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Krishnan Narayanan, Energy Control Technologies, USA, explains how turbomachinery control systems can help small scale LNG companies increase their ROI.

In comparison with baseload large scale LNG plants with capacities of approximately 5 million tpy, small scale LNG plants, with production capacity from 100 000 to 600 000 gal./d (0.05 to 0.35 million tpy), present unique design challenges during the Front End Engineering Design (FEED) phase. The expectation for small scale LNG plants is to be economically competitive with the mega LNG plants, without compromising on the safety, reliability, and availability of the process units and rotating equipment. Even though small scale LNG plants have relatively lower compression power requirements, the complexity of turbomachinery control system design is similar to that encountered in large LNG plants. This article will demonstrate how previously unavailable turbomachinery control technology can help small and mid scale LNG companies to maximise the return on investment (ROI) of their projects. Small scale LNG processes have additional benefits of scalability to achieve mid scale LNG plant production rates of 2 million tpy. Results from a dynamic simulation of parallel operating refrigeration compressors will be used to emphasise the control system design requirements.

Small scale LNG process technology

The liquefaction technologies based on expansion cycle and single mixed refrigerant (SMR) processes are commonly used to design small scale plants. An SMR process uses mixed refrigerant components of hydrocarbon (C1 to C5) constituents and nitrogen to cool the natural gas feed stream. A multi-section mixed refrigerant (MR) compressor is the most critical rotating equipment found in an SMR process. Figure 1 shows a process block diagram of a typical SMR process.[1, 2] Energy Control Technologies (ECT) has designed integrated turbomachinery control systems for LNG plants based on multi-variable constraint control technology. The main focus of this article is to share ECT's experiences in the design of an integrated compressor control system for an MR compressor in an SMR process.

Design challenges and new control technology

Irrespective of the size of an LNG plant, it is imperative that the safety and reliability of the process and rotating equipment is not compromised. The adaptation of best design practices and standards commonly used in the well-developed large scale LNG industry is highly recommended for developing the operative procedures and design of small scale LNG plant equipment. However, by employing rigorous design standards and safety HAZOP reviews, design engineers are faced with the challenge of managing the increased project costs and time to market with the ROI expectations of the LNG operators. Hence, it is important that design engineers review the proven technologies available in the market for critical systems that are both high quality in performance and cost-effective to justify the investment, without compromising the safety and reliability aspects. One such critical system in an SMR process is the compressor control system for the MR compressor.

Mega LNG plants built in the 1990s typically used expensive black-box proprietary turbomachinery control systems because they were the only option that met the high speed performance requirements. A black-box compressor control system used in a mega LNG plant is not considered by small scale operators, due to the high cost to benefit ratio. With no proven alternatives, and to reduce the cost of the control system while meeting the project investment criterion, design engineers installed cheaper basic control systems, thereby risking the reliability and safety of compressor operations. Today, programmable logic controllers (PLCs), with execution speeds equal to, or faster than, proprietary controllers, can handle complex turbomachinery applications cost-effectively. In addition, the field performance of an advanced compressor control system implemented in open-architecture hardware using PLC technology is on par with the performance requirements of control system specifications for large scale LNG plants. In addition to reducing CAPEX costs, it is also important to consider operability costs over the life cycle of compressor operation. A compressor control system deployed in an open PLC hardware platform is easy to maintain and operate, thereby minimising the operating costs of the control system.[3] Just as high speed PLCs are critical to accurately compute and execute complex turbomachinery control algorithms, the application design expertise and field service capabilities of a control vendor are equally important in delivering the performance objectives of a compressor control project.

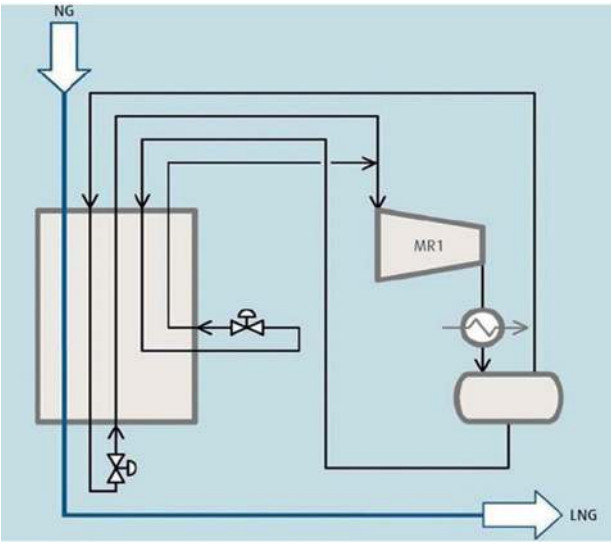


Figure 1. Single mixed refrigerant (SMR) process.

