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Research on the analysis and optimization method of offshore oil-platforms energy system

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Abstract. Offshore oil-gas platforms in the same area are generally connected through the power grid and subsea oil-gas pipeline networks. It has formed a typical integrated energy system which interacts with multiple energy sources, water, electricity, gas and oil. However, the traditional energy management research mainly focuses on the stability control of the platform's power network, and does not model the energy system of the platform group as a whole, which cannot reflect the characteristics of energy interaction between the platform groups. Therefore, this paper combs the current situation of energy utilization and operation control of offshore oil-gas platform energy system in a sea area of China, establishes the energy network of offshore oil-gas platform group, and puts forward the modelling, analysis and optimization method of offshore oil platform group. Firstly, focusing on the main energy coupling equipment (gas power station, gas heat station, electric heater,) of the platform, the energy efficiency analysis model is established to realize the energy efficiency diagnosis of the equipment. Then, based on the theory of Energy Hub, an electro-gas interaction optimization scheduling method is proposed to realize the optimization analysis of energy interaction between platforms. Finally, a calculation example of the actual platform group is given, which consists of three power generation platforms in China. The relevant research results will guide the closed-loop management of the operation, optimization and evaluation of the energy system. The application in the integrated energy management system of offshore oil-gas platform is helpful to improve the energy integration control of offshore oil platform.

1. Introduction

Offshore oil-gas platform is an isolated energy system, which needs a large number of electricity, mechanical power and thermal energy. The equipment of the process system is more concentrated, more compact and more automatic than the ground equipment. The energy use density of thermoelectricity is larger and the control and management technology of energy is more intelligent [1]. With the development of power technology and information technology, offshore gas-oil platforms have realized power interconnection and information interconnection, and developed from isolated platform to networked platforms group. With the introduction of waste heat recovery and utilization technology, associated gas power generation technology, and clean energy, the offshore platform energy system has been converted from a single power system to an integrated energy system [2, 3]. However, at present, the research of scholars mainly focuses on the offshore platform power system network and power grid stability control technology [4], the introduction of new energy [5, 6], as well as oil and gas treatment process Control and energy recovery [7, 8]. The platforms have realized information interconnection through optical network, but the energy data is still managed by

the single platform. The information integration and integrated energy management of the offshore platforms group have not been formed yet, and the integrated energy system analysis theory of the offshore platform is lacking.

The energy analysis of the whole platform group has the following problems. There is no comprehensive analysis combining power system data and process system data [9]. The efficiency of gas turbine, power station, electric heater, thermal station, transformer and other focused energy-consuming equipment fails to meet the standard, and energy efficiency evaluation indicators need to be established[10, 11]. Therefore, based on the Energy Hub theory, this paper studies the integrated modelling and analysis of gas, cold, heat and electricity, the on-line energy efficiency analysis and the optimization of energy interaction of offshore platform group. The research will help reduce the cost of crude oil production and realize efficient, low consumption, orderly adjustment and scientific management of offshore platforms.

2. System description and modelling

2.1. System description
The offshore platform group typically includes the central platform CEP (Centre Platform) and WHP (wellhead Platform). The central platform is mainly responsible for the processing of the liquid from each wellhead platform, while providing power to each wellhead platform and monitoring the production operation of the wellhead platform. The wellhead platform is mainly responsible for crude oil and natural gas collection, and is measured by single well metering system, which is transported to the central processing platform or other production treatment facilities by submarine pipeline.

