DYNAMIC SIMULATION OF C3-MR LNG PLANTS WITH PARALLEL COMPRESSION STRINGS

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ABSTRACT

The propane precooled, mixed refrigerant (C3-MR) cycle has been the mainstay of the LNG industry for many years. To minimize capital expenditures (CAPEX) while capitalizing on economy of scale, all of the operating LNG facilities using the C3-MR technology have chosen to use a single refrigerant compressor string with a single Main Cryogenic Heat Exchanger. With more producers entering the marketplace, alternative equipment configurations such as parallel refrigerant compressor strings with a single MCHE need to be evaluated to satisfy some of the producers' specific project considerations. To ensure proper operations, Air Products has used rigorous dynamic simulation tools to investigate possible operational scenarios for C3-MR plants utilizing parallel MR and parallel propane compression strings. These dynamic simulation tools have been demonstrated for compressor blocked discharge scenarios, control system performance and other applications [1] for existing operating LNG plants using the C3-MR technologies.

INTRODUCTION

Why Dynamic Simulation?

For parallel refrigerant compressor configuration in LNG plants, in the event that one of the compressor strings goes offline (for example, due to a spurious trip or a need for maintenance), can the plant stay online without causing a sympathetic trip in the parallel compressor string? This is a dynamic issue because steady state (time invariant) simulation shows that the plant can produce the design flowrate of LNG with two compressor strings operating in parallel and a lesser amount of LNG with only one compressor string online. However, a feasible control path still needs to be identified between steady state operation at design rate with parallel compression strings to partial production after one of the compressor strings goes offline.

Generic Flowsheet

Figure 1 shows a simplified C3-MR flowsheet with one MCHE and parallel mixed refrigerant and propane compressor strings. The natural gas stream is precooled using propane before entering the MCR® Main Cryogenic Heat Exchanger (MCHE). In the MCHE, the feed is further cooled and liquefied using a refrigerant comprised of a mixture of nitrogen and light hydrocarbons (i.e. methane, ethane and propane). The mixed refrigerant (MR) is in a closed loop where it is compressed, cooled and partially condensed against vaporizing liquid propane and further subcooled in the tubes of the MCHE and finally expanded into the shell of the MCHE as a cooling medium.

The dynamic simulation flowsheet, incorporating the MCHE and both the mixed refrigerant and propane loops, was constructed in Aspen Custom Modeler (ACM) using Air Products' proprietary dynamic models. These models are based on rigorous first principle equations in order to properly model the dynamics of this coupled system. For simplicity, the individual propane evaporators, compressor stages, suction drums, aftercoolers, block valves, anti-surge valves and controllers were not shown in Figure 1, but were included in the simulation model. The dynamic simulation results discussed below were obtained running ACM with Air Products' proprietary thermodynamic database. Specific plant information, such as proprietary MCHE variables, process piping, equipment and vessel volumes, compressor curves and heat exchanger UAs, etc., were incorporated into the simulation model. The dynamic simulation was running at a steady state prior to the start of the disturbances.

