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Innovative APC boosts LNG train production

APC application yields significant operability, economic benefits

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The appropriate use of advanced process control (APC)—specifically, multivariable predictive control (MPC)—has been well established in the hydrocarbon processing industry over multiple decades, and it is widely considered an essential contributor to production maximization on liquefied natural gas (LNG) trains. If correctly applied, APC software delivers more efficient operation of existing hardware assets and essentially provides a "cruise control" for the control room operator.

The Woodside-operated Karratha Gas Plant (KGP) has been progressive in the application of APC across all major process units, generating sustained benefits. Although the site is a mature APC user, there is a continual focus on innovation and design evolution to further improve APC benefits.

This article describes the implementation of APC on an LNG liquefaction train. Several generic APC project aspects are investigated, such as the use of a dynamic simulator and automated step testing to aid development. Also, details of the project's significant operability and economic benefits—including a 4,000% return on investment—are discussed with commentary on whether this success has been sustained beyond the "honeymoon" period.

PROJECT OVERVIEW

Woodside engaged Apex Optimisation to assist with a revamp of the existing APC on LNG train 4 (LNG4) and the implementation of a new APC on LNG train 5 (LNG5). The project was a collaborative effort, with both parties heavily involved in the design, implementation, commissioning and post-audit of the new APCs. The implementation kicked off in March 2010 after a functional design specification phase. The revamped LNG4 APC and the new LNG5 APC were commissioned in May 2010 and September 2010, respectively. A successful site acceptance test signaled handover to site support engineers in October 2010. Fig. 1 shows a schematic illustrating the process design for the two liquefaction trains.

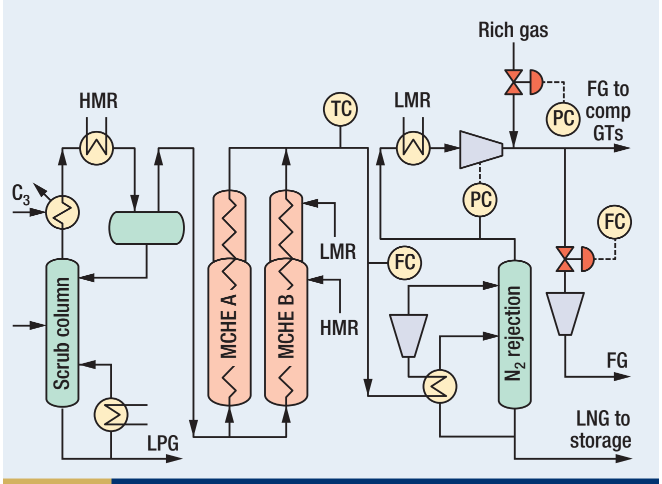

FIG. 1 Process design for LNG4 and LNG5.

Challenges to development. The execution of the project was challenging due to a range of factors:

- The design evolution significantly pushed the previous project's boundaries. Additional compressor power-management handles were included, the site electrical power-generation spinning reserve and fuel gas system capacity limits were added (these global constraints are relevant to both trains), and a more sophisticated approach to optimizer functionality was adopted. Hence, the scope of the modeling and custom functionality required was substantially different from that of the previous LNG4 APC application.
- The new applications are relatively large, with each having over 20 manipulated variables (MVs) managing more than 60 controlled variables (CVs) and some complex interactions (i.e., relatively high model density).
- Parts of the process are highly nonlinear in their behavior, and this can limit the applicability of linear APC technologies. Improved performance was needed during lower production conditions (e.g., turndown or hot summer temperatures), and this required some innovative use of transforms, gain scheduling and automatic logic to manage variable usage. Dynamic simulation was leveraged to develop the gain scheduling relationships.
- As the existing LNG4 APC had been unused for over a year, there was limited operator expertise with APC on the LNG4/LNG5 distributed control system (DCS) panel. This situation required careful management of the reintroduction of APC and operator training.
- The LNG5 train was relatively young, with a limited operating history. Furthermore, its operation was very different from that of LNG4, despite the equipment design being essentially identical. Mechanical changes to the LNG5 train during the execution phase of the APC project significantly changed the train operation and reset the LNG5 APC design needs. The project

engineers had to remain flexible to adapt to the changing basis while maintaining the project schedule.

