Technical and Economic Evaluation and Development Policy Suggestions of LNG Power Plants:
Evaluation and Development Policy

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ABSTRACT

The return on investment (RIO) of a liquefied natural gas (LNG) power plant is lower than that of conventional power plants with high pollution due to the "take or pay" supply mode of natural gas and the two-shift peak shaving operation mode in the LNG power plants. In this chapter, firstly, based on the characteristics of the gas turbine combined cycle (GTCC) unit for peak shaving and standby application, it is proposed to calculate the generation cost of LNG power plants according to the depreciation of operation life. Secondly, through the sensitivity analysis of power generation cost, it is found that fuel price and average efficiency are the first influencing factors. Next, to reflect the environmental protection characteristics of LNG power plants, the on-grid price included in the environmental value is put forward innovatively based on the calculation of the environmental cost and environmental value of natural gas power generation.

KEYWORDS

Environmental Assessment, LNG Power Plant, Policy, Power Generation Cost, Sensitivity Analysis

INTRODUCTION

As a green and efficient way of power generation, the LNG power plant has become an important part of national energy and environmental policy. However, because of the lack of macro-policy support for natural gas power generations, the ROI of natural gas power plants is also lower than that of other conventional power plants, mainly due to the following two reasons:

First of all, LNG power plants generally sign a "take or pay" contract with natural gas companies, which limits the daily, weekly and annual power generation of natural gas power plants. Meanwhile, it is not obliged for the natural gas seller to return the remaining, and a higher price will be paid for the part that exceeds the amount specified in the agreement. Besides, LNG is obliged to participate in auxiliary services such as modulation, phase modulation and emergency standby of the system. Therefore, the power plant is sandwiched between the gas supplier and the power purchaser with an extremely limited control strategy for power generation cost, and the additional cost for various adverse operating conditions must only be borne by the power plant independently (Kalehsar 2016).

Secondly, the LNG power plant, as the main peak shaving plant, adopts the two-shift operation mode of starting in the morning and shutting down in the evening, which reduces the unit operation

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time, and improves the generation cost of combined-cycle power plant to ignore the peak generation value (Jingwen et al. 2012). Moreover, frequent start-up and shutdown of two-shift operating units will inevitably affect the cost of power generation in terms of depreciation, maintenance cost and annual utilization hours. However, if the depreciation rate is taken according to the conventional plant parameters in the traditional generation cost calculation, the proportion of maintenance cost will inevitably lead to the calculated generation cost lower than the actual generation cost, and the loss caused by the cost difference will only be borne by the power plant (Shahidehpour et al. 2005).

Therefore, for the academic and business circles, how to objectively and reasonably evaluate the impact of the internal and external operating environment of LNG power plants, find problems and put forward reasonable policy recommendations is an urgent problem to be solved.

PROCESSING LNG FOR UTILIZATION

Taking natural gas from the earth is not an easy process. It utilizes bulk machineries for extracting the raw natural gas. The spot prediction of natural gas is also very tough process a big team and machineries works behind for extracting the raw natural gas from the earth. The raw natural gas consist of water molecules along with acid gases, which are very hazardous. Hence processing of NG is very important. Figure 2 shows the NG processing and its by products. At first NG is taken out from the earth through gas wells and carried away through receptors. The second step is removing the acid gases which is mixed along with NG naturally. After removal of acid gases the acid gases are treated for further usage. Then comes next with dehydration process. After dehydrating the gas liquefaction is done. Hence it is called as Liquefied Natural Gas. After fractionizing stabilization is done along with condensation. The output from the stabilizer is a pure Liquefied natural gas. During fractionation process LPG is obtained as by product. Processing of NG to LNG is shown in the figure 2.