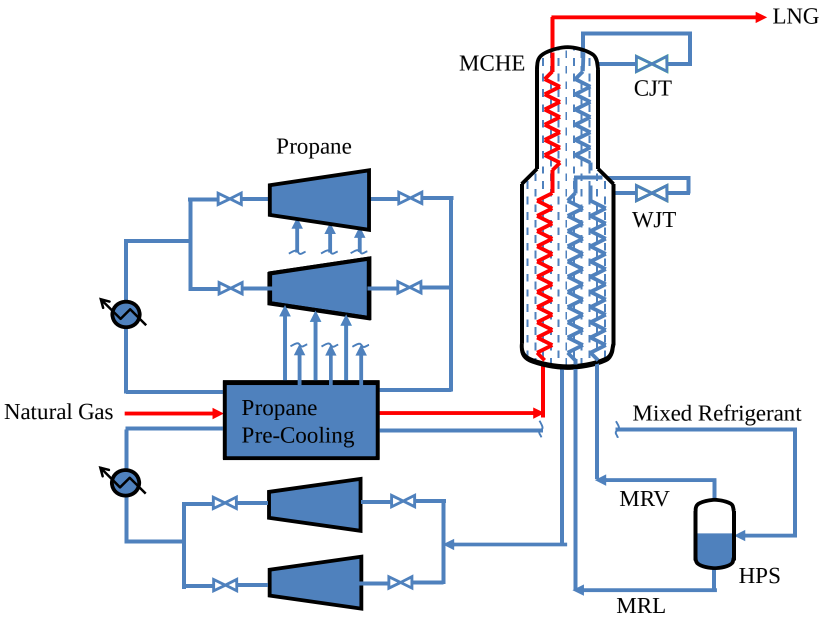

Figure 1. Simplified C3-MR Flowsheet with Parallel Compressor Strings

DYNAMIC SIMULATION EXAMPLES

Example 1: Taking a parallel MR compressor string offline

In this example, one of the parallel MR compressor strings is isolated from the process. If no adjustments are made to the Joule-Thomson (JT) valves or the remaining compressor string, the large volumetric flowrate that was being handled by both MR compressor strings will easily overwhelm and stonewall the remaining online compressor string. Dynamic simulation and analyses were used to determine the control actions needed to prevent the stonewall (high volumetric flow – low head) condition from occurring.

At the start of the disturbance, the LP inlet valve and the HP outlet valve to MR compressor string "A" were rapidly closed, isolating the string from the rest of the liquefaction process. Because the anti-surge control scheme was incorporated into the dynamic model, the anti-surge control valves on compressor string "A" opened and put the compressor string into a stable recycle. Several control actions took place simultaneously to prevent stonewalling compressor string "B".

First, the LP suction valve for compressor string "B" was partially closed. This reduced the volumetric flow to the "B" LP compressor suction preventing a stonewall condition. The "additional" mixed refrigerant that was flowing to compressor string "A" was temporarily stored in the MCHE shell until string "B" could compress it. This is seen in Figure 2 where there was an immediate rise in the MCHE shell pressure at the beginning of the disturbance. Figure 2 also illustrates that the level in the MR High Pressure Separator (HPS) rose more gradually as string "B" compresses the additional MR in the MCHE shell for storage in the HPS, thus reducing the pressure within the MCHE shell back to near its pre-disturbance value within several minutes.

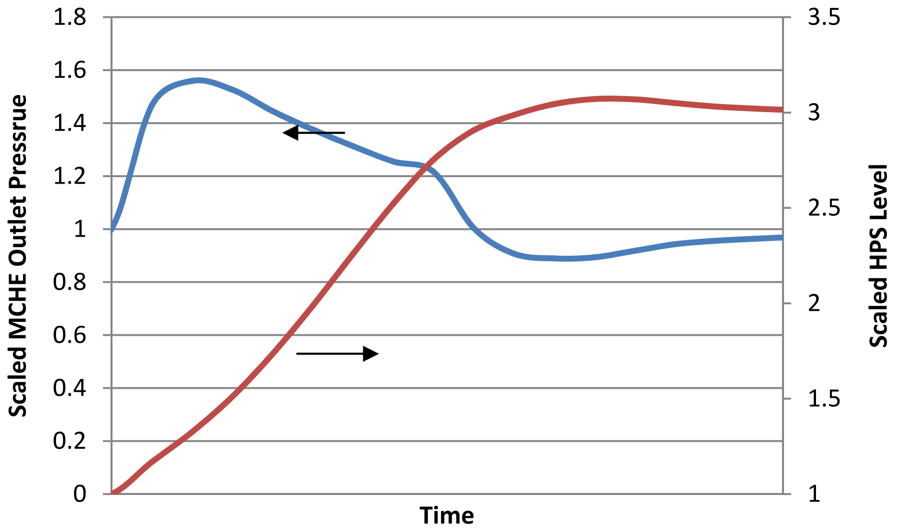

Figure 2. Scaled MCHE Shell Pressure and HPS Level

Second, as LNG production is proportional to MR compressor power, losing half of the process's compression capabilities means that LNG production will be roughly halved. In addition, to prevent the warm end of the MCHE from getting too cold and potentially tripping the remaining compressor string on low suction temperature, the LNG valve was closed to reduce production and the CJT and WJT valves were manipulated to adjust refrigeration appropriately while minimizing the effect of the disturbance on LNG temperature.

