DYNAMIC SIMULATION APPLICATION IN THE NATURAL GAS LIQUEFACTION PLANT

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China Huanqiu Contracting & Engineering Corporation Ltd (HQC-BJ), affiliated company of China National Petroleum Corporation (CNPC), has continued to develop new process and improve existing technology for hydrocarbon liquefaction and fabrication businesses and cryogenic storage business, since 1990’s, especially liquefied natural gas (LNG).

Nowadays LNG train capacity becomes larger, LNG Plant becomes to have multi trains, as well as environmental protection demand becomes more strictly throughout the world. Therefore, the performance-based design and refinement-based design are becoming the requirement of modern engineering design, and then dynamic characteristics of critical equipment and process systems need to be taken into account. HQC has studied dynamic simulation technology to apply in the LNG plant. The dynamic simulation model is built based on the proven practices of a mature LNG plant (for which HQC had provided all the technical and engineering construction services, including process design package of HQC-DMR (Dual Mixed Refrigerant developed by HQC) liquefaction process, front end engineering design, EPC and commissioning and start up.

In-house study involves liquefaction system, hydrocarbon fabrication and LNG storage, and analyzes various scenarios, e.g. emergency shutdown, black start up, compressor trip and so forth. Combining with engineering experience, operation and start up experience, the possible scenarios with large impacts to the operation and to the critical equipment are identified via the simulation procedure and simulation results, and the potential control optimization and key points of engineering design are also obtained. This paper will introduce the details for the dynamic simulation study for liquefaction unit.
1. INTRODUCTION

China Huanqiu Contracting & Engineering (Beijing) Co. Ltd. (HQC-BJ), affiliated with China National Petroleum Corporation (CNPC), is a technology-oriented state-owned enterprise. It engages in such diversified business as consultation, R&D, engineering, procurement, construction, construction management and commissioning guidance. It has fulfilled the tasks of consultation, engineering, construction and EPC contracting for over 2,000 cross-industry large- and medium-scale domestic and overseas projects in more than 60 years, including 14 categories of plants.

HQC has abundant experience in engineering and cryogenic technology, involving air separation and liquid nitrogen wash and ethylene complex. From the end of last century, HQC launched liquefied hydrocarbon businesses, to engineering design and construct Liquefied Natural Gas (LNG) receiving terminals and Liquefied Ethylene Gas (LEG) receiving terminals. During that period, HQC-owned intellectual property technology packaged in cryogenic storage and receiving & re-gasification of liquefied hydrocarbons has been formed. Furthermore, in 2009, according to CNPC group business development strategy planning, HQC undertook the responsibility of technology development of natural gas liquefaction. After more than 5 years of research, HQC-DMR, a new liquefaction process, was proposed and put into industrial applications. The process is a dual mixed refrigerant liquefaction process, consisting of two closed cycles, pre-cooling cycle (MR1 cycle) and liquefaction cycle (MR2 cycle). It has three process structures, of which the typical schematic studied for the dynamic simulation is shown as below, Figure 1.

![Figure 1 Schematic diagram of HQC-DMR (patent number: CN 201110328354.5)](image)

HQC-DMR technology was first applied industrially in Shaanxi province of China, Ansai LNG project with the capacity of 0.5 million tonnes per annum (mtpa). In August 2012, the plant was built and started up successfully. The overview of the plant is as shown in Figure 2, configured with one LNG train, one LNG storage tank and ten truck loading arms, as well as the utilities and auxiliary facilities. HQC provided all engineering and technical services.
In the second half of 2011, Tai’an LNG project, the second project using HQC-DMR, was begun to engineering, and completed the mechanical completion at late of 2013, started up successfully and passed the performance test in August 2014, transported first truck of LNG product on August 30th. The plant is located at Shandong Province of China, and has a capacity of 0.6mtpa of LNG production, shown in Figure 3. It maximized to use domestic materials and equipment in China, involving cold box (PFHE), mixed refrigerant compressors, boil off gas (BOG) compressor with cold suction, distributed control system (DCS), and so forth. The research of dynamic simulation is just based on the existing plant.

