Application of Improved Distributed Control System in Chemical Industry Production

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As a kind of clean and high quality fuel, natural gas has attracted more and more attention. With the global environmental problems becoming increasingly serious, reducing the use of oil and coal and other energy sources is becoming the key to adjusting national energy structure. It is China's major energy use policy to accelerate the use of wind energy, nuclear energy, solar energy, natural gas and other clean energy. The transportation of natural gas mainly depends on pipeline transportation, which greatly limits the development of natural gas. Due to its small volume and convenient transportation, Liquefied natural gas (LNG) can fully make up for the shortage of natural gas pipeline. After being liquefied, the volume of the natural gas can be reduced by 600 times. LNG can play a good role both in large-scale transportation on the sea and in land natural gas pipeline. Distributed control system has been gradually applied in various fields of industry. At present, it has become the mainstream of industrial automatic control system. Now, the new liquefied natural gas chemical factories are all equipped with a distributed control system. However, the basic control system cannot meet the needs of urban natural gas operators for liquefied natural gas production. With the expansion of the liquefied natural gas market, the city's natural gas operators have also established their own natural gas liquefaction factory in natural gas station. However, because the natural gas pressure on the inlet and outlet of the LNG factories changes with the fluctuation of the city gas load, the distributed control system cannot automatically adjust the production condition according to the pressure fluctuation. In order to solve this problem, this paper studies the natural gas liquefaction factories based on urban natural gas operators. Firstly, the distributed control system is studied. Secondly, it focuses on the application and principle of liquefied natural gas. Finally, according to the characteristics of urban gas, the DCS is improved so that it can meet the demand of liquefied natural gas production. After improvement, the production efficiency of LNG production factories is greatly increased, and its fault rate of operation is reduced. Besides, the whole process becomes more stable and safe.

1. Introduction

In the past 30 years, as the automatic level of the productive process gradually improves, DCS has played an increasingly important role in the field of industrial control. It also plays an irreplaceable role in the safety and stability of industrial enterprises, power and chemical production efficiency. More and more chemical factories start to consider the introduction of new control mode and the transformation of control system. They adopt the new techniques to completely change the existing mode of control, in order to improve the control level of the unit, the control efficiency, and the control strategy (Beierman, et al., 1982). Large scale chemical plants are usually composed of thousands of I/O measuring points, which are connected with the field equipment under the control of the DCS system and maintain the safety of the plant in a stable and safe way. In 1975, Honeywell Company from US releases the TDC2000 system. At the same time, Yokogawa Company, from Japan, releases the CENTUM system. Since then, the process control has entered the era of distributed control (Li et al., 2004; Sun, 2013). Among them, products from 1975 to 1980 are the first generation, while products from 1980 to 1990 years are the second generation, and products from 1990 to now has been called the third generation. DCS is a multi-computer system consisting of the process control level and the process monitoring level with communicating network as its link, whose basic idea is the decentralized control, centralized operation, hierarchical management, flexible configuration, and convenient configuration.

LNG (Liquefied natural gas) is a new type of quickly developing energy in the world (Xia, 2006; Xu et al., 2004; Zhang et al., 2007; Wang et al., 2015; Wang et al., 2016; Scarponi et al., 2016; Zhang and Tan, 2016; Tanabe and Turco, 2016; Van Wingerden and Salaun, 2016). LNG has become a professional, social and international industry (Pang, 2006). LNG industry is developed in the early twentieth Century. The United States begin to study the natural gas liquefaction in 1910. In 1937, the United Kingdom liquefies natural gas to store it, which is used for the winter supply load regulation. With the constant application of LNG, there are more and more LNG production factories. There are many kinds of natural gas liquefaction process, but it is the first choice to meet the requirements of gas utilization in urban gas industry. When the throttle valve is used to regulate pressure in distribution station, it not only produces a lot of noise, but also is harmful to cooling freezing and blocking downstream pipeline. What matters most is that there lies great pressure drop when adjusting the pressure, which will lose a lot of pressure energy (Mahmood et al., 2008; Xu et al., 2010). In 1968, Peak shaving type liquefying device, established by the United States Northwest Natural Gas Company, uses the liquefaction process of expander. The Idaho National Laboratory in America designs using small pressure gas pipeline to liquefy natural gas. This procedure can be directly applied to the pipeline natural gas station without being pre-treated by dehydration CO_2-removal. Figure 1 is a model of urban natural gas supply.
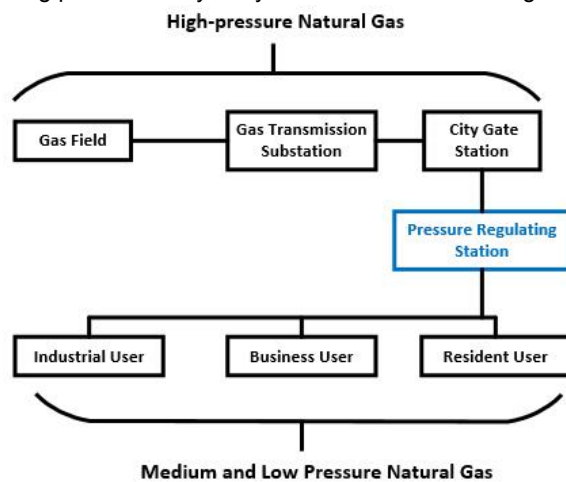

