

Virtual commissioning of a gas handling system

Gas reliquefaction units were designed by means of stationary and dynamic process simulation models

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Gas cargo such as liquid natural gas, ethane, ethylene and propylene is transported in liquefied form under cooling temperatures and pressures. Typically, pressures are low, which leads to very low temperatures. Although the cargo tanks are well insulated, gas continuously evaporates from the liquid cargo. This gas is called boil-off gas and has to be reliquefied during maritime transport in the reliquefaction system.

The reliquefaction system by TGE Marine Gas Engineering for five new vessels of Navigator Gas shipping company was designed with UniSim Design. First, a stationary simulation model was used for the basic design. Later, a dynamic simulation model was developed for the design of the automation and control system.

There are many differences between automation systems that are installed on a vessel and automation systems of a production plant. For instance, it is much more difficult to provide support and maintenance on a vessel than on land. As a consequence, sea based automation systems have to be designed, verified and tested very carefully. The requirements in this field are to some extent similar to the requirements in the automobile and aviation industries.

In order to develop automation systems that are safe, reliable and error free, automobile and aviation industries rely on hardware in the loop simulation. With

this technology, the automation system can be verified within a simulation based test environment.

TGE has decided to use hardware in the loop simulation in the design of the automation system of the new cargo handling system, too. This allows not only the development of an error-free automation system but also a substantial reduction in commissioning time.

Reliquefaction system

About 50% of the existing fleet of liquefied ethylene (LEG) carriers uses TGE designed cascade reliquefaction units to cool down cargo and maintain tank pressure. Liquefied ethylene is usually transported using semi-pressurised, fully refrigerated vessels that are equipped with IMO type C tanks (see **Figure 1**) and cascade refrigeration systems.

The basic technology of the cascade refrigerant systems have remained unchanged for years. The cargo tanks are cooled by an open cooling system compressing the

BOG in a two-stage process and condensing it against a refrigerant (see **Figure 2**). Two crank, oil-free piston compressors usually serve as cargo compressors. The refrigerant (propylene or R404A in place of R22) is compressed by oil injected screw compressors and condensed against seawater.

To date, the biggest ethylene carriers in operation are 22 000 m³ vessels built by Jiangnan Shipyard for Navigator Gas. A new generation of these vessels with 21 000 m³ capacity is under construction and the first of five vessels are to be delivered in 2014.

The vessels are designed to carry 21 different LPG, chemical gas and chemical cargoes. For 15 of them (including ethylene, propylene, ammonia, VCM and butadiene), refrigeration is provided. The vessels are capable of transporting up to three different grades, two of which may be cooled at the same time. Operating conditions and modes vary widely depending on the specific cargo.

A challenge in the design of the reliquefaction units was to improve performance and operability in order to meet increased requirements for loading rates and cooling down times. In addition, the same reliability and robustness of the units, which have operated successfully for 14 years, had to be maintained. As an example, cooling down capacity for ethylene in one-grade operation is 50% higher for the



Figure 1 5500 m³ bi-lobe tank under construction at Jiangnan heavy industry site in Shanghai