Through the investigation of the present situation of an oil platform group in China, the oilfield group consists of three central platforms and seven wellhead platforms, three central platforms are power generation platforms, each platform is equipped with 4 gas turbine generator sets. The drawing of material flow is shown in Figure. 1.
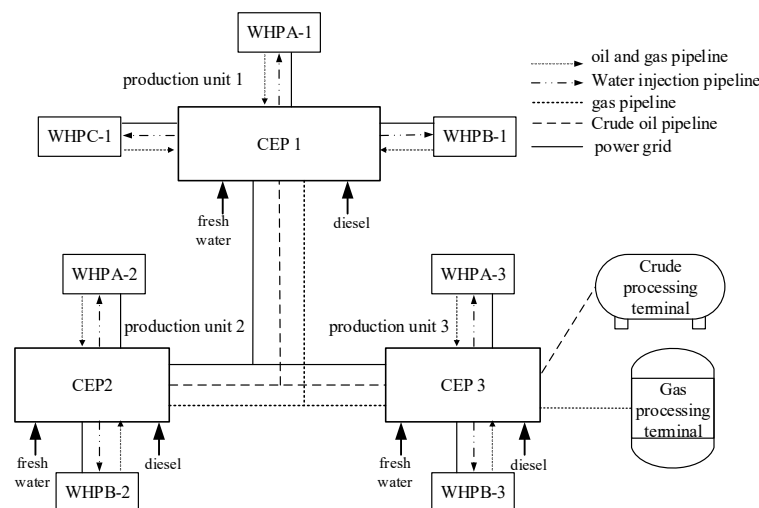

Figure 1. Schematic diagram of offshore platforms group
energy system.

Electricity, gas, fresh water and diesel are mainly energy consumed by CEP, while WHP mainly consumes electricity, diesel and fresh water. Gas mainly comes from gas wells, associated gas and sea pipe gas, used in gas turbine power generation, thermal dielectric boilers and gas compressors, pressurized delivery. The source of electricity is gas turbine power generation, used for household consumption, process power, pumps, compressors, electric heating, air conditioning and so on. Diesel from land distribution, used in fire pumps, diesel cranes, diesel generator diesel and so on. Freshwater is mainly used for domestic water and process water. Crude oil is sent to crude processing terminal on

land after oil well extraction and process separation from CEP3. Gas turbines are usually equipped with waste heat recovery boilers, and heat recovery is used for process pipe network heating.

A central platform and several wellhead platforms around it to form a production unit, each production unit can be viewed as a node of the Energy Hub. The energy interaction between WHP and CEP is realized through electricity. CEP is interconnected through power grid, gas pipeline and crude oil pipeline. The crude oil pipeline mainly focuses on external transportation and crude oil is not used in this system.

To sum up, the system presents the characteristics of power-gas coupling, and the distribution and scheduling of electricity and gas between platforms are the core to realize the energy stability and economic supply of each platform.

2.2. System modelling
The energy system of offshore platform group is the coupling link of electric/gas/heat, and the coupling relationship of energy can be described by Energy Hub model. Energy Hub Model is an input-output port model that describes the coupling relationship between "source, network, and load" in integrated energy systems. The relationship between various energy inputs and different load outputs in the energy hub model is represented by a converter coupling matrix [12, 13]. Energy Hub model can be described as (1).

$$L = CP \tag{1}$$

Where
L = input matrix
P = output matrix
C = converter coupling matrix.

The most important energy coupling device in each production unit is gas turbine and waste heat system, electric heating system, the electrical system. In the Energy Hub model, a single platform energy system can be simplified into GT (gas turbine) composed of gas turbines and waste heat recovery devices, TF(transformer) represented the power supply and distribution system, EH(electric Heater) as the electric heating system. The crude oil does not involve energy interaction, and the proportion of diesel and water energy is too small to consider in the model. At the same time, the model ignores the platform air conditioning system [14, 15]. Although it is an energy coupling link, the load is too low. The Energy Hub model of single platform is shown in Figure.2,
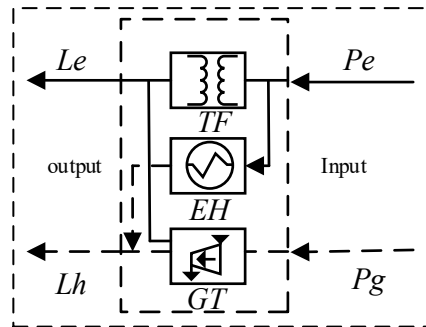

Figure 2. Schematic diagram of single
platform model.