Figure 1. Processing NG to LNG
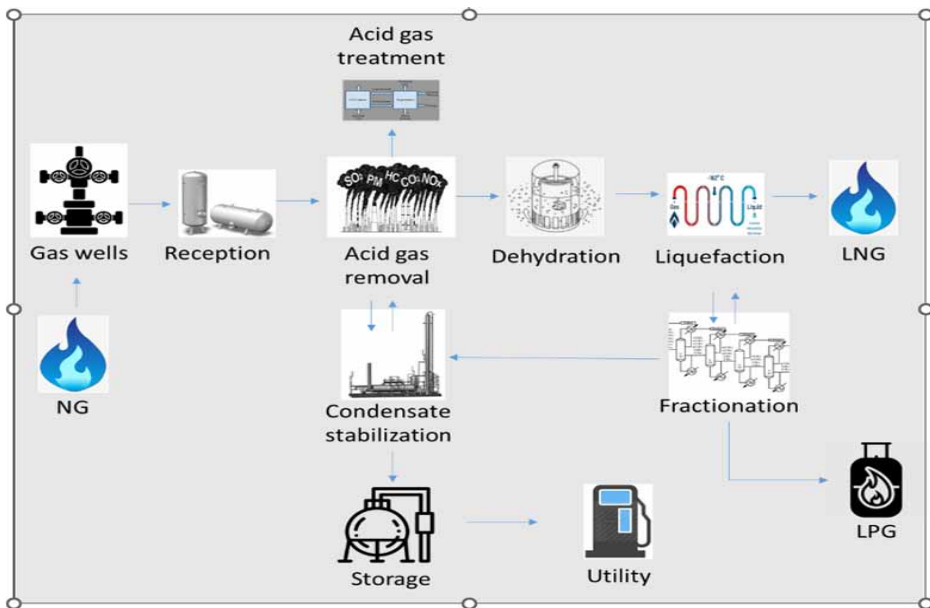
CALCULATION MODEL OF COST OF ELECTRICITY OF LNG POWER PLANTS

Total Cost Of Electricity

LNG power generation cost (yuan/MW) is composed of three parts: 1) cost of depreciation (COD); 2) cost of fuel (COF); and 3) cost of maintenance (COM) [4]. If the COD of an LNG power plant is calculated by the straight-line depreciation method, the calculation formula of cost of electricity (COE) is as follows Equation 1:

$$COE = COD + COF + COM = (1.083 \sim 1.147)\left[\frac{SICD}{t * n * (1-S)} + \frac{3.6 * CF(1)}{\overline{\eta}_N (1-S)}\right] \tag{1}$$

Cost of Depreciation (COD)

$$COD = \frac{TCR}{P * \tau * (1-S) * n} = \frac{SICD}{\tau * n * (1-S)} \tag{2}$$

Where,

TCR--Dynamic present value of total investment cost of power station;
P--Net power of the power station, MW;
τ-- Annual operating hours of power generation equipment, h;
S-- Line loss rate from the generator terminal to the power sale settlement point, generally 3% - 7%. If the power sale settlement point is bounded by the enclosure of the power station, s » 0% - 0.5%;
SICD=TCR/P-- Dynamic ratio investment cost relative to net power conversion of power station, yuan/MW;
n--Economic life of the power plant, i.e., depreciable life of the power plant, generally, a = 25-30 years in foreign countries, 20-30 years in China (Du 2002).

Cost of Fuel (COF)

$$COF = \frac{3.6 \times CF(1)}{\overline{\eta}_N (1\text{-}S)} \tag{3}$$

Where,

CF(1)-- Fuel price in yuan/GJ;
$Q^a d$ -- Lower heating value of fuel, KJ/KG;

$\overline{\eta}_N$ Annual average net efficiency of the unit, related to the annual load condition.

Cost of Maintenance (COM)

The operation and maintenance cost is related to the water cost, material cost, employee salary, welfare fund, overhaul fund, loan interest of working capital consumed by the power plant and other expenses every year. According to statistics, the higher the parameters are, the larger the proportion of the maintenance cost of the unit with larger capacity to the total cost is (Du 2002).

$$COM = (7.65\% \sim 12.80\%)COE \tag{4}$$

Sensitivity Analysis of COE of LNG Power Plants

Through the partial differential treatment of COE formula, the main factors affecting the cost of power generation can be analyzed.

$$
\begin{aligned}
\rho_{COE} = \frac{dCOE}{COE} = {} & \frac{(1.083 \sim 1.147)\times SICD}{n\times\tau\times(1-S)\times COE}(\rho_{SICD}-\rho_n-\rho_\tau) - \frac{3.6(1.083 \sim 1.147)\times CF(1)}{\overline{\eta}_N(1\text{-}S)\times COE}\rho_{\overline{\eta}_N} \\
& + \frac{3.6(1.083 \sim 1.147)\times CF(1)}{\overline{\eta}_N(1\text{-}S)\times COE}\rho_{CF(1)} \\
& - \frac{S}{(1-S)\times COE}\left\{\frac{(1.083 \sim 1.147)\times SICD}{n\times\tau} + \frac{3.6(1.083 \sim 1.147)\times CF(1)}{\overline{\eta}_N}\right\}\rho_S
\end{aligned}
\tag{5}
$$

Note: $\rho_{SICD} = \dfrac{dSICD}{SICD}$, and the rest may be deduced by analogy.

