

RECOMMENDATIONS FOR RESTARTING A PARALLEL COMPRESSOR STRING BASED ON DYNAMIC SIMULATION

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ABSTRACT

Several LNG projects are using parallel refrigeration compressor strings with heavy duty industrial gas turbines to obtain higher capacity, increase efficiency at deep turndown, and achieve higher on-stream availability. Parallel refrigeration compressor strings also allow high train capacities when utilizing aero-derivative gas turbines, which typically have lower power outputs than industrial gas turbines. During the project phase, questions arise regarding how to restart a parallel refrigeration string while its companion string is already online and the liquefaction process is at reduced production. The offline string has a much warmer suction drum compared to the online string so the two strings perform differently. The main concerns during tie-in are avoiding a sympathetic trip of the online string and minimizing thermal disturbances to the liquefaction process during the transition to higher production. Dynamic simulation has proven to be a powerful tool for minimizing the sympathetic trip issues as well as developing optimal restart procedures.

This paper uses dynamic simulation to compare two different restart methodologies for a propane precooled mixed refrigerant (AP-C3MR™) process, the key factor being how the offline compressor suction is cooled:

- Injecting liquid refrigerant into the offline suction drum; and

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- Flowing cool gas from the common suction header through the offline string and then into a lower stage of the online string via an inter-string valve.

The paper also demonstrates that to minimize thermal disturbances on the refrigeration and LNG circuits, it is necessary to model the entire liquefaction process, including the Main Cryogenic Heat Exchanger (MCHE), in the restart simulation.

INTRODUCTION

LIQUEFACTION PROCESS OVERVIEW

Several recent LNG projects use parallel compressor strings to increase capacity, reliability and availability. Figure 1 below shows a simplified AP-C3MR™ flowsheet with a single MCHE, and parallel mixed refrigerant and propane compressor strings. The natural gas stream is pre-cooled by propane refrigerant before entering the MCHE. In this exchanger, 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 propane refrigerant is also in a closed loop where it is compressed, cooled, condensed, and subcooled against either air or water. It then vaporized to cool the feed and MR streams before returning to the compression step of its cycle. There are several driver configurations available for parallel compression that are independent of the restart methods discussed in this paper.