Energy Hub model input includes electrical energy and natural gas, natural gas input directly to GT, electrical energy input to TF and EH at the same time. The output of the model contains two parts, electrical energy and heat energy, the output of electrical energy by TF and GT co-supply, the output of thermal energy by EH and GT together[16, 17]. Converter coupling matrix is written as (2).

$$\begin{bmatrix} L_e \\ L_h \end{bmatrix} = \begin{bmatrix} \lambda_e \eta_e^T & \eta_e^{GT} \\ (1-\lambda_e)\eta^{EH} & \eta_h^{GT} \end{bmatrix} \begin{bmatrix} P_e \\ P_g \end{bmatrix} \tag{2}$$
$$\underbrace{\phantom{\begin{bmatrix} L_e \\ L_h \end{bmatrix}}}_{L} \quad \underbrace{\phantom{\begin{bmatrix} \lambda_e \eta_e^T & \eta_e^{GT} \\ (1-\lambda_e)\eta^{EH} & \eta_h^{GT} \end{bmatrix}}}_{C} \quad \underbrace{\phantom{\begin{bmatrix} P_e \\ P_g \end{bmatrix}}}_{P}$$

Where

η_e^T = transformer efficiency, %

η_e^{GT} = power station efficiency, %

η_h^{GT} =thermal efficiency of station, %

η_h^{EH} = heater efficiency, %

L_e = electrical load, kW

L_h = thermal load, kW

P_e = electrical load interaction, kW, the flow into the platform is positive, and the flow out of the platform is negative

P_g = gas thermal consumption, kW

λ_e =distribution coefficient, $\lambda_e \in [0,1]$

Based on the single platform model, the Energy Hub model of platforms group is shown in Figure.3,
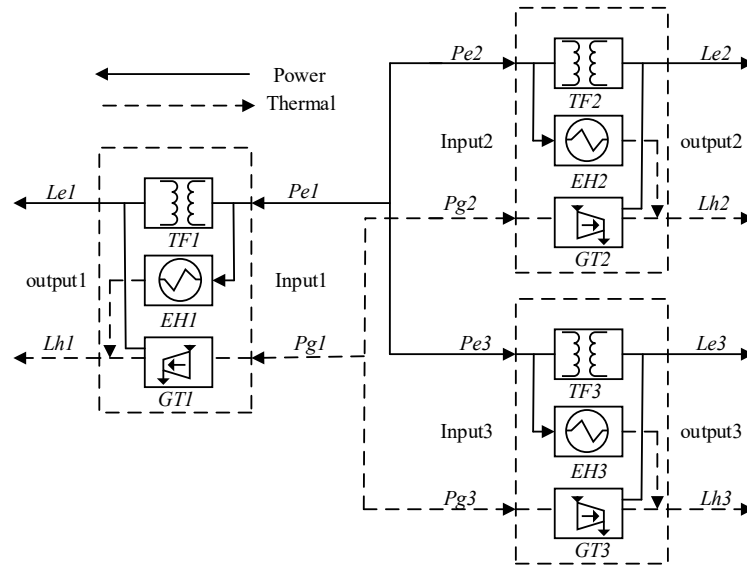

Figure 3. Schematic diagram of platforms group model.

The model of the platform group is composed of three single-platform hub models, each of which can generate gas and power, and natural gas and power can support each other. Converter coupling matrix is written as (3).

$$\begin{cases} \begin{bmatrix} L_{e1} \\ L_{h1} \end{bmatrix} = \begin{bmatrix} \lambda_{e1}\eta_{e1}^T & \eta_{e1}^{GT} \\ (1-\lambda_{e1})\eta_1^{EH} & \eta_{h1}^{GT} \end{bmatrix} \begin{bmatrix} P_{e1} \\ P_{g1} \end{bmatrix} \\ \begin{bmatrix} L_{e2} \\ L_{h2} \end{bmatrix} = \begin{bmatrix} \lambda_{e2}\eta_{e2}^T & \eta_{e2}^{GT} \\ (1-\lambda_{e2})\eta_2^{EH} & \eta_{h2}^{GT} \end{bmatrix} \begin{bmatrix} P_{e2} \\ P_{g2} \end{bmatrix} \\ \begin{bmatrix} L_{e3} \\ L_{h3} \end{bmatrix} = \begin{bmatrix} \lambda_{e3}\eta_{e3}^T & \eta_{e3}^{GT} \\ (1-\lambda_{e3})\eta_3^{EH} & \eta_{h3}^{GT} \end{bmatrix} \begin{bmatrix} P_{e3} \\ P_{g3} \end{bmatrix} \end{cases} \quad （3）$$