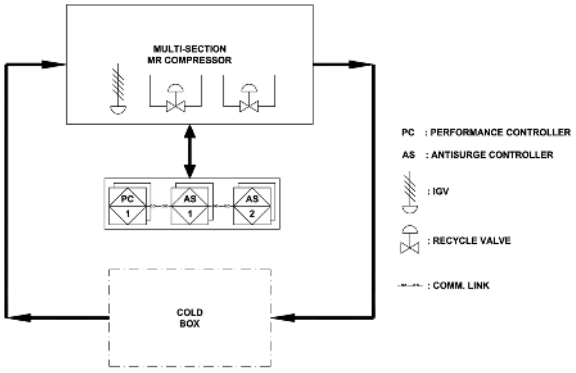


Figure 2. Turbomachinery control configuration for a multi-section mixed refrigerant (MR) compressor.

Control system design requirements

MR compressor configuration

Multi-section MR compressor design and piping layouts come in different configurations. The turbomachinery control system should be flexible to handle the different types of compressor configurations that are commonly encountered. Due to lower power requirements of the compression loop and increased efficiency, configurations using integrally geared multi-section compressors have been evaluated by Original Equipment Manufacturers (OEMs) and licensors as a viable option for SMR processes.[4, 5] Controllability analysis performed by ECT for a multi-section integrally geared MR compressor project confirmed that control system issues normally seen in straight-through MR compressor configurations are also applicable to integrally geared compressors. An important factor impacting the controllability of integrally geared compressors is how well the stage performance curves are matched for different load conditions. In addition, a 2 x 50% compressor network consisting of two parallel operating MR compressors offers a viable design configuration to scale the compression capacity for increased production rates. Unlike

the different types of driver configurations found in large scale plants, electric motor driven compressors are typical for small scale SMR processes. MR compressors are normally equipped with inlet guide vanes (IGVs) to regulate the capacity of the compressor and meet the refrigeration load requirements. Figure 2 illustrates an MR compressor control system configuration implemented by ECT for an SMR process.

Multi-variable constraint control technology

ECT's turbomachinery control system, which consists of anti-surge and performance controllers for MR compressors, was developed based on proven multi-variable constraint control methods. An MR compressor, like any other turbomachine, has defined boundaries of operating constraints, within which the compressor has to be operated to prevent equipment damage (Figure 3). The objective of a compressor control system is to accurately define the constraint boundaries and operate close to the limits, thereby maximising the operating envelope of the compressor in a safe manner.

Compressor surging and speed of response

An important operating constraint of a compressor is the surge limit line. Compressor surge is an unstable cyclical phenomenon characterised by rapid flow reversal due to flow separations occurring inside the compressor. Flow drop occurs in as little as 40 msec., with a complete surge cycle consisting of flow reversal and recovery occurring in a few seconds. The anti-surge controller that is used to prevent surge should have a complete cycle time in the range of 40 msec. A surge limit line is the locus of all the surge points for different operating speeds, IGV, and inlet conditions. Continuous operation in surge will lead to damage of the compressor or associated equipment, due to temperature increase, high vibrations, rotor rub against casing, driver overspeed, seal damage and bearing failures. In order to protect a compressor against surge and prevent repetitive cycles, it is important to minimise the response time of the control system, which is a function of: the controller scan time; the sizing and response time of the surge control valve; the rise time of field transmitters; piping design layout for cooler location; system volumes; and location of check valves.

Other constraints for MR compressors include: preventing low inlet temperature during sudden load reductions; limiting the motor current to prevent overload trip; limiting a discharge pressure to prevent pressure relief valve (PRV) flaring; and monitoring of compressor choke condition that is detrimental to the machine.

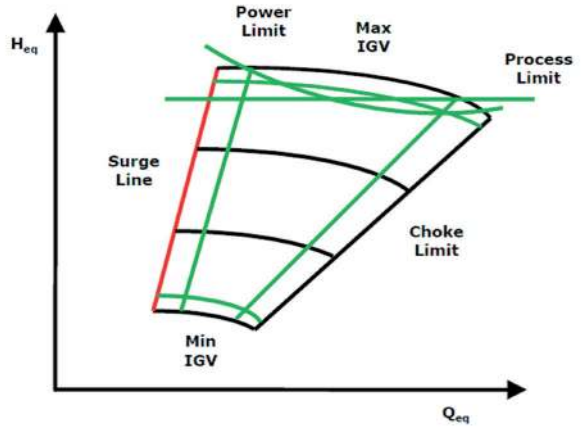


Figure 3. Compressor operating constraints.