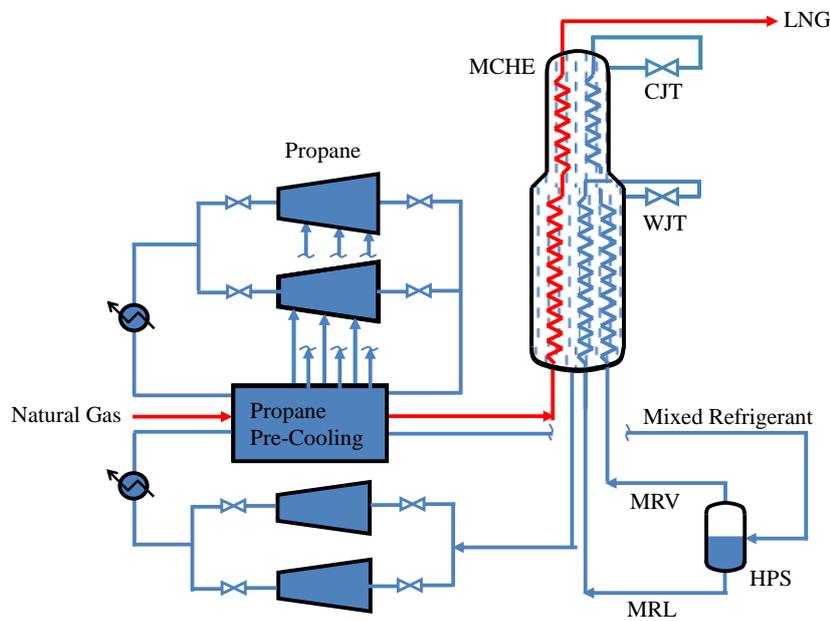


Figure 1 – AP-C3MR™ Process Schematic

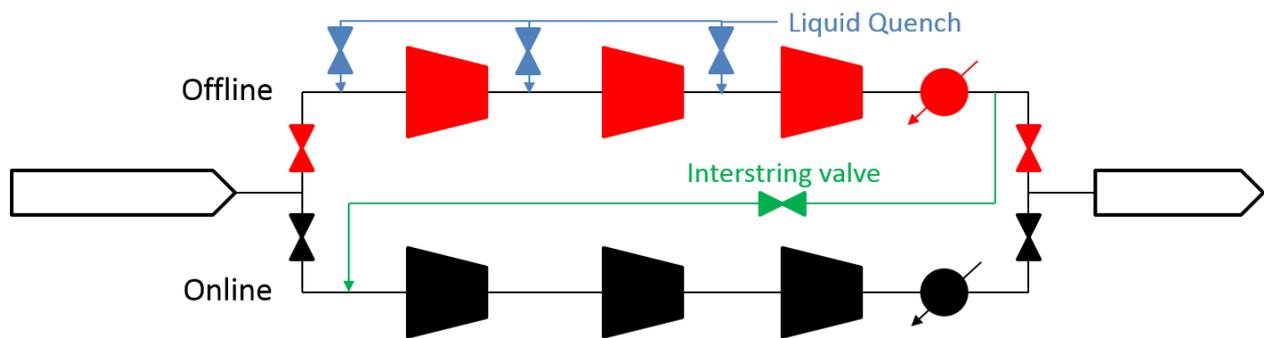
RESTARTING 1 of 2 PARALLEL REFRIGERATION STRINGS

During the project phase, questions arise on the best method to restart a parallel refrigeration string when its companion string is already online and the liquefaction process is at reduced production. The challenge is that the offline string is running on full recycle with a warm suction drum while the online string's suction drum temperature can often be 40 – 50 °C colder.

The goal of a successful tie-in is restoring the liquefaction process to full production without inducing a sympathetic trip in the companion string and while

minimizing thermal disturbances in both the refrigeration and natural gas circuits.

A generic multistage compressor string is illustrated schematically in Figure 2. **Error! Reference source not found.** Options for tie-in include the use of liquid quench and inter-string connections to equalize pressure and temperatures between the offline compressor string and its online companion. For illustration purposes, the quench and inter-string valves are only shown for one string. Propane and mixed refrigerant liquid (MRL) quenching fluid is taken from the Propane Accumulator and High Pressure MR Separator, respectively and injected into offline suction drums to cool the compressor suction. Typically, quench capability is installed for each propane stage in addition to the lowest MR stage.



Inter-string or crossover valves connect the highest aftercooler discharge of one string with the low pressure suction drum of its companion string. These valves provide a flow path to draw cool gas from the common header upstream of the suction drum, through the offline string and back into the online string. After trips or during maintenance, these valves can also be used to depressure the offline string by transferring refrigerant inventory into the main circuit without flaring or recovering it in a separate unit.

SCENARIOS

To fairly evaluate different restart options, each option was simulated on the same dynamic flowsheet of a generic AP-C3MR™ process. The simulation, containing more than 10,000 algebraic and differential equations, modeled the MCHE, Joule-Thomson (JT) valves, parallel refrigeration strings with multiple compressor stages and associated aftercoolers, valves and antisurge controls, High Pressure MR Separator, Propane Accumulator, and a network of propane evaporators with level valves and controllers.

This paper compares three restart methods:

1. Crossover-only (Xover);
2. Quench-only (Qonly); and
3. Quench without venting (QwoV).

Prior to beginning the tie-in procedure, one refrigeration string was isolated from liquefaction process, depressured to approximately 2 bara at both the LPMR and LPC3 suction drums and running on total recycle.

The crossover-only (Xover) simulation assumed the depressuring step was done by transferring refrigerant inventory to the operating refrigeration string via the MR and C3 crossover valves. No refrigerant inventory was lost during this transfer. The MR string tie-in is done by opening the crossover valve, creating a flow path to draw cool gas through the offline compressor string and back into the online string.

The quench-only (Qonly) simulation assumed no crossover valves were present so approximately 9% of the MR circuit inventory and 3% of the C3 circuit inventory were flared or sent to fuel during depressuring. The C3 and MR string tie-ins were completed only using quench valves. To save time, circuit inventories were replenished during tie-in operations.