When the MCHE warm end temperature difference reduces, indicating that more refrigeration may be needed for the current production level, the WJT and CJT valves were adjusted to balance refrigeration with the heat load and the LP suction valve to compressor string "B" was returned to full open. Notice in Figure 3 that the warm bundle warm end (WBWE) temperature difference rose rapidly early in the disturbance due to MR inventory in the shell and rising shell pressure. As soon as the JT valves were reduced, the temperature difference stopped increasing and started to fall and come to a new steady state as the balance between heat load and refrigeration was restored.

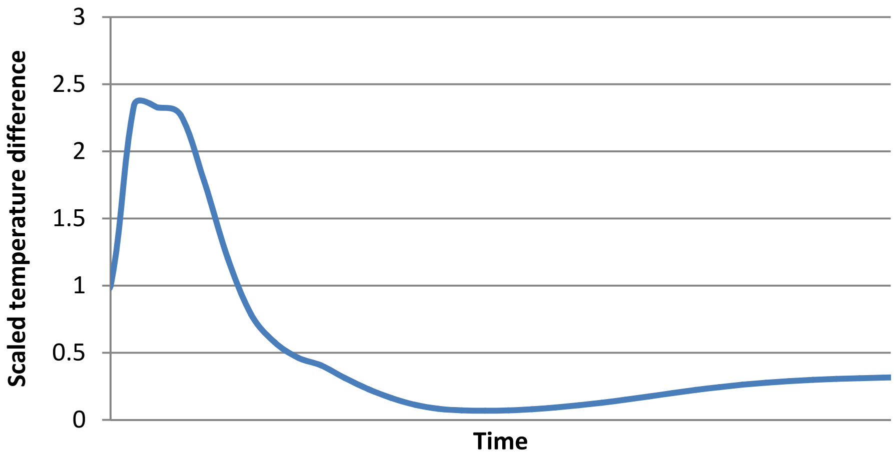

Figure 3. Scaled Warm Bundle Warm end Temperature Difference

As with any disturbance to the process, the desire is to minimize the impact on LNG temperature while maintaining plant fuel balances. In Figure 4, the LNG outlet temperature rose sharply early in the disturbance and returned to near its pre-trip value as production was reduced. At the new steady state, the LNG temperature was a few degrees warmer than the initial value because the WBWE temperature difference is smaller (the temperature profile was more pinched) which can be seen previously in Figure 3.

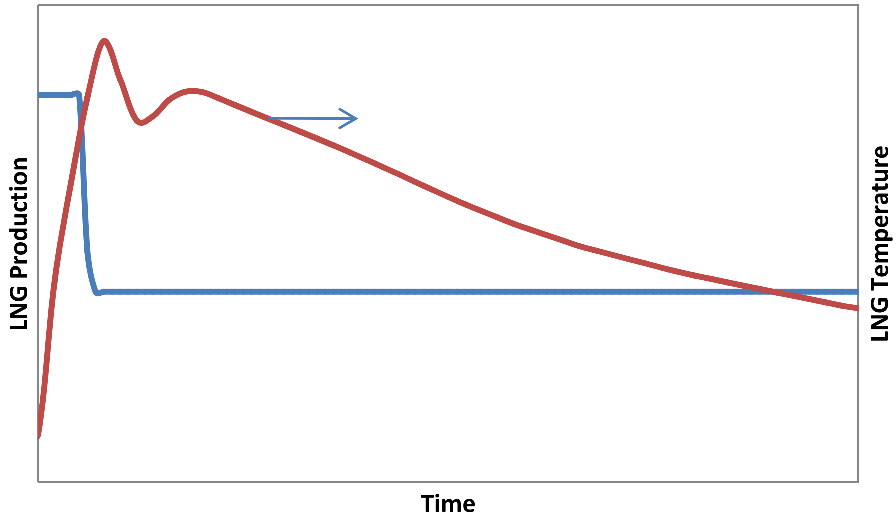

Figure 4. LNG production and temperature for Example 1

During this disturbance, the parallel propane compressors saw reduced volumetric flowrates as there was less propane boilup from the evaporators due to reduced mixed refrigerant and feed flowrates. The propane compressors moved up on their head-flow curves (closer to surge) but anti-surge valves did not need to open. Well within an hour, the process came to a new steady-state with one MR compressor online as illustrated in Figure 4. In the next example, we will discuss the simulation to bring an offline MR compressor string back online.