Figure 1: The model of urban natural gas supply

2. Distributed Control System

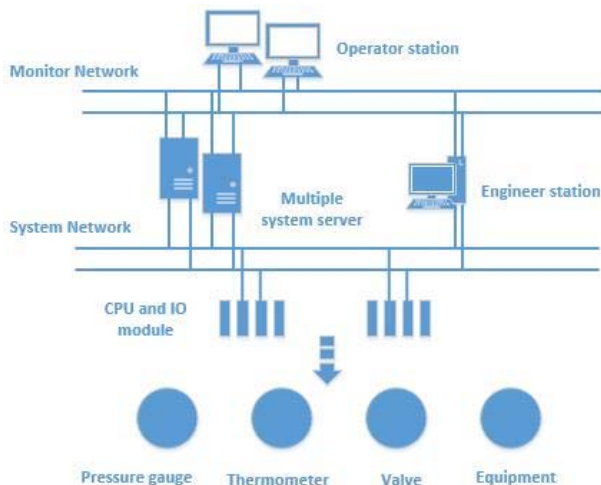### 2.1 Distributed Control System Structure

Figure 2: The structure of DCS

Distributed Control System is based on computer network and communication technology. It includes process control and process monitoring of system, and according to the system function, it can be divided into a

hierarchical structure which contains the process control level, control management level, production management level, and management level. It is characterized by decentralized control, centralized management, integration, information, intelligence, and miniaturization. DCS can complete automatic detection, automatic adjustment, automatic protection, automatic operation and other functions. DCS system is an integrated automation system which is composed of the engineer station, operator station, field control station, communication control station, data station. These stations are connected by control network using fieldbus technology. Then DCS can complete large or medium-sized distributed control system (DCS), and large data acquisition and monitoring system (SCADA) function. Figure 2 shows the structure of DCS.

2.2 DCS Hardware and Software Configuration

The hardware structure of the system is mainly composed of engineer station, operator station, field control station (including the main control unit and I/O unit equipment), control station, communication system, network server, network monitoring and control network system etc. The function of the engineer station is to run the corresponding configuration management program, and to centrally control and manage the whole system. The operator station is used to run the corresponding real-time monitoring program so as to monitor and control the whole system. The function of the data station is to run the corresponding management procedures, and then it can manage the entire system of real-time data and historical data. The function of the field control station is to run the corresponding real-time control program in order to control and manage the site. Field control station is mainly responsible for data acquisition, control output, and control operation, etc. It includes CPU main control module, power module, and IO module.

The system software includes the configuration software of the engineer station, operator station software, field controller software, and data station software, etc. Configuration software is installed on the engineer station, which includes database control, equipment configuration, controller configuration, report configuration, graphics configuration, engineer online downloading, historical data query and other components. Operator station software is installed on the operator's station, which helps users to complete monitoring human-computer interaction interface, including flow charts, trends, parameter list, alarm, and other operating functions. The data station software is installed on the data station, which completes the centralized management and monitoring of the real-time and historical data system. It also provides the service for the data request of each station. The software of the control station is installed on the main control unit in the field control station, which completes the data acquisition, conversion, and control operation.