The quench without venting (QwoV) simulation assumed that crossover valves were present. Thus during the depressuring step, refrigerant was transferred to the operating refrigeration string via the MR and C3 inter-string valves. No refrigerant inventory was lost during this transfer and the inter-string valves were closed after the depressuring step. The MR and C3 string tie-ins were completed only using quench valves.

BASIS

All three simulations require preparing the offline propane string for increased load. This was accomplished by opening the isolation valves, introducing propane quench from the C3 accumulator to cool each of the offline C3 suction drums and then gradually equalizing the pressure between the drums at each pressure level. The offline C3 string ran in partial recycle until there was sufficient heat load on the propane system from the MR and Feed circuits due to the production ramp. As the heat load increased, load sharing between the C3 strings gradually brought the second C3 string back online.

After preparing the offline C3 string for increased production, the production was ramped over 40 minutes from approximately 55% to 100% of design production as seen in Figure 3.

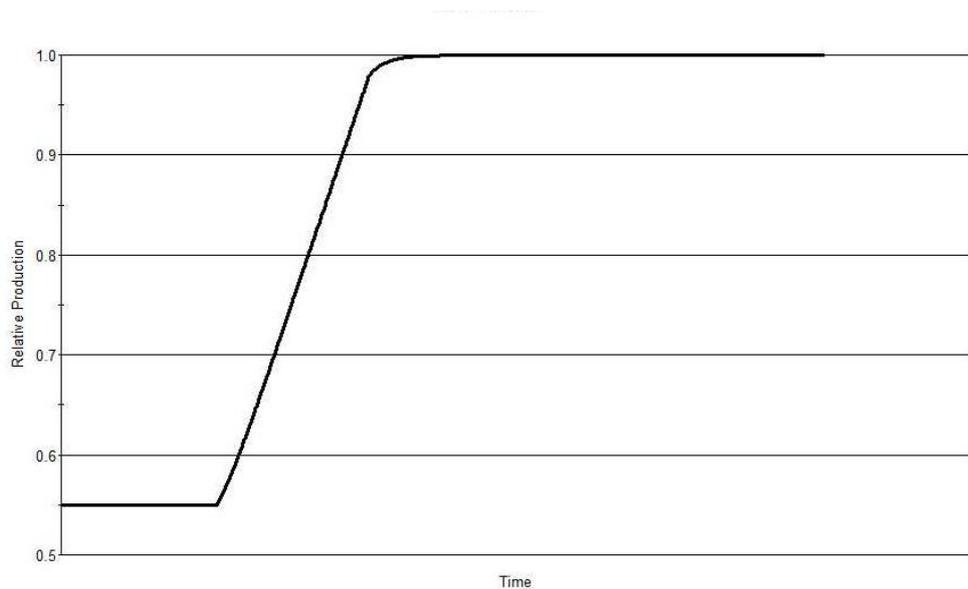


Figure 3 - LNG Production

COMPARISON OF SIMULATION RESULTS

The LNG temperature transient for each simulation is seen in Figure 4. Note that all three simulations have slightly warmer LNG during the transition to full production. To have sufficient MR flow for both compressor strings, additional MR circulation is needed before the offline string can be allowed to take flow. Using Air Products' Enhanced C3MR control scheme, gradually ramping production increases MR circulation as seen by an increasing power demand from the online refrigeration string (point A in Figure 5 through Figure 7). Once there is sufficient MR circulation, compressor load sharing controllers gradually bring the two strings to the same operating point.

As the offline string begins to take part of this additional circulation, this refrigeration is initially not available for liquefying natural gas because it takes time for the offline string to generate enough head to open its discharge check valve and contribute flow to the liquefaction process. This delay causes the LNG temperature to warm slightly near the beginning of the production ramp. The rate at which the LNG Temperature controller returns the measured LNG temperature to the desired setpoint is dependent on tuning parameters which were the same for each simulation in this study.

