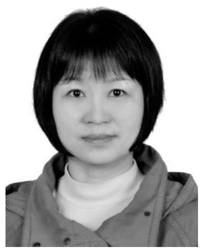

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