According to the above formula, for the COE calculated by the straight-line method:

Relative changes of SICD, n and τ, ρ_{SICD}, ρ_n, ρ_t is exactly the opposite to that of ρ_{SICD}.

2) Relative changes of COF and average net efficiency, $\rho_{CF(1)}$ and $\rho_{\overline{\eta}_N}$ also have an equal but opposite influence on the relative change of COE.
3) For LNG power plants, generally

$$\frac{CF(1)}{\overline{\eta}_N(1\text{-}S)\times COE} \rangle \frac{SICD}{n\times\tau\times(1-S)\times COE} \tag{6}$$

Then the impact of COF and average efficiency on COE will be greater than that of specific investment cost, annual utilization hours and depreciation life of power plant on COE, becoming the first influencing factor.

Case Application: Calculation of COE of the Huizhou LNG Power Plant in China

In Huizhou LNG power plant, the CCGT unit jointly manufactured by Mitsubishi Heavy Industry/ Dongfang Steam Turbine Plant is adopted, with an installed capacity of 3×390 MW. Among them, the gas turbine is M701F type, single shaft heavy-duty, the steam turbine is triple-pressure, reheating, with double-cylinder lower exhaust, and the waste heat boiler is horizontal, triple-pressure, reheating, fired-free, with natural circulation and outdoor layout, which is manufactured by Hangzhou Boiler Group/U.S. NE.

Determination of Calculation Parameters

1) Dynamic storage investment
   Referring to relevant literature and actual situation, the dynamic storage investment of Huizhou power plant can be calculated as 3,544 yuan/KW.
2) Annual utilization hours

The annual utilization hours are considered as equivalent generation utilization hours of 3500 hours. The reason is that the gas turbine operates in a combined cycle mode, and the daily generation period is in the medium and peak periods. However, in these two periods, it will not always operate at 100% output. Considering the fluctuation of unit output, planned maintenance (about 30 days/year) and temporary maintenance of the unit, 3,500 hours/year of combined cycle mode is feasible.

3) Conversion of natural gas price

Table 1 shows the conversion between natural gas heat and price. The low heating capacity of Huizhou LNG power plant is 8,940 kcal/m^3, equivalent to 37.43 MJ/m^3.

Table 1. Unit conversion of LNG price

P_{LNG} yuan/m^3	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.65	1.7
P_{LNG} yuan/GJ	26.72	29.39	32.06	34.73	37.4	40.07	42.75	44.08	45.42

4) Other parameters

The capital accounts for 25% of the investment, the operation period is 20 years, the gas price is 1.65 yuan/m^3 (including tax), the comprehensive depreciation rate is 6.67%, the overhaul rate is 3.5%, the annual power generation is 3,500 hours, the auxiliary power consumption rate is 3%, and the internal rate of return of capital is 8%.

Calculation Results of COE Composition

Under the above conditions, the COE of the power plant under different annual utilization hours and different COFs is shown in Table 2.