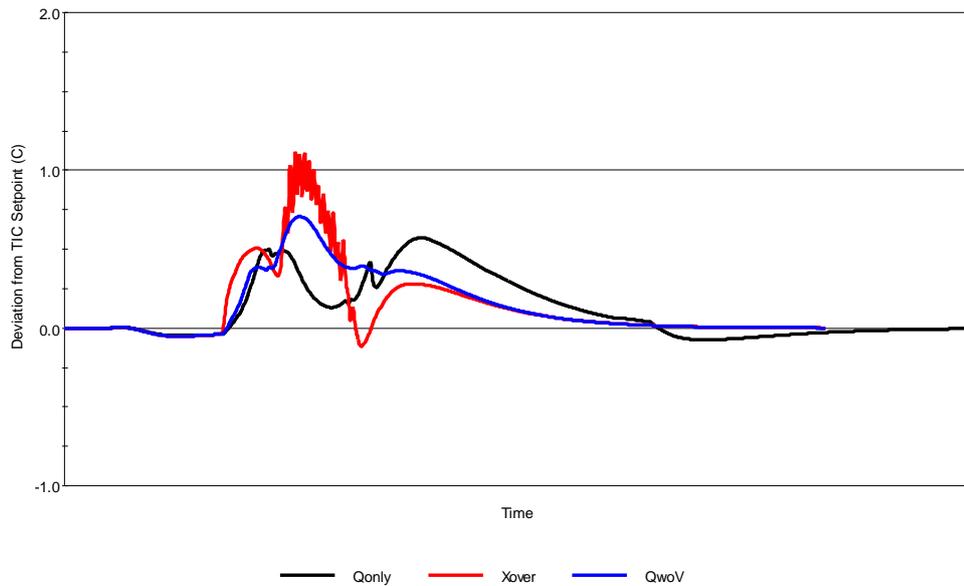


Figure 4 – LNG Temperature

Figure 5 through Figure 7 show the gas turbine power for both the online and offline strings for each simulation. In the Xover case, the disturbance from the hot discharge gas being put into the online LPMR suction drum causes chatter in the anti-surge valves of both strings which is reflected in their power demand (Figure 5). In contrast, using quench for restart shows the power demand of the offline compressor string smoothly increases while demand decreases slightly for the online string as they begin to share refrigeration load. Eventually they equally share the circulation load.