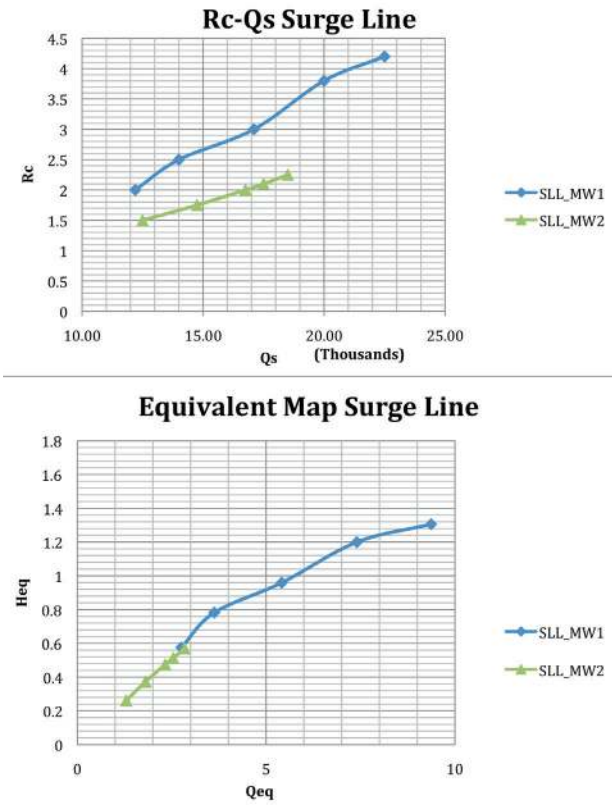


Figure 4. Equivalent map model for invariant surge line.

Equivalent map models

Due to fluctuating suction conditions expected for an MR compressor, along with changing molecular weight from a different composition of mixed refrigerant constituents, the surge limit line defined in OEM-supplied performance curves is not fixed (Figure 4). Equivalent map models of head and flow parameters derived using dynamic

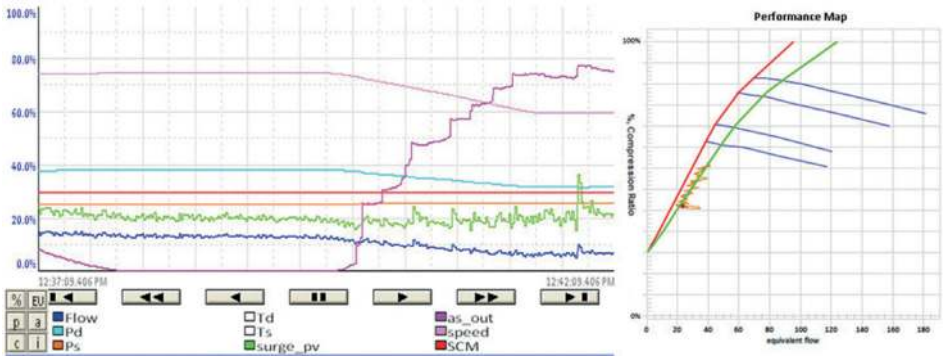


Figure 5. Closed-loop surge adapter and preventer response during process upset conditions.