Table 2. Calculation of COE composition

Annual utilization hours/h		2500	2500	3000	3500	4000	4500	5000
COF yuan/m³								
1.2	COD (deprecation)	0.09134	0.073072	0.060893	0.052194	0.04567	0.040596	0.036536
	COF (fuel)	0.23797	0.23797	0.23797	0.23797	0.23797	0.23797	0.23797
	COE (total cost)	0.378707	0.357698	0.343693	0.333689	0.326186	0.32035	0.315682
	COD/COE	0.24119	0.204284	0.177174	0.156416	0.140012	0.126723	0.115737
	COF/COE	0.628375	0.665281	0.692391	0.713149	0.729553	0.742843	0.753828
1.3	COD (deprecation)	0.09134	0.073072	0.060893	0.052194	0.04567	0.040596	0.036536
	COF (fuel)	0.257801	0.257801	0.257801	0.257801	0.257801	0.257801	0.257801
	COE (total cost)	0.401512	0.380504	0.366498	0.356495	0.348992	0.343156	0.338487
	COD/COE	0.227491	0.192041	0.166149	0.14641	0.130863	0.118301	0.107939
	COF/COE	0.642075	0.677525	0.703416	0.723155	0.738702	0.751264	0.761626
1.4	COD (deprecation)	0.09134	0.073072	0.060893	0.052194	0.04567	0.040596	0.036536
	COF (fuel)	0.277632	0.277632	0.277632	0.277632	0.277632	0.277632	0.277632
	COE (total cost)	0.424318	0.403309	0.389304	0.3793	0.371797	0.365961	0.361293
	COD/COE	0.215264	0.181181	0.156416	0.137607	0.122836	0.110929	0.101126
	COF/COE	0.654301	0.688384	0.713149	0.731958	0.746729	0.758636	0.768439
1.5	COD (deprecation)	0.09134	0.073072	0.060893	0.052194	0.04567	0.040596	0.036536
	COF (fuel)	0.297462	0.297462	0.297462	0.297462	0.297462	0.297462	0.297462
	COE (total cost)	0.447123	0.426115	0.412109	0.402105	0.394602	0.388767	0.384098
	COD/COE	0.204284	0.171485	0.14776	0.129803	0.115737	0.104422	0.095122
	COF/COE	0.665281	0.698081	0.721805	0.739762	0.753828	0.765144	0.774444
1.6	COD (deprecation)	0.09134	0.073072	0.060893	0.052194	0.04567	0.040596	0.036536
	COF (fuel)	0.317293	0.317293	0.317293	0.317293	0.317293	0.317293	0.317293
	COE (total cost)	0.469929	0.44892	0.434915	0.424911	0.417408	0.411572	0.406904
	COD/COE	0.905305	0.881146	0.865039	0.853535	0.844906	0.838195	0.832827
	COF/COE	0.675195	0.706792	0.729553	0.746729	0.760152	0.77093	0.779775
1.7	COD (deprecation)	0.09134	0.073072	0.060893	0.052194	0.04567	0.040596	0.036536
	COF (fuel)	0.337124	0.337124	0.337124	0.337124	0.337124	0.337124	0.337124
	COE (total cost)	0.492734	0.471726	0.45772	0.447716	0.440213	0.434378	0.429709
	COD/COE	0.954337	0.930177	0.914071	0.902567	0.893938	0.887227	0.881858
	COF/COE	0.684191	0.714661	0.736529	0.752986	0.76582	0.776108	0.78454

Technical and Economic Evaluation

According to Table 2,

1) The COD accounts for 25%-10% of the total COE, which is characterized by the higher annual utilization hours, the smaller proportion of COD to COE, which also reflects the low unit cost of the combined cycle power plant.
2) The COF accounts for 60%-80% of the total COE, which is characterized by the higher annual utilization hours, the larger proportion of COF to COE. When the annual utilization hours are 3,500 h and the fuel price is 1.6 yuan/m^3, the COF accounts for about 75% of the total COE, which is also consistent with the data provided by the factory.
3) The COM in the COE is included in the calculation in this table according to the fixed proportion, while in the actual situation, the COM and the annual utilization hours are in a quadratic curve relationship, that is, the life loss of the unit is directly related to the number of starts and stops and the length of continuous operation time. It is generally believed that the life loss of the unit in the two-shift operation year is large, so the coefficient in the calculation formula of maintenance cost should take the large values (Wang et al. 2013).
4) From the relationship between the total COE and the annual utilization hours, the COE is high when the annual utilization hours are low. The reason is that when the COF and the total annual unit depreciation remain unchanged, but the annual utilization hours of the unit decrease, the COD will increase. At the same time, the low annual utilization hours will lead to a significant proportion of debt return in the on-grid price, and the pressure on enterprises to repay loans will increase greatly.

Calculation of Environmental Value of Power Generation in LNG Power Plant

Economic considerations are often decisive in the decision-making of energy structure, but the decision made in this way is obviously not fully in line with the requirements of sustainable development strategy. In the comparative evaluation of various energy sources, not only the internal cost, but also the external cost (environmental control and environmental governance cost) brought by economic activities should be calculated.