• Interfacing to some of the compressor packages required an exotic approach. In particular, one key compressor handle was hosted on a separate DCS network on the other side of the control room. This context required careful software design and operator training to ensure that the final mechanism was robust and intuitive to both DCS operators.

• Automatic step testing was adopted in order to reduce the duration of the step-testing phase; this had not been previously attempted onsite.

• An aggressive schedule was required to commission two large applications within seven months, which kept the intensity high throughout the duration of the project.

These challenges were overcome through teamwork among the participants. Close operator involvement was critical to project success, as this fostered ownership of the project and ensured that each process control improvement implemented was intuitive for the operators and appropriate for the widest range of process conditions.

One of the major APC benefits delivered is improved consistency in how the process is managed. To realize this benefit via sustained APC usage, consistency in how the APC is operated is paramount. Therefore, thorough operator training is essential to the project process. Fig. 2 shows Woodside DCS operators at work in the control room.

USE OF DYNAMIC SIMULATORS TO ASSIST MODEL DEVELOPMENT

In recent years, the use of a dynamic simulator (i.e., an operator training simulator, or OTS) has been promoted by advocates as a more efficient way of developing APC. The ability to speed up real time, avoid real-life plant reliability and load disturbance impacts, reduce engineering support requirements, and potentially complete the APC development well before the plant is commissioned makes the OTS very appealing to cost- and schedule-focused customers. These factors prompted Woodside to investigate the use of an existing OTS to assist with the conceptual design and initial ("seed") model for the automated step-test phase.

While the OTS is typically fit for the purpose of investigating an APC optimization strategy and controller structure, is it appropriate for APC model development? One can build an OTS to varying levels of fidelity (with cost implications), and the main objectives are typically:[1]

FIG. 2 Woodside DCS operators at work.

• Enabling thorough DCS and emergency shutdown system checkout and verification before construction

• Providing useful operator training on the process with the target system interface

• Providing a useful "what if?" tool for engineering analysis of process changes.

Ascertaining OTS fidelity. To achieve these objectives, the OTS requires a level of fidelity that is well practiced and accepted by OTS developers. However, a standard OTS may not have the fidelity required for complete APC model development; what is required is a function of both the APC modeling needs (the APC design) and the nature of the process included in the APC scope. Even if it is identified as an OTS objective up front, the distant APC topic may struggle to justify a costly increase in the OTS fidelity among more traditional construction project needs.

The question then becomes, "How can it be known if the OTS has the required fidelity?" This question is not an easy one to answer unless an operating plant can be used as a datum, or unless the process is extremely well understood from a modeling perspective and the required fidelity exists.

In our LNG liquefaction APC example, the OTS system was developed alongside the construction project, with traditional objectives in mind and well before APC was considered. The development of the OTS was given heavy focus (including post-commissioning improvements to OTS accuracy in selected areas), with high acceptance of the simulator's value. When using the OTS for the APC model development, we found that the thermodynamics-related models were reasonably accurate at base-case production rates. However, there were discrepancies around many of the ΔP-related models (especially those associated with complex devices such as hydraulic turbines with multiple flow elements) and turndown-related models (such as those associated with flow regime changes experienced inside the spiral-wound cryogenic heat exchanger). Given the exotic nature of the cases where accuracy was lacking and the relative importance of these items to the traditional OTS objectives, this is not a surprising outcome from a traditional OTS used outside of its original purpose.

The value of the OTS in our LNG APC case was essentially limited to the actions listed below:

• Formulating the optimization strategy and controller structure

• Being able to interrogate turndown cases, which are relevant for hot-weather operation, without suffering production losses on the plant or needing to contemplate a second step test in more difficult summer conditions—thus, providing valuable data on relative gain changes, which was used in the gain scheduling logic

• Providing useful, initial models for the automatic stepping tool. As the new APC design was different in both DCS control basis and scope, the previous model could not meet this need in all areas.