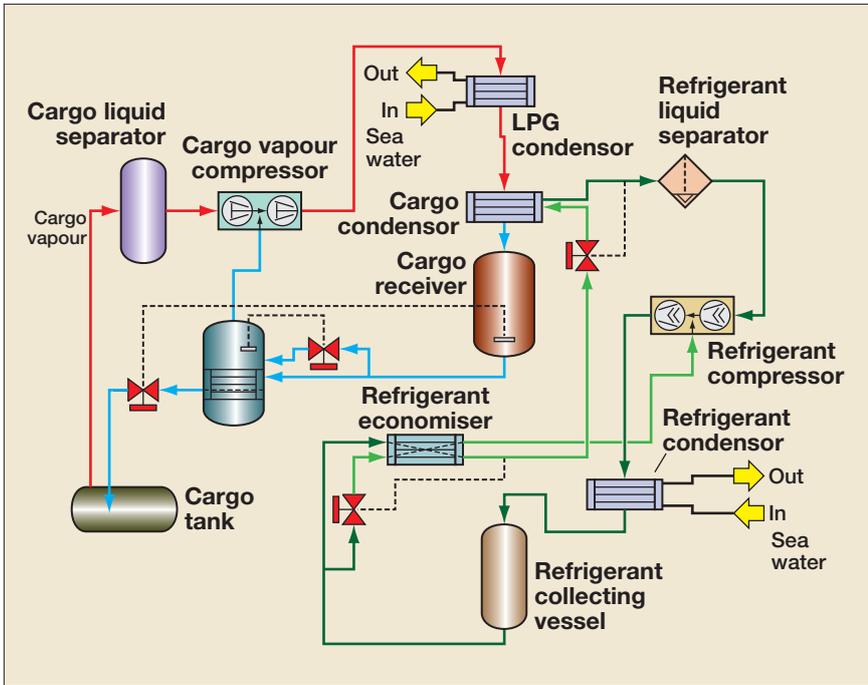


Figure 2 Reliquefaction system

new systems. In order to meet all requirements, compressors of higher capacity and new modes of operation have been introduced.

Dynamic plant simulation and design of automation system

Dynamic Process Simulators like Honeywell UniSim Design, Invensys Dynsym, or AspenTech

Aspen Hysys Dynamics are based on so-called first principle process modelling engines that allow realistic modelling of the transient behaviour of processes typically found in the oil and gas and chemical industries. In order to create a process model, the user selects readily available components and thermodynamic packages to define physical properties and phase equilibria of the system and then creates a flowsheet by adding and linking generic unit operation models (such as pipes, vessels, pumps and distillation columns) and control equipment (valves, PIDs, and so on). The resulting model can be initialised to a specific initial condition and run through different predefined scenarios as part of a dynamic simulation study.

Dynamic simulation studies are a standard tool in the process industries for analysing and optimising transient process behaviour. Application examples for operability or safety studies include dynamic flare load estimation in

