

Parallel refrigeration machines have been in use for decades in the LNG industry primarily for the Phillips Cascade LNG process which utilizes parallel methane, ethylene and propane variable speed compressors. Operation of these compressors has been successfully done by controlling suction header pressure of the individual refrigeration circuits and using load-sharing control to balance the parallel compressor strings. Load-sharing is accomplished by equalizing the individual compressors' distance from surge parameter. Additionally, by the use of proper load-sharing control, the individual compressor strings are easily and automatically sequenced online and offline.

In contrast, plants using the Air Products licensed C3/MR LNG process (see Figure 1) have historically used individual compressor strings for both the mix refrigerant (MR) circuit and the propane (C3) precooling circuit. In earlier plants, the MR circuit consisting of two independent variable speed compressor strings operating in series. The C3 circuit also consisted of two independent variable speed compressor strings operating in series with one string being a three stage compressor with sidestreams and the other string being a single stage booster compressor. Both the MR compressor strings and the C3 compressor strings are controlled using series load-sharing.

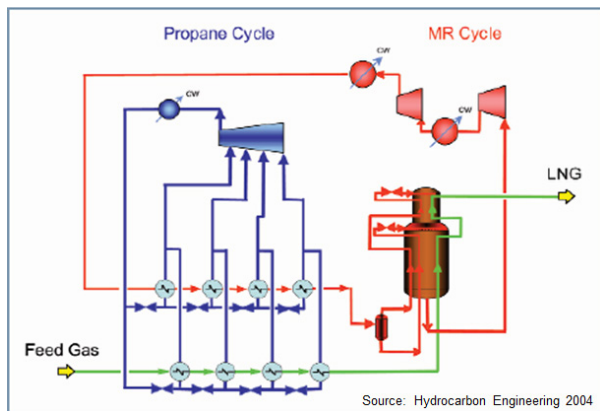


Fig. 1- Typical APCI C3/MR LNG Process

In the mid to late 1990's, the MR compressor configuration changed to three compressors on the same shaft driven by a gas turbine and helper motor combination. The C3 compressor strings changed to a single four stage compressor with sidestreams also

driven by a gas turbine and helper motor combination. The throughput of the MR compressor string is dictated by the LNG production rate and controls around the main cryogenic heat exchanger (MCHE) and for the most part allowed to float. In some cases the performance of the MR compressor is adjusted by operators by varying the MR LP axial compressor's vane angle. The C3 compressor string's throughput also floated based on process demands with the exception of preventing the suction pressure from going below atmospheric pressure by recycling. Recently however, LNG plants using the APCI license are being designed using parallel refrigeration compressor strings with either variable speed or constant speed drivers and therefore proper load-sharing control must be considered in order to have safe and reliable operation.

When two or more compressor strings are working in parallel, surge protection and process efficiency can be maximized by operating them equidistant from their surge control lines. In contrast, conventional load-sharing systems throttle back the compressors one at a time. One might be operating on its surge control line while the others run flat out. That machine would then be exposed to the full brunt of any disturbance and would often be recycling even when other compressor(s) could easily take up the slack. Larger surge protection margins might also be needed, further eroding process efficiency.

Another common approach is to operate the compressors at the same flow rate or rotational speed. Unfortunately, even supposedly identical compressors will usually have different surge limits at the same speed of operation. As a result, this approach also fails to keep the compressors equidistant from surge. While this strategy is better than sequential loading, there is still a high likelihood that one compressor will be more apt to surge or go into recycle before the others.

As shown in Figure 2, a CCC load-sharing system for compressors operating in parallel consists of one master pressure or flow controller (MPIC), a load-sharing performance controller (LSIC) per compressor, and one antisurge controller (UIC) per compressor section. These control loops use a unique combination of protection and control methods (see Figure 3) to

cooperatively maintain the desired pressure or flow while keeping the compressors the same distance from their surge limits:

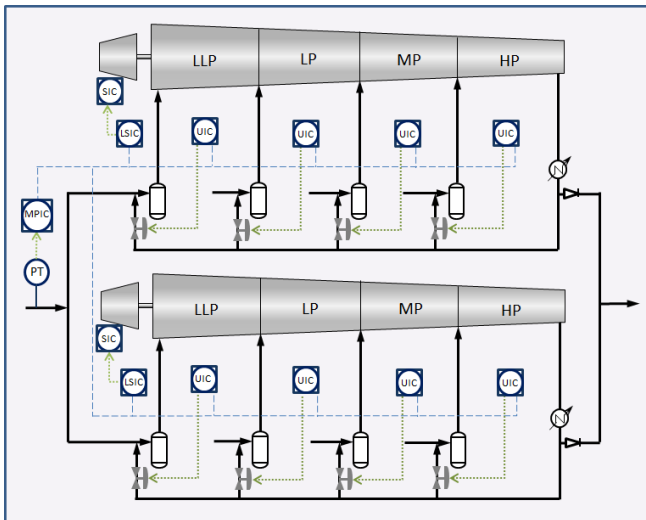


Fig. 2 - Parallel Load-Sharing Control System

- Primary Capacity Control regulates the header pressure or flow.
- Load Balancing keeps the compressors the same distance from surge to avoid unnecessary recycling.
- Recycle Balancing equalizes the recycle rates of the compressors when recycling is unavoidable.
- Pressure Override Control provides accelerated capacity control when the header pressure or flow exceeds a defined limit.

The master controller calculates its PID control response from the deviation of its capacity control variable. Any change in the resulting master control response is transmitted to the load-sharing and antisurge controllers, which make appropriate changes in their own output signals.

During normal operation when the compressors are not recycling each load-sharing controller applies a gain to the master control response and adds this to its own accumulated integral response. Under these conditions, the primary capacity control responses of the antisurge controllers are zero. This increases the compressor speed and throughput without directly changing the recycle rate. During turndown operations

when fewer throughputs are needed and the compressors are already recycling, each antisurge controller applies a gain to the master control response and adds this to its own surge control response. This raises the recycle rate, thus reducing net flow without hindering surge protection. Under these conditions, the primary capacity control responses of the load-sharing controllers will be zero. The overall effect is to throttle the compressor network by manipulating the most appropriate control elements (speed set points or throttle valves and recycle valves). This integrated approach minimizes recycling without compromising surge protection.

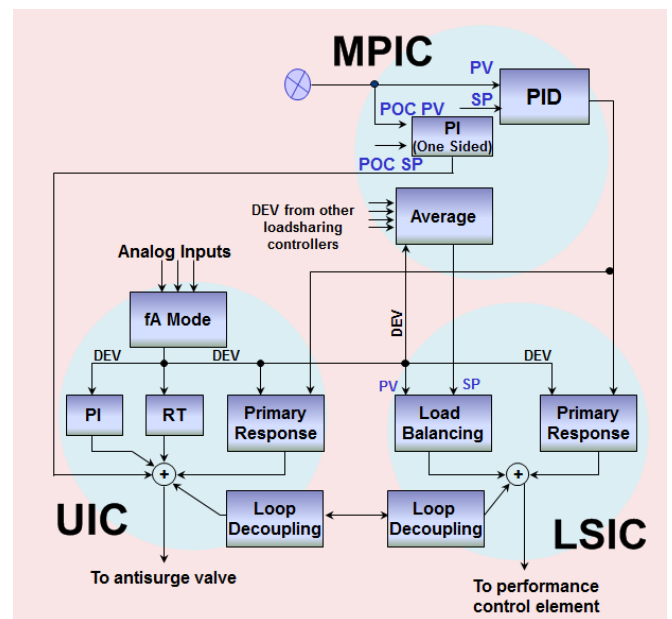


Fig. 3 - Load-Sharing Control Scheme

The load-balancing response is used to keep all of the compressors operating the same distance from surge. This is achieved by dynamically biasing the outputs of the load-sharing controllers. Each load-sharing controller selects the lowest deviation (DEV) from surge reported by any of its companion antisurge controllers (that is, that for the section closest to surge) for use as its load-balancing control variable. The load-balancing set point is received from the master controller which determines the set point by averaging the deviations selected by the load-sharing controllers. Each load-sharing controller calculates a PID load-balancing response to the difference between its selected deviation and master controller's average deviation. It then calculates its output signal

by adding the primary capacity and load-balancing responses. This raises or lowers the flow rate through each compressor until all are operating the same distance from their surge limits.

When operating at reduced rates, parallel compressors are often recycling. These recycle rates may differ between parallel compressors or compressor sections even if the compressors are considered identical. Recycle balancing works to equalize recycle on all operating compressors or compressor sections running in parallel. Each antisurge controller compares its output to the output of the parallel antisurge controller(s) and if its output is less, it will increase its recycle rate to match the highest output.

In addition to the load-sharing and load-balancing control responses, a pressure override control (POC) feature can be used to raise the recycle flow to help control excessively large or rapid changes in the capacity control variable. When controlling the suction pressure, POC is initiated when that variable drops below the set point by a defined amount. When controlling the discharge pressure or net flow, POC is initiated if the chosen variable rises above the set point by a defined amount. The POC response is sent to the antisurge controllers, which compare it to their own control responses and use the higher of the two. Thus, this feature never reduces the recycle rate below that needed to prevent surge. If the POC response is higher than the surge protection response, it will increase the recycle flow rate and suction pressure while lowering the net flow rate and discharge pressure.