Example 2: Bring a parallel MR compressor string back online

In this scenario, the process was running at a steady state with one MR compressor string (“B”) online and MR compressor string “A” needed to be brought back online in order to return production to full rates. Compressor string “A” was assumed running at the same speed as string “B” but it was in full recycle with its anti-surge controllers actively holding the stages on their surge control lines and its block valves were closed so it was initially isolated from the process.

String “A” LP suction drum was very warm (at the LP aftercooler outlet temperature) compared to the string “B” suction drum because string “A” has been on recycle. String “A” LP suction drum is pre-cooled by an appropriate stream of gas that prevents overcooling, maintains MR composition and uses refrigerant efficiently so that operator attention is minimized and later adjustments are not required. The rate of cooldown is controlled by the flowrate of cooldown gas and manipulation of the string’s anti-surge valves. Once both LP Suction drums’ temperatures were equilibrated, the block valve downstream of the “A” high pressure compressor discharge was then opened. When sufficient head had developed, the check valve at the high pressure discharge opened and compressor string “A” began to contribute refrigeration to the process.

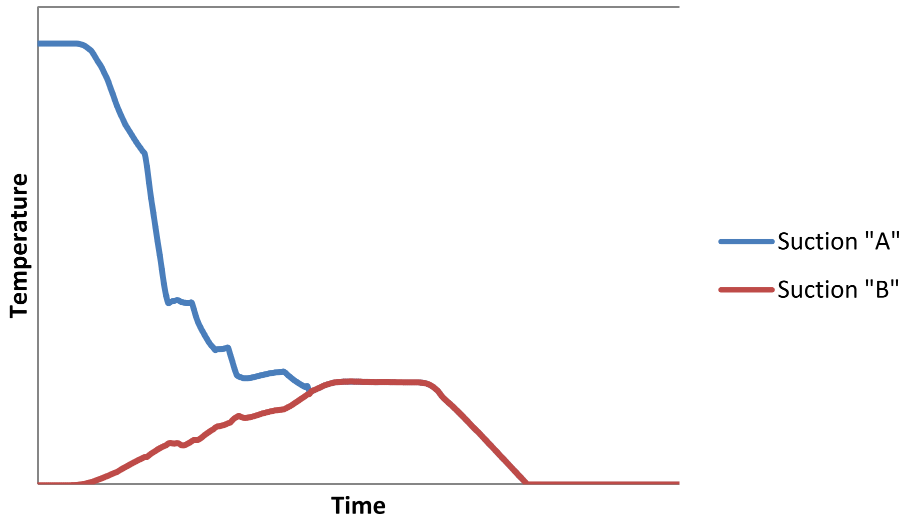

Figure 5. LPMR Suction Drum Temperatures

As seen in Figure 5, using this cooldown method did slightly warm the string “B” LP Suction temperature. However, Figures 6 and 7 shows that this did not affect LNG outlet temperature during cooldown because the steady state control system used (APCI’s Enhanced Control Scheme [2]) adjusted the JT valve openings in response and maintained the desired LNG outlet temperature.