Calculation of Pollutant Discharge

The pollutant emission rate of natural gas power generation is based on a large number of measured data at home and abroad (Ede et al. 2011). See Table 3 for the emission of pollutants from burning 106 m^3 natural gas.

Table 3. Emission standard of natural gas pollutants

Pollutants	SO2	NOX	CO2	CO	TSP	Ash	Slag
Emission ratio	11.6	6.2×103	2.01×10^6	0	238	0	0

According to the installed capacity of the power plant of 350MW, the annual operation of 5,000 hours, the annual power supply of 1.75 billion KWh, the unit heat value of coal quality of 21.2 MJ/kg, the power consumption rate of coal-fired power plant of 6%, and the low heat value of natural gas of 36 MJ/m^3, the calculation formula of annual fuel consumption of each type of power plant is as follows:

Annual coal consumption = (annual power generation × 1000 × 3600 ×/(21.2 × 106))/(power supply efficiency × (1-service power rate)

Annual gas consumption = (annual power generation × 1000 × 3600 ×/(36 × 106))/power supply efficiency

Table 4. Parameters of each power plant

Power technology	Generating efficiency %	Efficiency of power supply %	Coal consumption of power supply
Conventional coal-fired power station	38	35.72	855,000 t·a⁻¹
Conventional coal fired power plant (with FGD)	38	35.34	894,560 t·a⁻¹
CCTG	55.3	53	3,300,000,000 m³/a

The calculation result in Table 4 is converted to the pollutant emission per KWh as follows:

Table 5. Comparison of pollutant emission from power generation of various power stations

Type of power stations	SO2	NOX	CO2	CO	TSP	Ash
Conventional coal-fired power station	8.794	3.909	845.766	0.126	0.194	68.406
Coal-fired (with FGD)	0.92	2.198	946.7	0.143	0.036	117.06
Natural gas power station	0.0022	0.6789	379	0	0.0087	0

According to Table 5, when the annual power supply is 1.75 billion KWh, the use of natural gas for power generation can decrease more than 15,000 tons of SO2, 5,700 tons of NOx, 810,000 tons of CO2 and 120,000 tons of ash annually. Compared with the power stations with FGD, 1,610 tons of SO2, 26,000 tons of NOx, 990,000 tons of CO2 and 200,000 tons of ash can be reduced. If the total installed capacity of LNG power generation project phase I in Guangdong is 3,150 mw and the operation period of gas power station is 20 years, the LNG project will bring a considerable environmental value, which can alleviate the increasingly serious environmental pollution.

Table 6. Statistics of environmental cost of various power stations (yuan/KWh)

|	SO2	NOX	CO2	CO	TSP	Ash	Total
Conventional coal-fired power station	0.052764	0.031272	0.019453	0.000126	0.0004268	0.0068406	0.110882
Coal-fired (with FGD)	0.00552	0.017584	0.021774	0.000143	0.0000792	0.011706	0.056806
Natural gas power station	0.0000132	0.005431	0.008717	0	0.00001914	0	0.014181

Calculation of Environmental Cost and Environmental Value

The calculation results of environmental cost of pollutant emission from various power stations are shown in Table 6:

The environmental cost of the three kinds of power stations can be obtained by analyzing the above table. The comparison shows that the environmental cost of natural gas power generation is 9.67 fen/KWh less than that of conventional power plants, and 4.262 fen/kWh less than that of coal-fired power plants with FGD. Therefore, the environmental value brought by gas power generation is 4-10 fen/kWh.

According to the above study, the comprehensive environmental cost caused by generation pollutants of each power station is shown in Figure 2.

Figure 2. Environmental cost of various power stations
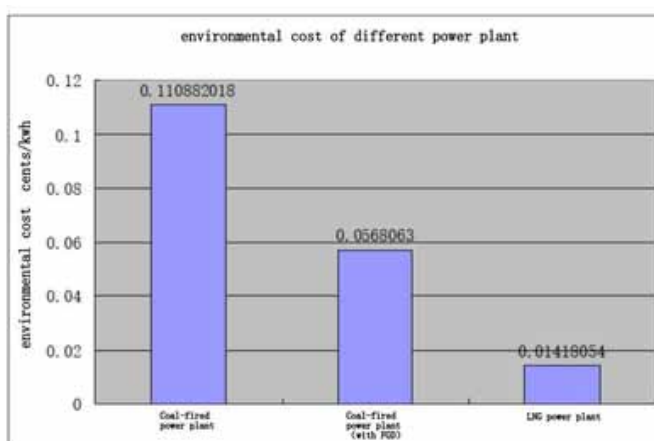
In all kinds of power plants, the environmental cost brought by the emission of SO2, NOx and CO2 from conventional coal-fired power plants accounts for the main part; in coal-fired (with FGD) power plants, the environmental cost brought by the emission of NOx, CO2 and ash accounts for the main part; in contrast, the environmental cost brought by the emission from natural gas power plants is mainly caused by NOx and CO2.