Benefits of simulation. A dynamic simulator of typical fidelity (OTS or desktop engineering tool) can be useful in verifying an APC design concept in terms of control and optimization strategies. This need is more relevant for complex processes where the pre-APC operation does not exploit all the available degrees of freedom and some methodology needs to be developed. The APC model accuracy required for accurate model development and full APC benefits would be much higher than that required for strategy verification.

A complete OTS-based APC model was developed as part of the functional design phase to support the automated step test.

TABLE 1. Accuracy assessment results for final OTS-based APC model

Plant area	Proportion of final models closely resembling OTS-based models	Comments
Scrub column	94%	Good form and gain from OTS models
Liquefaction	31%	OTS gains were regularly less than half of plant test gains (10% at times)
Hydraulic turbines	0%	OTS gains were sometimes inaccurate by two orders of magnitude

After the final model was verified post-commissioning, a comparison was performed to assess the accuracy of the OTS-based model. The results in several key areas are presented in Table 1.

In summary, the knowledge gained from using an OTS for APC model developments (as distinct to APC design and optimization strategy) reinforces the following guidelines:

- Understand the relevant accuracy of the OTS well. There are obvious implications for developing APC on young or difficult OTS processes prior to plant commissioning. In some instances, the OTS has relevant accuracy inherently (e.g., the C_3 splitter example, where the distillation models are the key aspect[2]). In other areas, the important APC needs are not necessarily aligned with key OTS objectives.
- Understand the value of using the OTS in APC development; i.e., is it prohibitive to step test on the real plant for operational or economic reasons?
- Do not underestimate the value of working on the real plant and interacting with operators for developing an operations understanding (as distinct to a process understanding) and cultivating APC understanding.
- Always be prepared for some model error when commissioning the APC on the real plant, and allocate sufficient time to resolve any problems.

USE OF AUTOMATED STEP-TEST TECHNIQUES

Automated step-test techniques have been promoted in recent years as a way of providing a rich data set in a short period of time, thereby reducing project cost. Also, simultaneous testing of multiple MVs could improve the accuracy of the gain ratios that are important to the performance of the application.

This LNG liquefaction APC project was the first incidence in which the site had used this technique as the primary step-test approach, after successful testing on the liquid petroleum gas (LPG) fractionation unit suggested it would be a time-saving option. Despite the best endeavors of the project team, the LNG train experience was somewhat different, with the net result being neutral relative to a traditional, manual step test.

The reality was that this particular LNG liquefaction process was not well-suited to this technique, for the two reasons listed below:

1. The daily variation due to ambient temperature swings is six times the maximum MV step size allowed for the test. The automated tool works purely on process feedback, whereas anyone operating the plant knows what moves have to be made before the sun comes up. The manual test is superior in this case, as the tester can plan moves using all information available, not just APC variables. Thus, when using the tool as intended, the moves required to control the process swamped the random steps required for model identification.
2. Also, the extent of the load disturbances encountered during a normal day demands both the need for minimal optimizer action and the inclusion of extra steps in addition to the automated steps.

For other processes where this is not the case, and manual step-test costs are greater, this approach may offer a tangible reduction in the step-test duration.

Test automation results. Based on our cumulative experience with a range of automated step-test techniques, our conclusions from test automation are set out below:

- Using the available APC model as a true model identification "seed" model (as opposed to simply a model used by the APC to manage the process during the test) may considerably speed up the model development process. A further enhancement would be the ability to assign confidence to sub-models to assist the initial model identification.
- With some processes, it is not viable to switch off the optimizer action for long periods, much less for the duration of a step test. In our LNG example, the superseded DCS controls provided a high level of optimization that had to be matched during the step test. The automated test must accommodate this need with some sort of mild optimization.
- It may be useful to automatically change step direction if a full step size is not feasible due to potential limit violations. If partial moves are applied, additional steps may be required to achieve the same data quality.
- As there can be a need to make extra moves on a real plant, it may be desirable to include all moves made during the step test—not just those made by the automated tool—in the model identification approach, as a means of reducing the total test duration.
- Real-time model identification can be very useful, but one should not rely only on automated model identification to signal that testing is complete. In one instance, this approach produced some false negatives, which would have prolonged the test further if additional identification was not undertaken using traditional approaches—i.e., manual data grooming, careful slicing, and finite impulse response (FIR) generation over multiple times to steady state (TSS).
- Engineers should not be required to work more intensely than a manual step test in order to manage the automated testing. Keeping in mind that the traditional approach offers some additional value:
    1. Time for detailed discussions with operators at the panel is very effective from both a "public relations" and training perspective.
    2. Time to observe the plant behavior and "experience the challenge for the APC" provides useful insight into how the APC should act and sets helpful expectations for the model identification. Unfortunately, this valuable experience is generally negated by automated testing tools, which step multiple MVs simultaneously as the CV responses can no longer be seen by the eye.
    3. Time to consider DCS control servo response and make repairs early can greatly improve the final result.