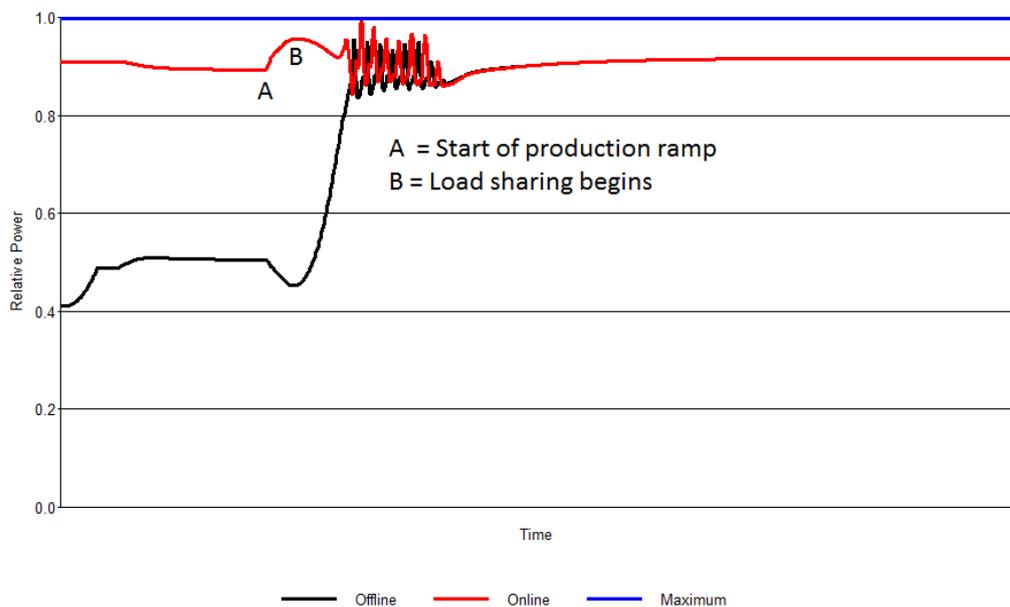


Figure 5 – Power Demand for Xover Simulation

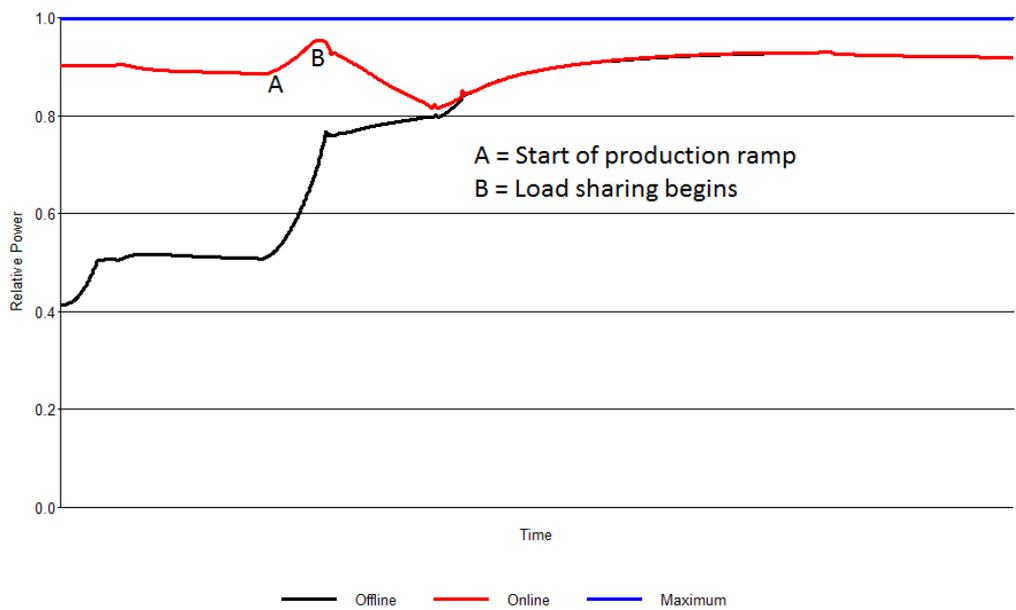


Figure 6 – Power Demand for Qonly Simulation

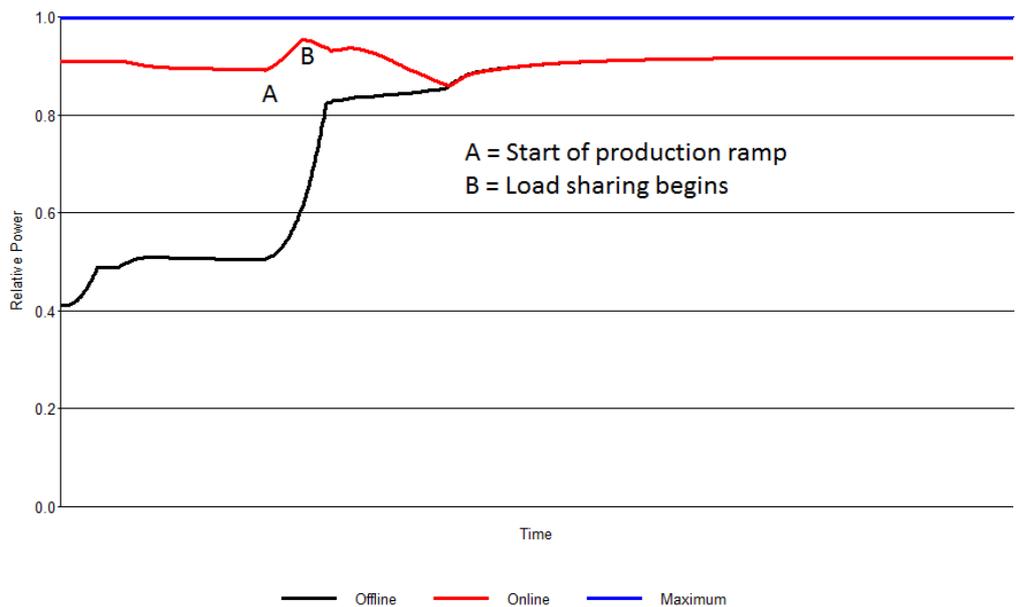


Figure 7 – Power Demand for QwoV Simulation

While there was no loss of refrigerant inventory in the Xover and QwoV cases due to the presence of inter-string valves, inventory was removed (either flared or sent to fuel) prior to restarting the compressor string in the Qonly case. That lost inventory needs to be replenished, either during or immediately

following the restart to have sufficient inventory to reach full design production. For this simulation, the inventory was restored during the restart sequence.