On-Grid Price of LNG Power Plant After Environmental Value Included

On June 29, 2008, the National Development and Reform Commission issued a notice on increasing the electricity price of China Southern Power Grid. According to the notice, to decide to adjust the electricity price of our province from July 1, 2008, the on-grid price (including tax) of existing coal-fired units in our province will be increased by 2.60 fen per kilowatt hour, and the benchmark on-grid price of new coal-fired units (including cogeneration units) installed with desulfurization facilities will be adjusted to 0.4792 yuan per kilowatt hour (Cornot-Gandolphe 1993).

Assuming that the SIC of LNG power plants is 3,544 yuan/kW, the annual operation time is 3,500 hours, and the price of natural gas is 1.5 yuan/m^3, then the trial on-grid price excluding tax is 0.482 yuan/kWh. Based on the above comparison, LNG power plant has an environmental value advantage of 4.262 fen/kWh compared with coal-fired power plant with FGD facilities. Then, after taking into account the value subsidy, the on-grid price excluding tax of LNG power plant is competitive.

ANALYSIS OF THE IMPACT OF ANNUAL UTILIZATION HOURS ON GAS POWER GENERATION

Sensitivity Analysis of On-Grid Price to Operating Hours

When SIC = 3,544 yuan/KWh, the unit operation hours vary from 2,000 to 5,000, and the gas price varies from 1.1 to 1.5 yuan/m³. The sensitivity of the on-grid price to the annual utilization hours is shown in Figure 3.

Table 7. sensitivity of annual utilization

Annual utilization hours	On-grid price
1000	0.1
1500	0.2
2000	0.3
2500	0.4
3000	0.5
3500	0.6
4000	0.7
4500	0.8
5000	0.9
5500	1

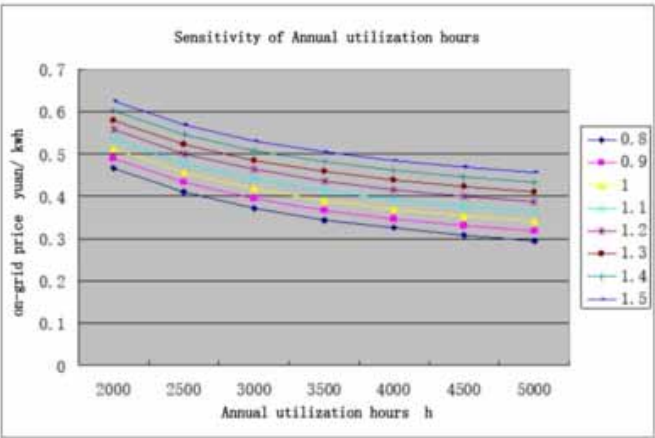Figure 3. Sensitivity of on-grid price to operating hours

Table 7 represents the sensitivity of annual utilization of power by comparing annual utilization cost and on grid price. Considering the large change base of unit operation hours, it is observed from the figure above that the on-grid price changes by 1-5 fen/KWh every 500 hours, especially between

2,000 hours and 3,500 hours. The on-grid price has a strong sensitivity to the operation hours. In this period, the on grid price changes by 2.3-5 fen every 500 hours. The calculation shows that the change range is different in different time periods. When the gas price is 1.5 yuan/m^3, the proportion change trend of on-grid price is shown in Figure 4 and Figure 5.