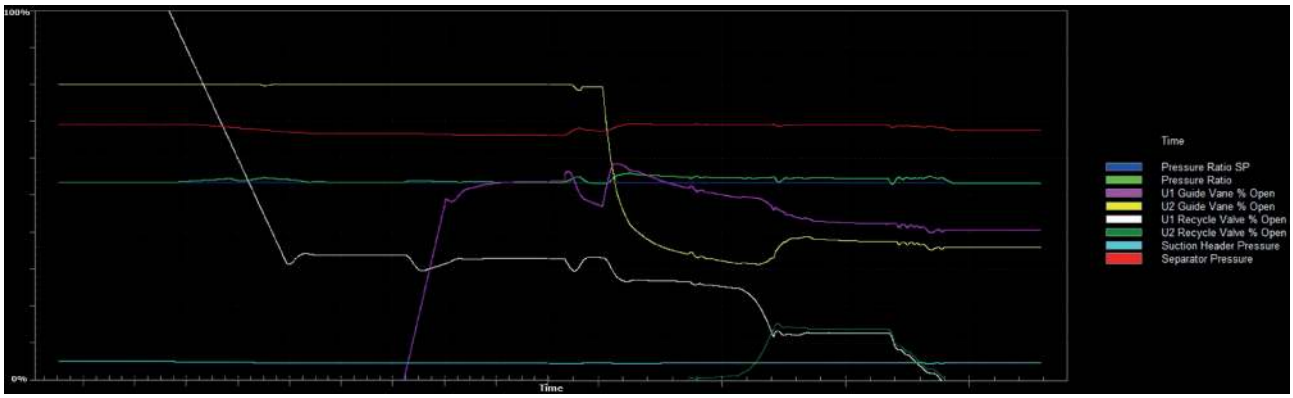


Figure 6. Load sharing control for parallel MR compressor.

similitude principles have been proven to accurately define the surge limit line that does not change with varying inlet conditions and gas compositions (Figure 4). Accurate definition of the surge limit line that is invariant to suction conditions is of paramount importance to MR compressors, since the gas composition and molecular weight changes significantly from startup and part load conditions (low MW) to full load operation (high MW).

Advanced control algorithms and linear surge control techniques

Non-linear compressor curves, in combination with a highly dynamic surge phenomenon, render basic control methods ineffective for surge protection. Advanced control algorithms based on linearised surge control parameters are fundamental to the design of a world-class anti-surge controller. Algorithms, such as an adapter-based dynamic control response that anticipates process load changes and a preventer-based closed-loop control step response that adaptively opens the valve in proportion to the magnitude of process upsets, have been effectively used in the field for preventing compressor surging during process trip conditions (Figure 5).

Capacity controller and parallel operation

A performance controller regulates the MR compressor capacity by controlling the IGV to meet the refrigeration load requirements. During plant startup and part-load operation, the performance and anti-surge controllers are highly interactive due to compressor recycling. An integrated control system with interactive control algorithms that cancel out the negative interactions between the various loops avoid delays during plant startup, and prevent process shutdown during load reductions.

Parallel operating configurations of MR compressors are a practical option to scale compression capacity of SMR processes. Efficient distribution of compressor throughput among parallel compressors is an important design requirement. A design strategy that ensures all operating compressors recycle simultaneously during part-load recycling conditions maximises the turndown of compressors in an efficient manner.

Figure 6 shows the dynamic simulation output for a parallel MR compressor system from startup to full load operation. The dynamic simulation of the parallel compression system and cold box was developed by ECT in conjunction with the OEM, EPC/licensor, and the end user. An emulator of the compressor control system was used to integrate with the process model to achieve real-time load sharing control of the compressors. The simulation tool was instrumental in solving the following problems: compressor surging due to recycle piping design and valve sizing; and negative control interactions between the MR compressor and cold box system.

Fault tolerant control action

High availability of a turbomachinery control system is a key requirement to avoid production losses. Best design practices followed in the industry to prevent unscheduled shutdowns of a compressor from single point failures include a redundant PLC configuration consisting of duplex processor cards, IO modules, power supplies, racks, and communication modules. Field transmitter and control valve failures are major sources of spurious control responses. Fault tolerant control algorithms that can sustain field failures by automatically switching to an alternative control variable strategy or by positioning the outputs to a fail-safe state, without jeopardising the compressor protection and process operation, are critical to maximising the availability of a control system.

Conclusion

Independent of the plant capacity, the adaptation of best design practices and standards commonly used in the well-developed large scale LNG industry will influence LNG plant designers to apply proven design methods that ensure safety and reliability of equipment. Expensive, black-box based proprietary control systems were the norm in the 1990s. Previously unavailable field-proven turbomachinery control technology can benefit the designers and operators of LNG plants in maximising the ROI of their projects. **LNG**

References

1. 2012 – 2015 Triennium Work Report, Small scale LNG – International Gas Union, June 2015.
2. KOHLER, T., BRUENTRUP M., KEY R. D., and EDVARDSSON T., 'Choose the best technology for small-scale LNG production: Linde Engineering', *Hydrocarbon Processing* (January 2014).
3. SCHMUTZ, S., 'Utilizing open platform architecture, expertise for improved compressor control: Energy Control Technologies', Gastech, (October 2015).
4. WEHRMAN, J., ROBERTS, M., and KENNINGTON, B., 'Machinery/Process Configurations for an Evolving LNG Landscape: Air Products', Gastech, (February 2011).
5. GRABAU, D., 'Refrigeration Compressors for Small Scale LNG', Cameron – Process and Compression Systems.