Besides the two already built facilities mentioned above, HQC had also developed two PDPs (process design package) for large-scaled LNG projects using HQC-DMR. One is for tropical environment and with a capacity of 2.6mtpa; the other is for polar environment and with a capacity of 5.5mtpa. In addition, HQC has provided Pre-FEED, technical solutions for many domestic and overseas natural gas liquefaction projects.

Nowadays, global LNG demand is ever-increasing. LNG Plant becomes to have more trains and much larger train capacity. Therefore, the performance-based design and refinement-based design are becoming the requirement of modern engineering design, and then dynamic characteristics of critical equipment and process systems need to be taken into account [1-4]. HQC is making continuous progress, to improve existing technology [5-7] and to meet the requirements for more efficient and safe. This paper shows some HQC’s research of dynamic simulation in LNG plant since 2016.
2. DYNAMIC SIMULATION

2.1 Research Objectives

Dynamic simulation focuses on the transition process and describes the variation of parameters with time. It can be used to predict the rationality and operability of engineering design, to optimize control system, to evaluate operation safety of facility and train operators.

Due to the characteristics and functions of dynamic simulation, the research work has been carried out. It is desired to evaluate or improve our existing technology and engineering design, and for future LNG projects provides engineers the behavior and performance of process system and critical equipment in FEED and EPC phase to assist in determining control scheme and operation procedure, as well as design improvement.

The proven practices of a mature LNG plant built with independent intellectual liquefaction technology (HQC-DMR) are selected as research objects. Because we have sufficient simulation input conditions, design data and equipment specification data, and well know the device performance. The extensive information and experience will benefit for the model creation and problem analysis, and favorable to ensure the correctness and accuracy of the dynamic model.

LNG plant generally has the units of purification, liquefaction, hydrocarbon fabrication unit and LNG storage. The dynamic simulation analyses for the units have carried out in-house study. This paper will only focus on the liquefaction unit dynamic simulation.

2.2 Process Description

In the liquefaction process flow, there are two refrigerant compression cycles (MR1 cycle and MR2 cycle), and two cold boxes (plate fine heat exchange) operated in parallel for heat exchange of natural gas and refrigerant. In addition, a scrubber tower is configured to remove heavier hydrocarbon from natural gas after precooling, and the cold energy required by scrubber reflux is matched with the refrigeration duty of cold box. The process flow is shown as Figure 4. For simplicity, control valves and compressor anti-surge circuit are not shown in this figure, but are included in the dynamic simulation.

(1) Natural Gas Process Flow

Natural gas feeds into cold box from top side, and flows downwards. It is precooled by MR1 refrigerant cycle, and condensed partially, and then the gas-liquid mixture flows into scrubber tower after appropriate decompression. Via cryogenic fractionation, heavier hydrocarbon of natural gas flows out from scrubber bottom to destabilization facilities. Overhead discharge flows into cold box and cooled partly, after phase separation the liquid is pumped into scrubber as top reflux, and gas phase returns to the cold box for further cooling to liquefaction. Finally, liquefied natural gas (LNG) flows out from the cold box bottom, and is decompressed and routed to storage tank.

(2) MR1 Refrigerant Cycle

MR1 (mixture of ethane and propane) is compressed by a two-staged centrifugal compressor, and then cooled by desuperheater and condenser and subcooler in sequence. Subcooled MR1 feeds into Cold Box, in which the MR1 will flow downwards and split into two parts to provide refrigeration at two temperatures in two different pressure level, that is, low pressure (LP) loop and high pressure (HP) loop, to pre-cool natural gas and MR2. After
throttle and heat transfer, the MR1 of LP loop flows out from Cold Box and back to MR1 Compressor 1st stage suction, the HP loop back to 2nd stage suction.

(3) MR2 Refrigerant Cycle

MR2 is the mixture of nitrogen, methane, ethane and propane, and compressed by a two-staged centrifugal compressor, ether. It is cooled by 1st stage discharge cooler and 2nd stage discharge cooler in sequence, and then cooled further by MR1, leading to partial condensation. After phase separation, gas and liquid flow into different channels in cold box, and the two streams cooled down to different temperature level and then throttled to provide refrigerant duty for liqation and subcooling of natural gas. Finally, the combined MR2 streams flow back to MR2 compressor suction.