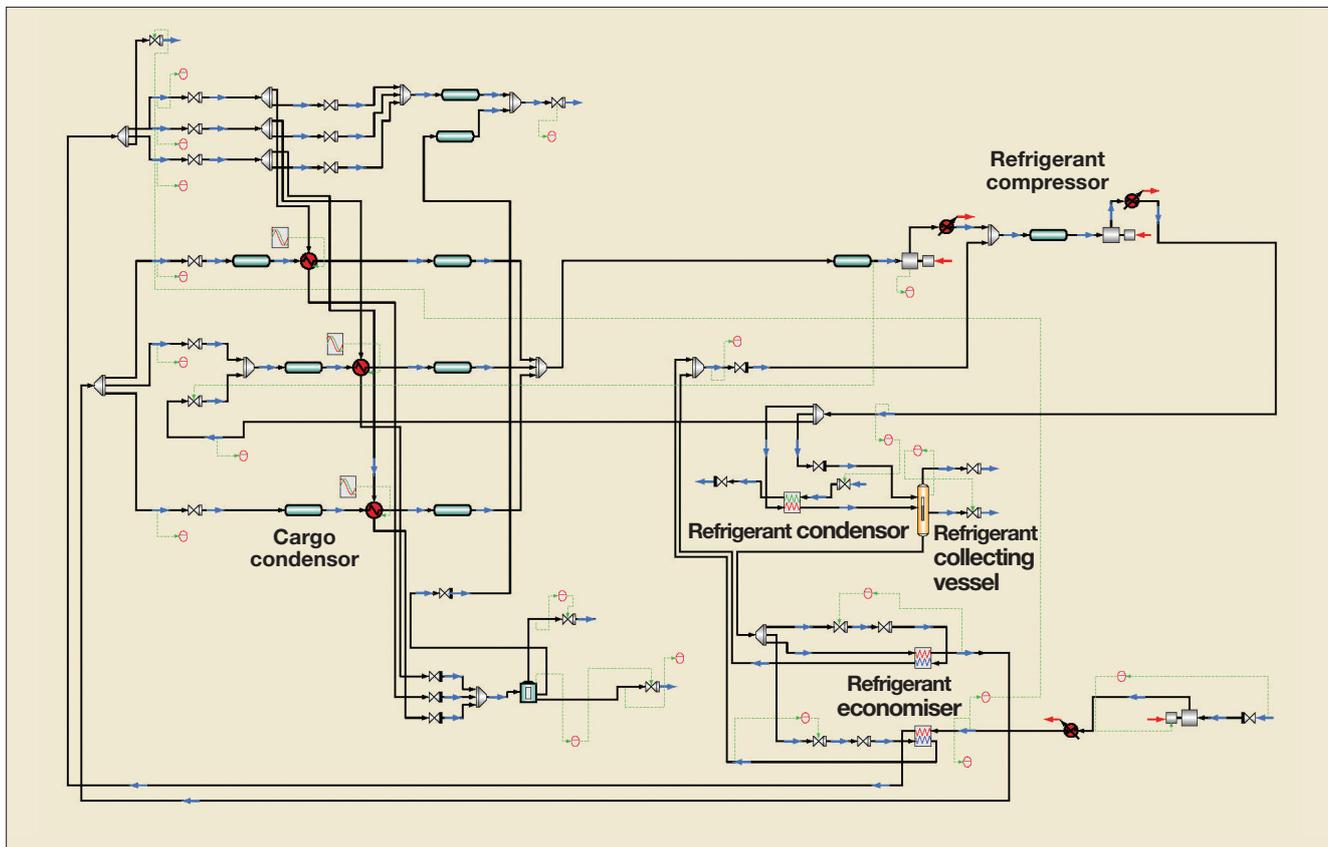


Figure 3 Dynamic simulation model of reliquefaction system

refineries¹ or onshore gas fields,² and compressor studies.³

In order to design a control concept for the reliquefaction system, a dynamic simulation model was developed (see Figure 3).

This model served as the basis for the design of a new control concept that makes it possible to operate the reliquefaction system with all cargoes and all operation modes within a single control structure. It is TGE's first fully automated cascade refrigerant cycle for LEG carriers. In addition, the reliquefaction system is kept in a stable and stationary operation point independent of any load on the system. In order to ensure that the reliquefaction system operates in a satisfactory manner in all operating conditions, special attention was paid not only to efficiency but also to robustness of the solution.

Hardware-in-the-loop simulation

Hardware-in-the-loop (HIL) simulation is a technique that is used in the product development cycle in which real components interact with simulated components.⁴ Early

applications date back to the 1970s.⁵ Today, HIL simulation has become an integral component in the development process of electronic control units especially in the automotive and aviation industries.^{4,6} In the basic structure of a HIL simulator, the control unit is a real component and the plant is simulated.

Due to the fact that a gas carrier

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cargo handling system is installed on a seagoing vessel, activities such as troubleshooting and maintenance are difficult to handle. As a result, the automation system of a gas carrier cargo handling system has

to be designed, verified and tested very carefully. The aim is to have an error-free system. Figure 4 presents the HIL simulation structure of TGE's gas carrier cargo handling system.

The automation system of TGE's cargo handling system is based on a Siemens S7 programmable logic controller (PLC).

In order to test the automation system, two simulators were used: Simit and UniSim. Simit can be smoothly integrated into Siemens automation hardware and software infrastructures and supplements