3. Production Technology and Application of LNG

Liquefied natural gas (LNG) is a kind of low-temperature liquid mixture, which is formed by pre-treating natural gas raw material and removing the impurities, and then through the low temperature freezing process at about -162 ℃. The production process generally contains the refrigeration cycle, mixed refrigerant refrigeration cycle, and expansion refrigeration cycle. Before going into the users, high pressure natural gas, transported by long distance pipeline, needs to reduce the pressure to the required pressure level in the sub stations, and then it can be transported to the city gas transmission and distribution network to supply downstream users. Antihypertensive treatment loses a lot of energy. In order to make full use of the energy, expansion refrigeration can be used to produce LNG. The turbine expander is to achieve energy conversion by changing the rate of the working fluid. The working fluid expands in the turbine expansion to obtain kinetic energy, and output it by the external wheel, through which the energy and temperature of the working fluid can be reduced. The production process is also called differential pressure liquefaction process. High pressure natural gas depressurizes in the way of isentropic expansion in the turbo expander, and refrigerating output of the process is as follows.

$$Q = m(h_{in} - h_{out})\eta_1 \tag{1}$$

Among them, Q is the refrigeration output, m is the gas mass flow rate, h_{in} and h_{out} are respectively inlet enthalpy and outlet enthalpy of the expansion working substance, and η_1 is the turbine efficiency. If all of the expansion work is used up, the energy loss of the process is as follows.

$$\Delta E = T_0 S_g = T_0 m(s_2 - s_1) \tag{2}$$

Among them, ΔE is the loss of energy, s_g is the entropy, and s is the entropy ratio. The process of natural gas liquefaction includes pre-treatment (purification), liquefaction, storage, loading and auxiliary system, among which the main process includes natural gas purification and liquefaction process. First of all, dehydration is conducted through molecular sieve. Material, whose molecular diameter is less than the aperture diameter of the molecular sieves, can enter the zeolite crystal. Then it will be absorbed. Otherwise, it will be rejected. The

molecular sieve also determines the order of preferential adsorption according to the polarity of different substances. Generally, High polar molecules are more likely to be adsorbed. The second step is the removal of benzene. Activated carbon is adopted to remove benzene and heavy hydrocarbons, to make sure that the benzene content is below 10ppm, and the heavy hydrocarbon content is below 10ppm. The third step is the removal of carbon dioxide. Liquefied gas removes carbon dioxide by using 13X molecular sieve, so that the content of carbon dioxide is less than 100ppm in the liquefied gas flowing from the bottom of adsorption tower. The fourth step is to remove mercury. Because mercury at low temperatures will cause serious corrosion to aluminum equipment and pipes, it must be removed. Sulphur impregnated activated carbon is used to remove mercury, so that the content of mercury in the air after removing mercury is less than 0.01g/Nm3. Finally, the purified natural gas is liquefied. After purification, the main component of natural gas is methane. When the natural gas is cooled to -162 ℃, it will be condensed into liquid. The methane under pressure will be liquefied at high temperature, and then the liquefied methane can be obtained after cooling and depressurization. It is this principle that can be exactly used in a variety of liquefied refrigeration cycles. After being cooled, condensed and super-cooled to -162 ℃, liquefied natural gas (LNG) can be produced. Figure 3 is the work flow of LNG plants.
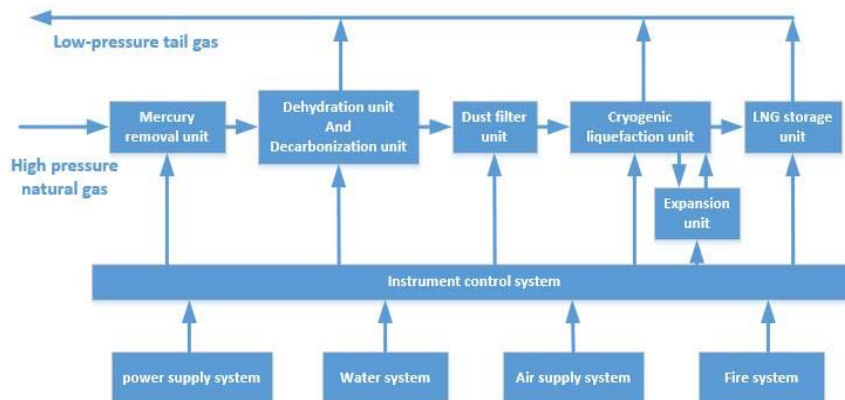

Figure 3: The work flow of LNG plants

Main technical features of LNG production by pressure energy device are as follows.

1) The booster expansion turbine is used to make expansion refrigeration, by using natural gas pipeline pressure gap. At the same time, the output power in the expansion process is absorbed by coaxial supercharger to increase the raw material gas pressure, so that the liquefied natural gas has low energy consumption.