Due to venting of inventory in the Qonly case, both the C3 accumulator and High Pressure Separator (HPS) start at a lower initial inventory as seen in Figure 8 and Figure 9. In the QwoV case, the initial level in both vessels is the same as for the Xover case because circuit inventories were preserved using the inter-string valves.

During the simulations, the propane liquid level initially falls for all the simulations as each of the C3 suction drums are being quenched in preparation for restart. For the Qonly simulation, the C3 makeup valve is opened and feeds into the common LP suction header. Once the quench valves around String A begin to close, less inventory leaves the propane accumulator and the level rises. The amount of propane added to the circuit was equal to the amount flared or sent to fuel. It is assumed there is sufficient propane available to make up on demand. Note that the propane accumulator does not empty during the transition to full production.

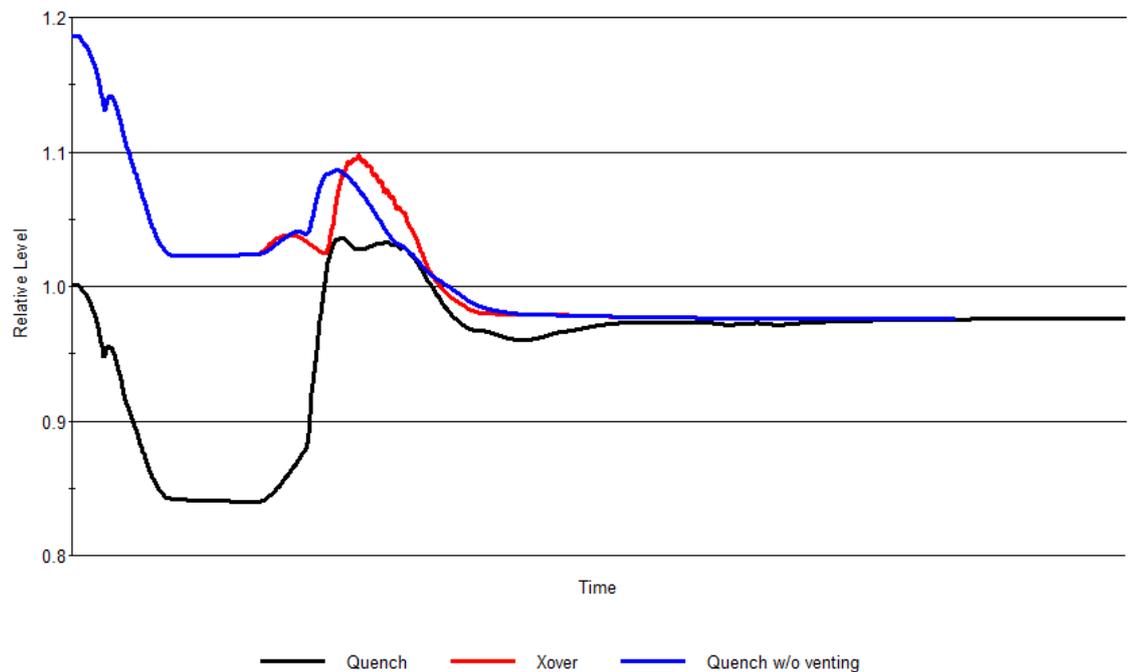


Figure 8 – Propane Accumulator Level

In Figure 9, the HPS level does not decrease until the MR string is being prepared for restart by opening the LPMR quench valve. For the quench-only (Qonly) simulation, the rising HPS level corresponds to opening the MR makeup valve which feeds into the common LP suction header at the MCHE shellside outlet. The High Pressure MR Separator does not empty during the transition to full production. It is assumed that there was sufficient MR refrigerant at the circulating composition available for makeup on demand. The amount of MR added to the circuit was equal to the amount flared or sent to fuel. Note that

the QwoV and Xover simulations mimic each other as both simulations transferred the MR inventory to the online string prior to restart.