3. Model analysis and optimization

3.1. Energy efficiency analysis

In the platforms group model, gas turbine, power station, electric heater, thermal station, transformer is the main coupling link of electricity, gas, cold and heat. The modeling and analysis of coupling objects efficiency is the foundation of model solving. Data acquisition and monitoring of the main equipment on the platform is realized through an automated system, which makes it possible to conduct on-line analysis and diagnosis of the main equipment energy efficiency based on data and energy efficiency analysis model [12].

（ⅰ）Power station energy efficiency model.

The main generator set of the offshore platform is a dual-fuel (diesel and natural gas) gas turbine , and the energy efficiency model of the power station is written as(4).

$$\eta_e^{GT} = \frac{3600 \times N}{G} \tag{4}$$

Where

N =The load of the power station, kW

G = The heat consumption per hour of the power station, kW

3600 is the energy ratio coefficient, kJ/h.

（ⅱ）Heat station energy efficiency model.

Most of the energy in the turbine generator is lost in the form of flue gas, so it is necessary to utilize the waste heat of high-temperature flue gas to improve the overall efficiency of the unit. Efficiency model combines heat and power supply device of turbine and waste heat recovery device.

$$\eta_h^{GT} = \frac{3600 \times (N + Q_R)}{G} \tag{5}$$

Where

Q_R = The heating power of the waste heat recovery device, kW

(ⅲ) Energy efficiency model of electric heater.

Due to the insulation requirements of pipeline transportation and the heating requirements of process separation, there are a large number of electric heat tracing heaters and process electric heaters for offshore platforms, which are mainly used for fluid heating. Efficiency model:

$$\eta_h^{EH} = \frac{\rho_c C_{cp} D_c (t_{out}^c - t_{in}^c)}{P_{EH}} \times 100 \tag{6}$$

Where

D_c =The fluid flow rate, kg/s

C_{cp} =The fluid heat capacity, kJ/ (kg · ℃)

ρ_{cp} =The fluid density, kg/ (m3)

t_{out}^c =The outlet temperature of the fluid, ℃

t_{in}^c =The Inlet temperature of the fluid, ℃

P_{EH} =Heater power, kW

(ⅳ) Transformer energy efficiency model.

The transformer of the offshore platform is the main equipment of the power distribution system. The model is as follows:

$$\eta_e^T = \frac{\beta S_H Cos\varphi_2}{\beta S_H Cos\varphi_2 + P_{cu} + P_{Fe}} \times 100 \tag{7}$$

Where

β =The load rate, %

S_H =The capacity, kVA

$Cos\varphi_2$ = the margin power factor, kg/ (m3)

P_{cu} = copper loss, kW

P_{cu} = the iron loss, kW

3.2. Energy interaction optimization

The platforms group consists of three platforms, the energy interaction is between the platforms, and there is no energy interaction with the outside world. At the same time, the power was used up on all three platforms, with no outgoing power. The original source of energy for the whole system is natural gas. Therefore, the problem of energy optimization between platforms is mainly the natural gas optimization. The natural gas consumption of three platforms is selected as the objective function, and the optimal solution model of the interconnection system is established:

$$\min F_{GT} = \min \sum_{k=0}^{N} (F_{k,GT}) \qquad (8)$$

Where

F_{GT} = The Total gas consumption of platform group

N = The number of GT on the platform group

$F_{k,GT}$ = The gas consumption of number k, kW

$F_{l,GT}$ = Gas consumption, m3/s

The constraint conditions of the single platform is (9).

$$\text{s.t.} \begin{cases} 0 \leq \lambda_e \leq 1 \\ \sum_{l=0}^{m} k_{l,GT} P_{l,GT} = P_g \\ F_{l,GT} = f_{l,GT}(P_{l,GT}, p_{l,GT}^s, T_{l,GT}^s, p_{l,GT}^d) \\ (F_{l,GT}, p_{l,GT}^s, T_{l,GT}^s, p_{l,GT}^d) \in D_l \\ k_{l,GT} = 0/1 \\ l=1,2,...,m \end{cases} \qquad (9)$$

Where

m = The number of GT on the platform

$k_{l,GT}$ = The Run. Stop state of GT on the platform, $k_{l,GT}$ =0, Stop, $k_{l,GT}$ =1, Run.