It is widely regarded that most efficiency tools added to a well-proven methodology are no replacement for sound engineering judgment. Generalizations about efficiency improvements will be tested by the more challenging APC projects. One needs to have confidence in significant efficiency gains to warrant deviation from the trusted methodology, especially when the payback on these projects is already substantial.

CUSTOMIZATION OF APC APPLICATIONS

Woodside has nearly 15 years of experience with APC applications in the relatively demanding environment of an integrated production facility. The context is demanding in the sense that personnel turnover is high at the remote site, and the costs of poor performance are severe. Accordingly, effort is required to maintain appropriate skill levels at the site.

This experience has proven the value of appropriate APC customization to improve availability and robustness. Indeed, the inability of the previous APC application to accommodate the full range of operations was one of the main reasons for its demise. A few examples of how the generic APC software was augmented are discussed below.

Gain scheduling for turndown. Analysis of previous APC performance and OTS scenarios confirmed significant gain changes at reduced production rates. These changes demanded custom logic to manage gain scheduling, according to production rate ranges using discrete gain multipliers. (Continuous formula-based gain scheduling was not preferred due to the risk of producing ill-conditioned matrices.) The logic also provided some automatic shedding of specific MVs and CVs during turndown to accommodate the unique operating context.

Model adaptation for hydraulic turbines. The power extraction from the hydraulic turbines is akin to climbing to the summit of a hill, with constraints applying a ceiling on how high one can climb. The model gains are very much a function of the status of the surrounding DCS controls, and if the alternative flow path opens up (the Joule Thompson [JT] valve), the wicket gate is moved in the opposite direction to maximize power extraction (i.e., one is on the opposite side of the hill and needs to walk in the other direction to climb it).

In the past, this scenario had constituted a challenge for the APC that was avoided by instructing the operators to ensure that the JT valve was shut before giving the wicket gate control to the APC. However, it was still possible to suffer load disturbances, which bounced the process onto the opposite side of the gain inflexion point. The results were not positive.

With the addition of simple logic to flip the gain sign and drop/activate specific constraints, the new APC has improved robustness by allowing the operators to give the hydraulic turbine control to the APC, regardless of the DCS control state. The APC will honor the correct constraints with appropriate wicket gate moves, and will walk the process over to the "correct side of the hill" when feasible.

Product price-driven optimization. Another feature of the new APC design is the ability to specify product prices and use them to dictate the subtleties of the optimization toward either maximizing LNG production or LPG extraction. This arrangement is different from simply specifying maximum LNG or maximum LPG, as each of the relevant MVs has differing effects on the yield of each product. It is useful to provide some "shades of gray" in terms of the optimization options.

Aside from a purely economics-driven optimization, the APC has maximum LNG and maximum LPG modes to assist logistics needs without sacrificing valuable production (e.g., tank-top scenarios that affect only one product).