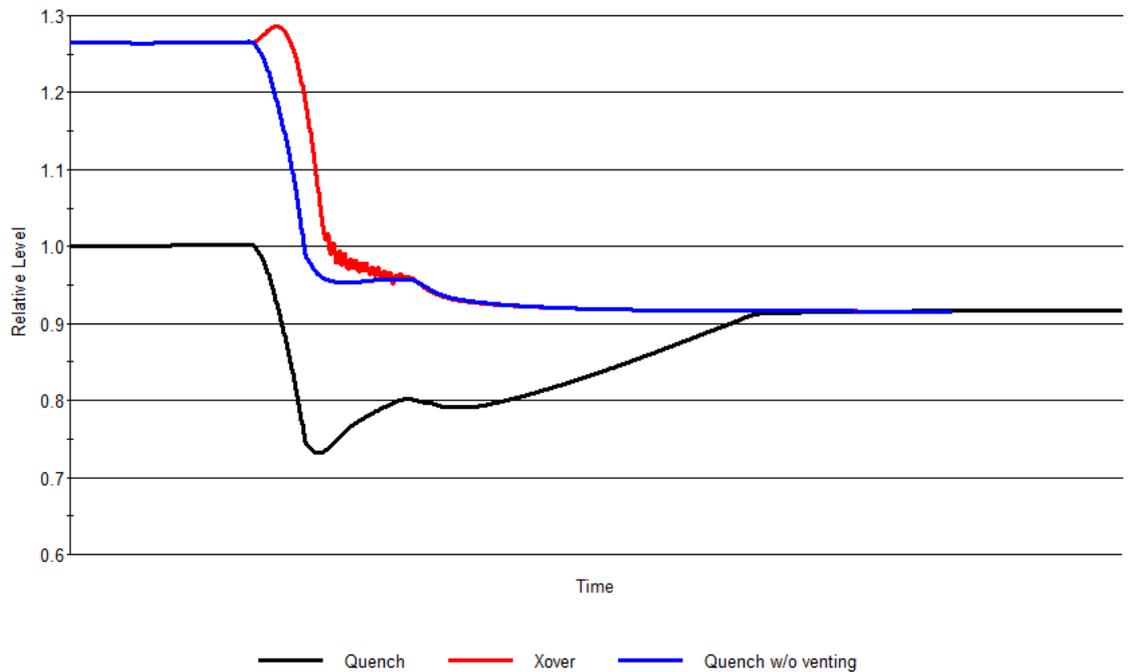


Figure 9 – High Pressure Separator Level

Figure 8 and Figure 9 also illustrate the importance of minimizing the amount of refrigerant stored in these vessels while operating at design rates as these vessels will need to accommodate additional refrigerant in the event of a tripped string if it is not vented prior to restart.

CONCLUSIONS AND RECOMMENDATION

The dynamic simulation results indicate that all three methods can be successfully used to tie-in the offline compressor string. The use of MR and C3 quench efficiently cools the offline suction drums without disturbing the online string, creating less impact on the LNG temperature. However, without inter-string valves to transfer refrigerant to online string, venting refrigerant from the offline string may be needed to restart the compressors. This would require the addition of refrigerant makeup to return to full production.

Tie-in of a parallel compressor string can be accomplished using inter-string connections only. However, simulation results show that this method introduces disturbances to the online string due to the addition of warm gas through the inter-string valve to the colder suction drum of the online string. In addition, this option requires larger diameter piping for the inter-string connections than would be necessary to simply depressure the offline string.

The results of this analysis demonstrate that one preferred method to tie-in parallel refrigerant strings uses liquid quench valves *and* small inter-string valves to recover refrigerant thereby reducing or eliminating flaring.

While the simulations and techniques discussed in this paper were done for an AP-C3MR™ process with two parallel refrigeration strings, these same ideas are applicable to single and dual mixed refrigerant (AP-SMR™ and AP-DMR™) processes and any of these processes with three or more parallel refrigeration strings.