$P_{l,GT}$ = Gas thermal consumption, kW

$F_{l,GT}$ = Gas consumption, m3/s

$f_{l,GT}(P_{l,GT}, p_{l,GT}^s, T_{l,GT}^s, p_{l,GT}^d)$ = GT characteristic equation

$p_{l,GT}^s$ = Gas inlet pressure, Mpa

$p_{l,GT}^d$ = Gas outlet pressure, Mpa

$T_{l,GT}^s$ = Gas inlet temperature, ℃

D_l = Run parameter thresholds, ℃

The constraint conditions of the platform group is (10).

$$\text{s.t.}\begin{cases} \begin{bmatrix} L_{e1} \\ L_{h1} \end{bmatrix} \leq \begin{bmatrix} \lambda_{e1}\eta_{e1}^T & \eta_{e1}^{GT} \\ (1-\lambda_{e1})\eta_1^{EH} & \eta_{h1}^{GT} \end{bmatrix} \begin{bmatrix} P_{e1} \\ P_{g1} \end{bmatrix} \\[2em] \begin{bmatrix} L_{e2} \\ L_{h2} \end{bmatrix} \leq \begin{bmatrix} \lambda_{e2}\eta_{e2}^T & \eta_{e2}^{GT} \\ (1-\lambda_{e2})\eta_2^{EH} & \eta_{h2}^{GT} \end{bmatrix} \begin{bmatrix} P_{e2} \\ P_{g2} \end{bmatrix} \\[2em] \begin{bmatrix} L_{e3} \\ L_{h3} \end{bmatrix} \leq \begin{bmatrix} \lambda_{e3}\eta_{e3}^T & \eta_{e3}^{GT} \\ (1-\lambda_{e3})\eta_3^{EH} & \eta_{h3}^{GT} \end{bmatrix} \begin{bmatrix} P_{e3} \\ P_{g3} \end{bmatrix} \\[2em] P_{e1}+P_{e2}+P_{e3} \leq \xi P \\[0.5em] \Delta f(P_{e1},P_{e2},P_{e3},Le_1,Le_2,Le_3,\ f_{GT}) \leq \xi f \\[0.5em] \Delta U(P_{e1},P_{e2},P_{e3},Le_1,Le_2,Le_3,f_{GT}) \leq \xi U \end{cases} \tag{10}$$

Where

ξP = Threshold of power deviation, kW

ξf = Threshold of power frequency, HZ

ξU = Threshold of power voltage, V

$\Delta f(P_{e1},P_{e2},P_{e3},Le_1,Le_2,Le_3,\ f_{GT})$ =Frequency deviation function of power grid

$\Delta U(P_{e1},P_{e2},P_{e3},Le_1,Le_2,Le_3,f_{GT})$ = Voltage deviation function of power grid

4. Results and discussions

4.1. Efficiency analysis result.
Typical equipment and typical daily operation data are selected in the researched platforms group. Energy efficiency is calculated according to the established energy consumption model and benchmarked with national standards, which is shown in is shown in Figure.4,
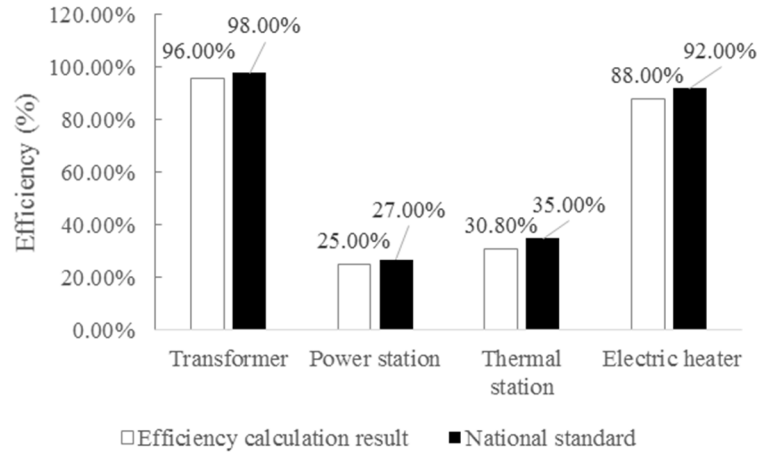

Figure.4 Efficiency calculation result of Energy coupled objects.