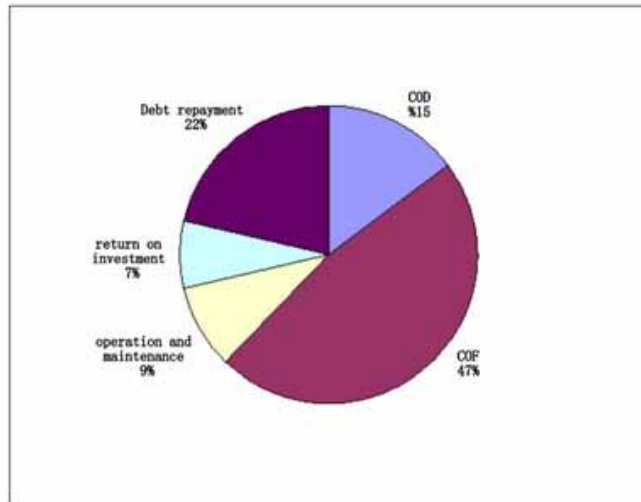Figure 4. Composition of on-grid price for 2,000h utilization hours

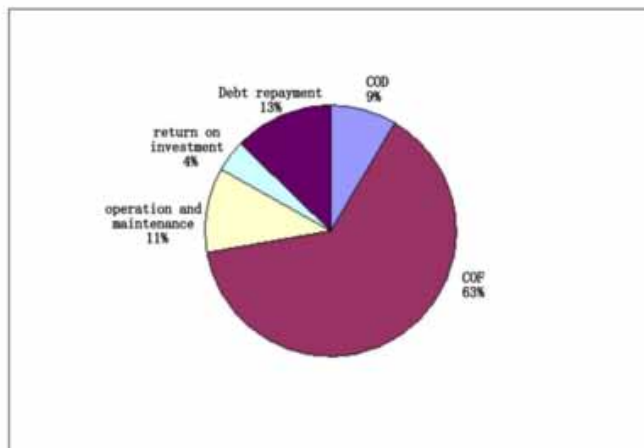Figure 5. Composition of on-grid price for 4,500h utilization hours

Figure.4 and Figure 5 show that when the unit operation hours increase from 2,000 to 4,500 hours, the on-grid price decreases by 0.17 yuan/kWh, and at the same time, the amount related to the unit operation hours also decreases by 16% in the on grid price(Chen et al. 2009, Kumar et al. 2011). The reason is that the function related to the operating hours of units is only the allocation of

fixed cost and capital income by analyzing the composition of on-grid price. Therefore, in the case of low annual operating hours, the proportion of depreciation cost and capital recovery is larger; on the contrary, in the case of higher annual operating hours, the proportion of fuel cost is more prominent (Cornot-Gandolphe 1993).

POLICY SUGGESTIONS FOR THE DEVELOPMENT OF LNG POWER PLANTS

Increasing Unit Operation Time in LNG Power Plant

1) As one of the major users in the natural gas industry chain, gas power station is one of the important ways to support the sustainable development of national energy industry. Because natural gas can't be stored on a large scale and there is a risk of "take or pay" contract, there must be a certain number of large users in the lower course of natural gas industry to achieve sustainable development (Cruz campas et al. 2017, Kang et al. 2018). Therefore, it is the guarantee for the smooth development of the natural gas industry to give the gas power station a reasonable unit operation time. In the case of high coal price, coal-fired units do not have cost advantages for gas-fired units (Wang et al, 2018). Therefore, more power generation should be encouraged for natural gas power plants with relatively low fuel costs.

Increasing Government Subsidies

In this paper, after the comparison between the natural gas power plants and different types of electricity price, it is found that the competitiveness of the gas power plant in the market will be enhanced, and the ability of the power plant to bear the rising natural gas price will be improved when the environmental value of gas power plant is included, which shows that reasonable financial subsidies or cashing in the emission trading market can bring gas power stations' superiority into full play and improve their competitiveness in the market. Because LNG power plants mostly adopt two-shift system for peak shaving, it is reasonable to reflect the peak shaving value of two-shift system for units in peak shaving operation through the time-of-use power price subsidy, and it is helpful to improve the viability of combined cycle power plants (Xiao et al. 2016).

Future Enhancement Plan

To annex smart grid along with LNG and to examine the result in terms of power consumption, power saving, comparing it with normal grid system. Will try to demonstrate smart grid by setting wind mill or solar plant and annex smart grid along with that. Setting a smart home which uses all smart appliances and implementing smart grid will be the future work. If we get funds will definitely implement it. If not possible will make a simulation using tools and examine the model.

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

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