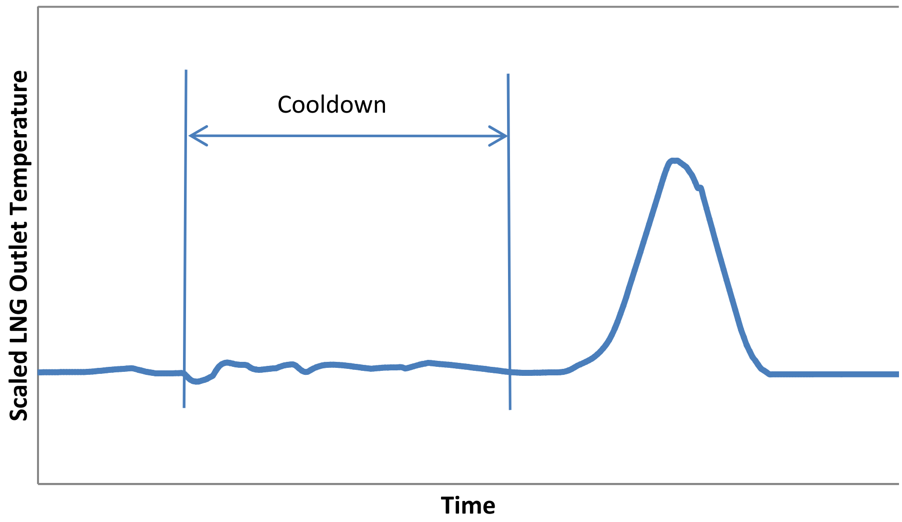

Figure 6. LNG temperature

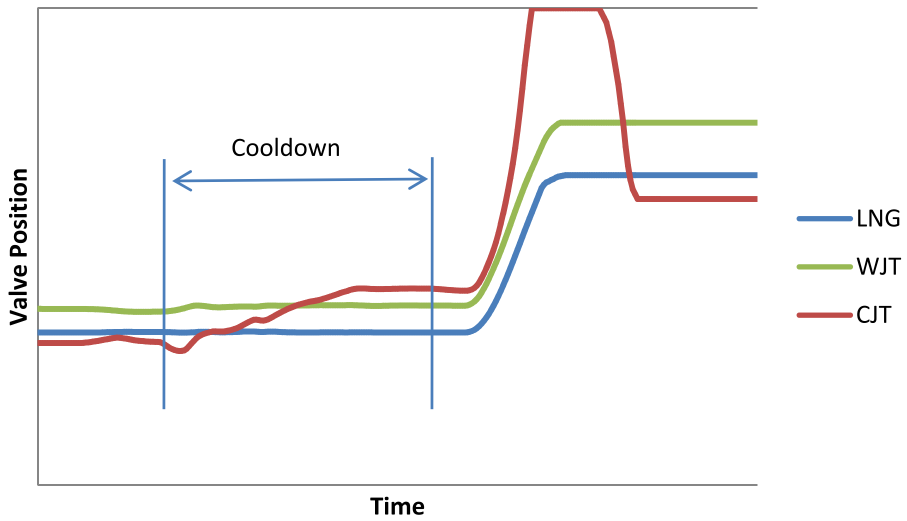

Figure 7. Valve Positions for Example 2

Once compressor string “A” was online, the LNG production setpoint was gradually increased to return the process to full production rates. Note that with Air Products’ Enhanced C3MR control scheme, increasing the LNG production setpoint will automatically open the refrigerant JT valves in proportion thus smoothly bringing the process back to the desired rate. In Figure 7, the CJT valve moved beyond its final position because the LNG production was ramped up faster than the available additional refrigeration from compressor string “A” became available.

Once MR compressor string “A” was fully back online, the LNG temperature cooled as seen in Figure 6, the CJT valve closed in response and the simulation came to a stable steady state at the desired rate. During the production increase, the parallel propane compressors moved to an operating point further away from surge as propane boil-up rates increased due to increased feed and mixed refrigerant flowrates.

CONCLUSIONS

Through rigorous dynamic simulation, it has been demonstrated that smooth and uninterrupted operation of a C3-MR LNG plant using parallel refrigerant compressor strings with a single MCHE can be achieved. The authors have successfully demonstrated a smooth transition from a normal operating point with all compressor strings running to an operating point at reduced production with one MR compressor string offline. In addition, the steps need to bring an offline MR compressor back into service without interrupting production were also successfully modeled. Analogous dynamic simulations have been successfully run taking one parallel propane compressor string either offline or back online with minimal disruption to the operation of the liquefaction plant.

REFERENCES CITED

[1] Okasinski, M. and Schenk, M. "Dynamics of Baseload Liquefied Natural Gas Plants – Advanced Modeling and Control Strategies" in Proceedings of LNG15, Barcelona, Spain (2007).

[2] Sicinski, M., Johnston, B., Roberts, M., and Trautmann, S. "Controlling Liquefaction of Natural Gas" US Patent 2009 / 0025422A.