It can be seen from the figure that the efficiency of heater, power station, thermal station and transformer fails to reach the evaluation value. Due to the harsh environment of the offshore platform, equipment degradation is fast, and there is no online analysis and monitoring system, its long-term deviation from the reasonable operation range. Figure.5 shows the average efficiency per month of power station.
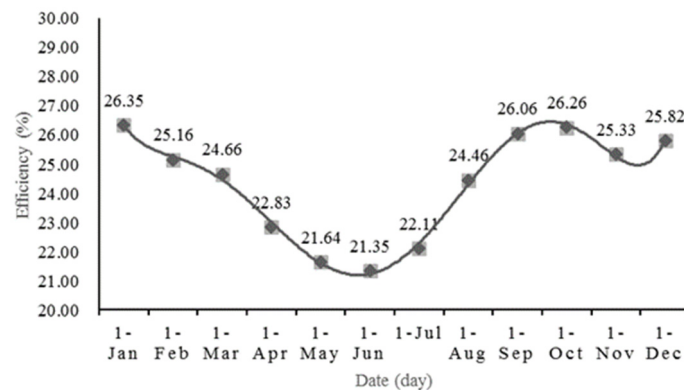
Figure.5 Annual efficiency curve of power station.

As can be seen from the curve, the efficiency decreased slightly before June, the low lowest point is 21.35%. And then it goes up to 26.06% and stays at that level. According to the operation log, there is a mechanical fault in the gas turbine, which was rotated in June. The efficiency reflects the running condition of the power station. It is an important way to improve the comprehensive energy utilization efficiency of offshore platforms to monitor the operation efficiency of key equipment in real time through energy efficiency model.

4.2. Energy interaction result

Based on the historical operation data and the operating conditions, the offshore platform group in summer were modeled and analyzed. Three typical load values in summer were selected and optimized by SQP (Sequential quadratic Programming) algorithm. SQP is considered as one of the most effective methods to solve nonlinear constraint optimization. The results are shown in table 1:

Table1. The Energy interaction of offshore platforms group

Platform running time		Operating Values		SQP optimal value	
		Pow interaction(kW)	Gas interaction(kW)	Pow interaction(kW)	Gas interaction(kW)
8:00	CEP1 Unit	542.21	11068.65	119.09	11491.77
	CEP2 Unit	939.82	5468.71	343.29	6065.24
	CEP3 Unit	1483.98	16655.43	462.38	15262.33
12:00	CEP1 Unit	431.71	10068.76	228.60	10271.87
	CEP2 Unit	977.94	5053.86	160.72	5871.08
	CEP3 Unit	1398.97	15155.32	389.32	13732.97
18:00	CEP1 Unit	341.54	11183.24	224.81	11299.97
	CEP2 Unit	901.90	5213.22	203.48	5911.64
	CEP3 Unit	1236.62	16212.39	428.29	15084.61

For offshore platform groups, the interaction of natural gas load is the main energy consumption of the whole platform group. Compared with the total amount of natural gas interaction before and after optimization at 8:00, 10:00 and 18:00, it reduced by 1.13%, 1.32% and 0.95% after optimization. Therefore, the optimization results can be used in the management system of platform group to guide the energy scheduling among platforms, and the operation mode is optimized by this method.

5. Conclusion

Based on the characteristics of offshore platforms group energy system, this paper analyzes the equipment energy efficiency of energy coupling link and establishes the Energy Hub model of the system. Aiming at the energy interaction of offshore platform group, the on-line energy efficiency analysis and electric-gas interactive scheduling optimization technology of offshore platform energy equipment are proposed. Based on the technologies of analysis, optimization, the closed-loop energy management and optimal operation of offshore platform groups are realized, and the operational optimization level and energy utilization efficiency of offshore platforms are improved, making up for the deficiencies in the research on the comprehensive energy system of offshore platforms.