2) Because the raw gas inlet temperature is low, gas heat exchanger between the raw material gas and pressurized airflow is set up. Therefore, the raw gas temperature of adsorbent bed is low to enhance the adsorption capacity of adsorbents.

3) The switch of the adsorption tower is controlled by the time program, and the valve position switch is interlocked. If the valve switch is not in place, the interlock will be realized so that there is enough time left to make the exchange go smoothly.

4. System Improvement and Implementation

Differential pressure liquefaction LNG production process mainly uses the pressure difference between the import and export for production. The characteristic of urban gas pipeline network is a low-pressure at night and at noon. LNG needs more stable import and export pressure to protect production. The fluctuation of gas pressure in cities and towns is frequent, which has a higher requirement for the skill level of workers and the automation level of all equipment. The traditional DCS system is mainly aimed at the design of stable production process, and cannot automatically adjust the working conditions of the equipment with the pressure fluctuation of the gas source. Workers have a high working pressure, and the safety of production equipment cannot be guaranteed. In this paper, according to the defects of DCS, an improved method is proposed to automatically adjust the working conditions according to the pressure of gas source. The automatic control system is optimized to reduce the frequency of the expansion machine so as to realize the continuous and stable operation of the device, improve the operation efficiency of the equipment, and ensure the safety of equipment and people.

According to the actual operation of the device, the operating conditions of the device can be divided into two conditions, night and daytime conditions. Automatic operation mode is used to take place of manual operation mode in the new operation mode. The automatic mode can be divided into two kinds of situations: the conversion period (the period of the pressure change of the gas source) and the stable operation period (the stable period of the gas source pressure). The conversion period is divided into the working conditions from the night conditions to the day conditions, which is from low load conditions to the high load conditions, and the working conditions from day conditions to the night conditions, which is from the high load conditions to low load conditions. In the conversion period, the most important is the nozzle of the expansion and the switch of the reflux valve. Load increases with the nozzle opening, and load reduces with the nozzle closed. Contrarily, load reduces with the reflux valve opening, and load increases with the reflux valve closed. The opening and closing degree of the reflux valve and its opening rate are determined by the technical people with the engineer's operating authority. After the system is completed, when the system adjusts the working condition, it can switch automatically according to the set parameter

Through the improvement of the system, the operator only needs to monitor the production status of LNG, and the high and low working conditions will be automatically conversed by the program. Figure 4 is the system diagram after the improvement.
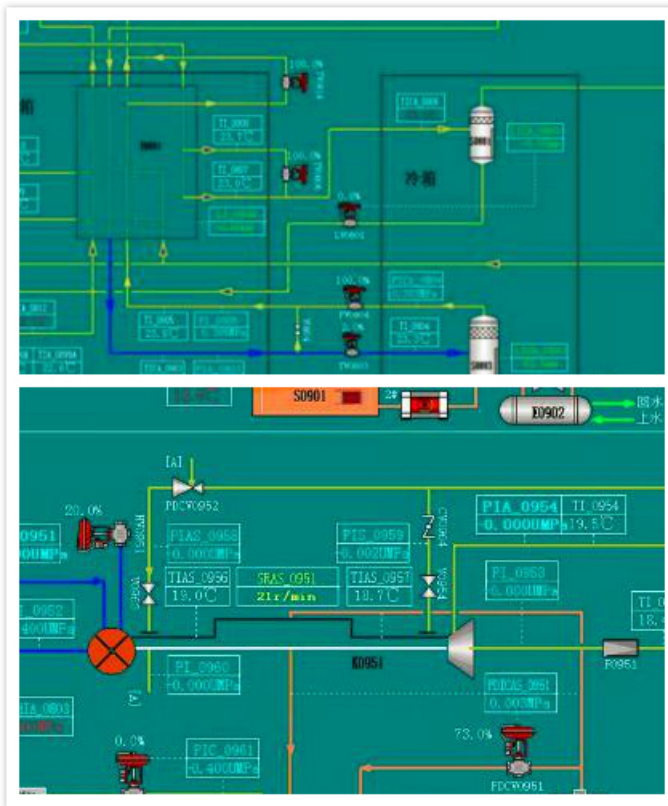

Figure 4: The system diagram after the improvement

5. Experiment and Analysis

5.1 System Platform

This paper uses HOLLiAS-MACS V 5.2.4 of Beijing Hollysys as the DCS platform. LNG differential pressure liquefaction production factory is the peak shaving LNG production equipment of a certain city. The software of the system includes configuration software, operator station software, data station software, and control station software. The compiler environment of the software configuration is as follows: Intel (R) Core (TM) i5-4300M @2.60GHz is the hardware environment, the Memory is 4G, and Windows 7 is the software environment.