The parallel MR and Propane compressors can utilize variable speed or constant speed drivers. For variable speed compressors, the control system varies compressor speed for capacity control and load-balancing. For constant speed compressors, suction throttle valves are necessary for capacity control and load-balancing. In some cases, parallel refrigeration compressors with sidestreams require throttle valves on the sidestreams as well in order to aid in startup of a parallel unit or prevent compressor surging when a unit is shutdown. See Figure 4.

In the typical APCI LNG plant design, the propane refrigeration circuit is used to precool the natural gas and the MR gas prior to these entering the main cryogenic heat exchanger (MCHE). The propane compressors provide the lowest cooling effect when the suction pressure is maintained near atmospheric pressure. Because of this, suction header pressure should be the primary capacity control variable with POC enabled in the first section antisurge controllers to allow for precise and stable control during turndown operation or process upsets.

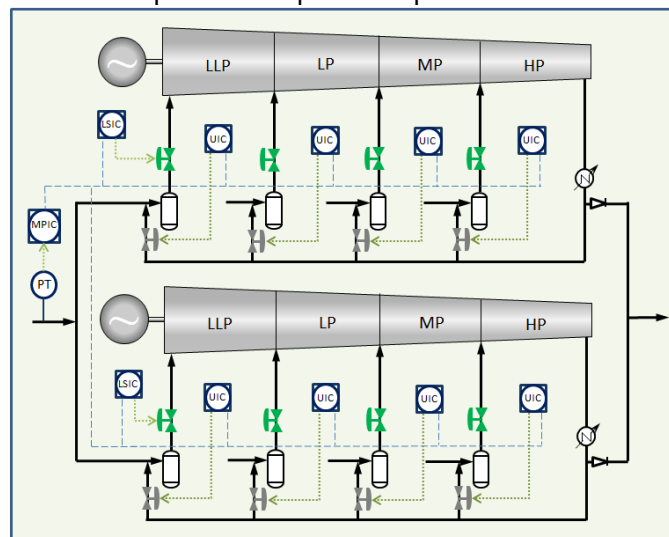


Fig. 4 - Constant Speed Parallel C3 Compressors

Controls around the MCHE have become more sophisticated but these control schemes do not take into account the control requirements necessary for efficient and safe automatic operation of parallel compressor strings. The MCHE control consists of manipulating Joule-Thompson (JT) valves and flow valves which directly affect the MR compressor throughput. See Figure 5. Integration between the MCHE control system and the parallel MR compressor performance and antisurge control system is desirable in order to avoid negative interactions. This is often not considered since the controls for the MCHE and the controls for the rotating equipment are developed independently and capacity control for a single fixed speed MR compressor string in previous plant designs was not used.

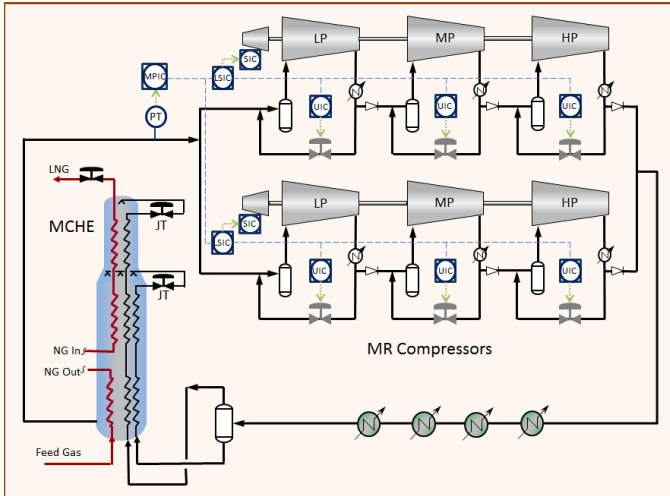


Fig. 5 - Parallel MR Compressors and MCHE

Without proper integration, the capacity control for the parallel MR compressor strings may require slower tuning than the MCHE control system. This provides steady control for the MCHE while allowing the proper load-sharing and load-balancing control needed for the parallel MR compressor strings.

With the move towards more complex turbomachinery arrangements as well as enhanced automatic controls around the MCHE, it is important to ensure that the needs of process control and turbomachinery control are simultaneously met in order to maximize production while safely and efficiently operating the machinery. Parallel compressor systems are required to operate under a wide range of conditions such as full production, turndown operation – either in recycle or single string operation, process upsets and transitional states when a unit is being brought on or off line. Having the appropriate load-sharing control system provides reliable operation of the compressors during these various operating conditions.

References

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