References

[1]   CNOOC Research Institute, West heat recovery and heat & electricity combined technical solution in offshore platform power stations, 2016. (in Chinese)

[2]   Nguyen Tuong-Van, Mari Voldsund, Peter Breuhaus, Brian Elmegaard. Energy Efficiency Measures for Offshore Oil and Gas Platforms. Energy, 2016:1-16

[3]   Thibaut Edouard, Leforgeais Bruno. Selection of Power from Shore for an Offshore Oil and Gas Development. IEEE Transactions on Industry Applications, 2015, 51(2):1333-1340.

[4]   Li xue, zhang an, jing jiajia, han hao. Research review of offshore platform power system. Power system and clean energy, 2016, 32(02):1-7.

[5]   Mariella Leporini, Barbara Marchetti, Francesco Corvaro, Fabio Polonara. Reconversion of offshore oil and gas platforms into renewable energy sites production: Assessment of different scenarios. Renewable Energy, Volume 135, May 2019, Pages 1121-113

[6]   Liu yujie. A brief analysis of energy for offshore oil and gas development. China investment,2012(07):81-82

[7]   Hossein Nami, Ivar S. Ertesvåg, Roberto Agromayor, Luca Riboldi, Lars O. Nord. Gas turbine exhaust gas heat recovery by organic Rankine cycles (ORC) for offshore combined heat and power applications -Energyand exergy analysis, Energy, Volume 165, Part B, 15 December 2018, Pages 1060-1071.

[8]   Julian Esteban Barrera, Edson Bazzo, Eduardo Kami. Exergy Analysis and Energy Improvement of a Brazilian Floating Oil Platform using Organic Rankine Cycles . Energy, 2015, 88:67-79.

[9]   Ye fang. Development of integrated fault diagnosis system for offshore platform power system. MS thesis. North China electric power university, Baoding. China.2012.

[10]   Yang jiachen. Research on optimal management of large-scale equipment for offshore oil platforms . MS thesis. Tianjin university, Tianjin, China.2004

[11]   Ji xiaofeng. Application of big data in key dynamic equipment field of cnooc offshore oil platform [J]. Science and technology and innovation,2017(16):149-151.

[12]   Li xue. Research on Energy coordination optimization of offshore power system based on Energy Hub. MS thesis. Southwest petroleum university, Chendu. China, 2017

[13]   Anan Zhang, Hong Zhang, Meysam Qadrdan, Xue Li, Qian Li.Energy Hub based Electricity Generation System Design for an Offshore Platform Considering CO2-Mitigation Energy Procedia, Volume 142, December 2017, Pages 3597-3602

[14]   Alabdulwahab A , Abusorrah A , et al . Coordination of interdependent natural gas and electricity infrastructures for firming the variability of wind energy in stochastic day-ahead scheduling[J]．IEEE Transactions on Sustainable Energy,2015,6(2)：606-615．

[15]   Chaudry M,Jenkins N,Qadrdan MCombined gas and electricity network expansion planning[J]．Applied Energy,2014,113：1171-1187．

[16]   Zhang Yibin . Study on the methods of analyzing combined gas and electricity networks[D]．China Electric Power Research Institute,Beijin, China,2005．

[17]   XU Xiandong, JIA Hongjie, JIN Xiaolong, YU Xiaodan, MU Yunfei. Study on Hybrid Heat-Gas-Power Flow Algorithm for Integrated Community Energy System. Proceedings of the CSEE, 2015, 14(35):3634-3642

[18]   Wu yao-zeng, xu zheng-hai, wang wen-xiang, qin xiao-gang. Energy conservation assessment of main mechanical energy equipment for offshore platforms . Inner Mongolia petrochemical industry, 2015, 41(21):53-55.

[19]   Li Bo, zhang zhongdong, kang Yang, yan tao, liu jianjun, zhi shujie, duan linjie, Chen zhenhai. Discussion on the optimization of natural gas pipeline network operation . Oil & Gas Storage and Transportation,2018,37(10):1147-1152.