5.2 System Operating Results and Analysis

Under the condition of the same gas source pressure, we calculate the equipment failure rate in 500 hours. As can be seen from table 1, the system failure rate is significantly lower than that before the transformation.

Table 1: The equipment failure rate

	Improved DCS	traditional DCS
Failure rate (%)	0.71	4.58

Through the transformation of the system, the automatic degree of the system is improved, and the workload of the operator is reduced. LNG production equipment matches the pressure change of gas source more scientifically, and the working efficiency is largely improved. As seen from table 2, 1000 hours of LNG production has been greatly increased.

Table 2: The LNG output of liquefaction plant

	Improved DCS	traditional DCS
LNG output (kg)	291670.00	233423.00

6. Conclusion

In this paper, an improved DCS system is proposed to solve the fluctuation of urban gas LNG production conditions. Firstly, the distributed control system is studied. Secondly, it focuses on the application and principle of liquefied natural gas. Finally, according to the characteristics of urban natural gas, the design of DCS is improved, so as to meet the demand of liquefied natural gas production. The production efficiency of the improved LNG production plant is greatly improved. At the same time, the failure rate is reduced, and the safety is more stable.

References

Beierman G.J., 1982, Self -turning regulators for a dals of multification and Systems, Automatica, 15(2), 209-215

Li Y.B., Sun Y., 2004, Analyzed and Prospected Technology of DCS. Control & Automation, 7, 11-12.

Mahmood F., Mahdi D., 2008, Recoverable energy in natural gas pressure drop stations: a case study of the khangiran gas refinery. Energy, Exploration & Exploitation, 26(2), 71-82.

Pang L.M., 2006, Discussion on the import of liquefied natural gas in China. Oil Forum, 5, 102-105.

Scarponi G., Landucci G., Ovidi F., Cozzani V., 2016, A lumped model for the assessment of the thermal and mechanical response of lng tanks exposed to fire, Chemical Engineering Transactions, 53, 307-312, DOI: 10.3303/CET1653052

Sun Y., 2013, The Design and Implementation of Process Control Functions of DCS. Xiamen University.

Tanabe M., Miyake A., 2016, Effective implementation of inherently safer design during design phase of modularized onshore lng projects, Chemical Engineering Transactions, 48, 535-540, DOI: 10.3303/CET1648090

Tanabe M., Turco C., 2016, Technical-hse management system in the design phase of an lng plant project, Chemical Engineering Transactions, 48, 541-546, DOI: 10.3303/CET1648091

Van Wingerden K., Salaun N., 2016, Lng-fueled-engine safety: design of protective measures using cfd, Chemical Engineering Transactions, 48, 31-36, DOI: 10.3303/CET1648006

Wang C., Qin H.D., Liu G., Guo T. (2016). Study on sloshing of liquid tank in large LNG-FSRU based on CLSVOF method, International Journal of Heat and Technology, Vol. 34, No. 4, pp. 616-622. DOI: 10.18280/ijht.340410

Wang C., Qin H.D., Shi Z.Q., Li J.X. (2015). Research on calculation method of thermal field of large LNG-FSRU under ultra-low temperature, International Journal of Heat and Technology, Vol. 33, No. 3, pp. 67-72. DOI: 10.18280/ijht.330309

Xia L.H., 2006, China's LNG development in the new energy landscape. International Petroleum Economics, 8, 103-107.

Xu J.F., 2004, Thoughts on developing the strategic value of LNG industry in China. Urban Gas, 5, 194-496.

Xu W.D., Zheng H.P., Lang X.M., Chen Y.J., Fan S.S., 2010, Recycling of natural gas pressure energy from high-pressure pipeline network. Chemical Industry and Engineering Progress, 29(12), 2385-2389.

Zhang J.X., 2007, Discussion on the interchange between Beijing LNG and Shaanxi Beijing gas. Urban Gas, 6, 98-99.

Zhang R., Tan H., 2016, Multi-objective optimization of power supply system for shipping lng off-loading process based on switching markov chain and genetic algorithm, Chemical Engineering Transactions, 48, 697-702, DOI: 10.3303/CET1648117