![Figure 4 Process Flow Diagram of Liquefaction Unit](image)

2.3 Modeling

The dynamic model is built and run using Aspen HYSYS software and referring to process flow of Figure 4. In the model, all control valves and control loops are included, all equipment and critical pipe are rated in details based on existing LNG Plant, as well as emergency shutdown (ESD) logics are also configured.

Tuning model makes the dynamic basic model run stably and correctly. The basic model is running at normal case and has attained steady state condition, and the operation parameters are well matched with design data. The basic model provides initial state for scenario analysis, involving the scenarios of ESD of compressor, normal shut-down, power failure etc.

In the research, besides the above mentioned scenarios, the black start-up has also been analyzed. This paper takes ESD case and black start-up case as examples to show the research of dynamic simulation analysis.

2.4 Simulation Case Example

(1) MR1 Compressor ESD

The ESD of compressor is triggered by stopping the main motor of respective compressors thereby cutting off the power supply. The model is run for 20 seconds with constant steady state conditions. At 20 seconds from the beginning of the simulation, the ESD sequence for MR1 trip scenario is triggered by pressing the MR1 compressor
trip button in Cause & Effect matrix. When MR1 compressor ESD is launched, operating conditions for MR2 will change accordingly and will be tripped due to high-high discharge temperature at around 157s.

The operating points and process parameters are recorded during the transient time period. Figure 6-7 show the compressors operating locus, the operating points enter surge area for very short time (less than 1 second) and then back to normal operation area, which means the compressors stopped safely.

Figure 5 MR1 Compressor (C-2001) Speed in MR1 Compressor ESD Case

Figure 6 MR1 Compressor (C-2001) Operating Locus

Figure 7 MR2 Compressor (C-2002) Operating Locus
Besides monitoring compressor operating locus, the whole liquefaction system responses (Figure 8) are also checked after the trip, including temperature, pressure and mass flow of streams, and valve opening, etc.

Figure 8 Liquefaction system responses after MR1 compressor trip

When MR1 compressor tripped, NG supply is to stop by closing feed valve. Reflux drum outlet valve starts to close while shut down reflux pump at a time of 60s after the MR1 compressor ESD launched. Dynamic response of the scrubber column system is recorded, and shown partly in Figure 9. The column overhead pressure and temperature dropped in some degree and remained in design range, and reflux separator level lowered to about 40% after reflux flow stop.

Figure 9 Scrubber column system partial responses
(2) Black Start-up

As normal operating steady state model is not suitable for black start-up case study, a separate initial dynamic simulation model has been prepared. The start-up case study is conducted by implementing operation procedures on the initial dynamic simulation model that has attained steady state condition. The operation procedure is configured in the event schedule referring to the operation manual and the equipment supplier’s start-up and commissioning procedures.

Liquefaction unit black start-up runs step-by step according to operating procedure, starts from nitrogen pressurization, and then natural gas and refrigerant filling, etc. There are 42 steps of operation in total. The operating points and process parameters are recorded during the transient time period to check the LNG system response during black start-up period, part of them shown in Figure 10.

![Figure 10 LNG system responses during black start-up period](image)

Compressors start up based on the compressor start-up profile, take MR2 compressor 2nd stage as example, the operating locus is shown as the first picture of Figure 10. The compressor speed raise up rapidly to the minimum commissioning speed at first, and then increases gradually. Correspondingly, adjust control valve opening and ASV opening, make-up refrigerant and enlarge natural gas supply, the refrigerant circuit is established and compressor discharge pressure and flow rate increase, the temperature of cold box and column decrease gradually. Finally the load of liquefaction unit reaches to the total percent of design.

3. CONCLUSIONS

The dynamic simulation flowsheets, including cryogenic heat exchanger, compression strings & refrigeration loops and scrubber column, are built based on the proven practices of the mature LNG plant, which provide a framework to evaluate transient operation and variable operation. The research results show that the interaction of the physical process and the control system has been efficiently studied of different operating scenarios. The control system is effective, and the ESD logic is reliable and operable. In the dynamic simulation for start-up case, the key steps of operation procedure are further clarified, and sensitive design points are determined. Furthermore, the operation procedure is solidified in the model, which provides a good model foundation for other case study,
such as start with pressure etc. The dynamic simulation provides a method of verification and improvement for engineering design and operation.

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REFERENCES