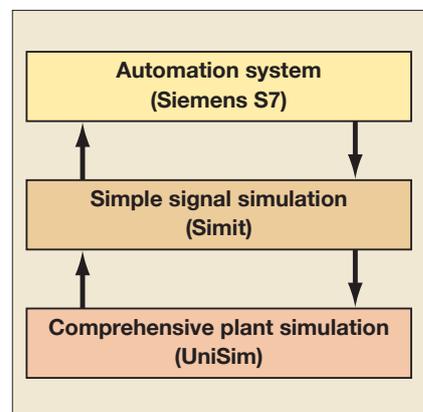


Figure 4 HIL simulation of TGE's gas carrier cargo handling system

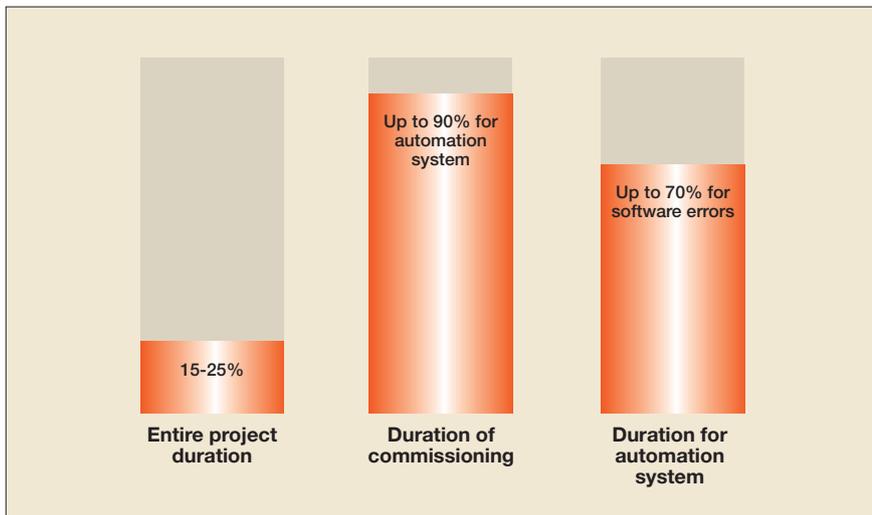


Figure 5 Fraction of commissioning and project duration for software error elimination

the automation interface hardware (Profibus DP, Profinet IO). Communication between the automation system and Simit is carried out as in the real system at the field bus level.⁷

Simit does not provide a first principles modelling engine. Consequently, a dynamic UniSim model was used for testing the reliquefaction system. In these tests, Simit established communications between UniSim and the S7 PLC. The interface between UniSim and Simit was developed using UniSim Design OLE Automation client-server technology.

Virtual commissioning of automation system

Elimination of errors and debugging of automation software is one of the main tasks during a system's commissioning phase. In the case of machine tools, a study from 1997 provides the data for **Figure 5**.⁸ The duration of commissioning takes approximately 15-25% of the entire project. About 90% of this period is required for commissioning the automation system, of which up to 70% are needed for the elimination of software errors (see **Figure 5**).

Commissioning engineers for gas carrier cargo handling systems still experience the same difficulties. In addition, commissioning of these systems has to deal with a core problem: commissioning time is very limited. Some preliminary testing without cargo can be done

in the shipyard. Subsequently, a trial run with one cargo and duration of about one week takes place. It is neither possible to verify the complex logics of the automation system in detail nor to analyse and optimise the dynamic behaviour of the reliquefaction system for different cargos and load scenarios. As a consequence, TGE decided to carry out a detailed HIL simulation study of the gas

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carrier cargo handling system at an earlier design stage.

Simit provides a test environment for the S7 based automation system. A strong point is its ability to test the logic controls of the S7 PLC. Therefore Simit was used to test and verify the logic controls of the cargo system.

UniSim was employed for a detailed analysis of the S7 code components that control the central reliquefaction system. The dynamic

behaviour of this system was examined for a representative subset of cargos and all load scenarios.

In a final test session, human machine interface, start-up behaviour, normal operation and several fault scenarios were verified with experienced engineers from the shipping company.

As a result of these inquiries, several logic faults and control algorithm specific implementation errors have been eliminated in front of the tests at the shipyard and the trial run.

Conclusion

TGE Marine Gas Engineering has developed a new, more flexible, and more powerful gas carrier cargo handling system. This system is able to handle a high number of different cargos such as LPG, gases and chemicals. For the majority of these cargoes, refrigeration is provided. This function is performed by reliquefaction units that were designed by means of stationary and dynamic UniSim Design process simulation models.

Elimination of errors and debugging of automation software is one of the main tasks during the commissioning phase of a cargo handling system. Due to the fact that commissioning time is very limited, the complex logics of the automation system and the dynamic behaviour of the reliquefaction units cannot be verified in detail during this phase. Therefore, TGE decided to carry out a detailed HIL simulation study of the gas carrier cargo handling system at an earlier design stage.

In the HIL simulation study the automation system was extensively tested and evaluated. Simit was used for the verification of the complex logics. The S7 code components, which control the central reliquefaction system, were tested by connecting them to a dynamic UniSim Design process simulation model and carrying out a virtual commissioning. As a result, several logic faults and control algorithm specific implementation errors have been eliminated.

With the HIL simulation, virtual commissioning of the automation system has been realised. This will significantly contribute to a safe, reliable and error-free gas carrier cargo handling system.

UniSim is a registered trademark of Honeywell International Inc. DYNASYM is a registered trademark of Invensys Inc. Aspen Hysys Dynamics is a registered trademark of Aspen Technology Inc. SIMIT is a registered trademark of Siemens AG

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