PROJECT RESULTS

The overall results of the project were exceptional, given the challenges faced. Results included:

- Excellent operator acceptance of all the developments implemented during the project (i.e., DCS control improvements, instrument repairs and APC commissioning), with APC uptimes consistently greater than 97%. Operator feedback shows that the new APC makes objectives easier to achieve.
- A tangible contribution to improved reliability as a result of the APC maintaining the process within constraints on a minute-by-minute basis. In particular, the APC manages some difficult operating envelope constraints associated with the large axial compressors employed in the liquefaction process. Prior to the APC, manual management of this relatively tight feasible space, coupled with the production changes driven by diurnal swings, left the DCS operators under continual pressure.
- The production increase achieved with the same process equipment represents a decrease in specific energy consumption and a relative reduction in carbon footprint for this important clean energy-producing process.
- The project was completed on schedule and within budget, despite an evolving design datum being prevalent throughout the execution.
- The APC benefits delivered a significant boost to the bottom line for North West Shelf Joint Venture Partners, with a 3%–5% increase in LNG4/LNG5 production (depending upon ambient conditions) and a 4.7% increase in LPG production verified. This production increase delivered an overall project payback of less than two weeks, or a return on investment of 4,000%.
- At the 2011 Process And Control Engineering (PACE) Zenith Awards, the project won the Oil & Gas category and the

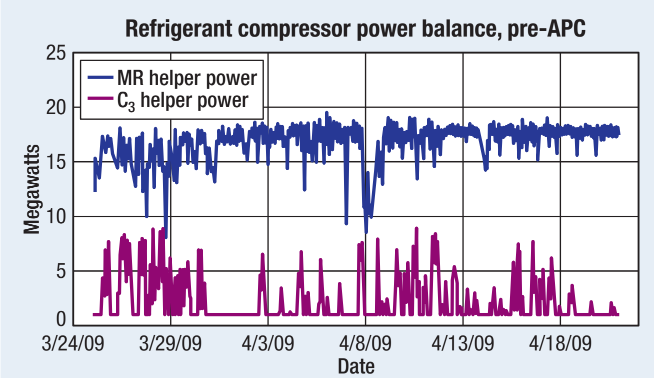

FIG. 3 Power consumption of the primary compressors pre-APC.

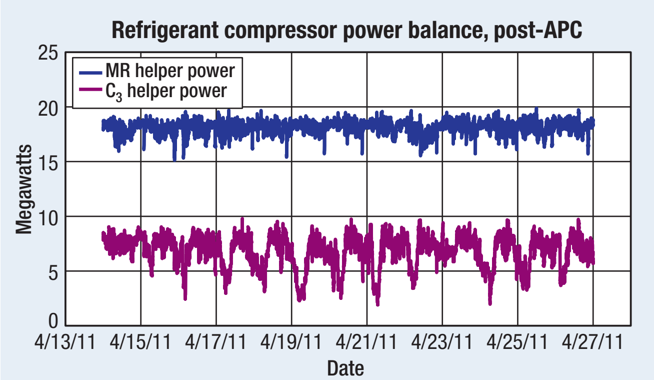

FIG. 4 Power consumption of the primary compressors post-APC commissioning.

Project of the Year Award ahead of 50 competing projects.

The LNG production benefits are best illustrated by the reduction in compressor power giveaway, which is an inherent characteristic of the process design. That is, production is either limited by the helper motor power on the mixed refrigerant (MR) compressor or the propane (C_3) compressor. The amount of spare compressor power not applied to the process represents a production loss. Fig. 3 shows power consumption of the primary compressors before the APC.

Following the commissioning of the new APC, the higher average power consumption was a significant contributor to the increased production capacity. Fig. 4 shows power consumption of the primary compressors after APC commissioning.

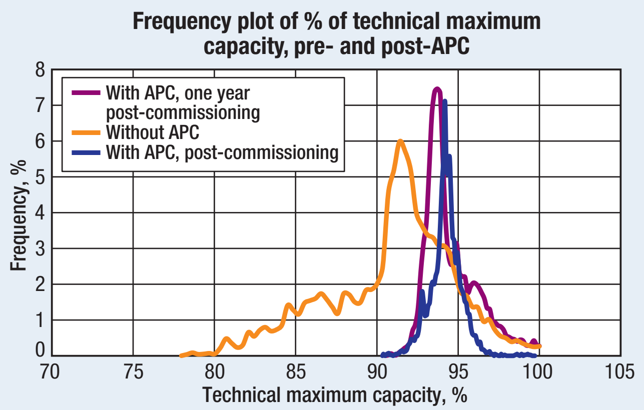

FIG. 5 Comparison of production vs. technical maximum capacity.

It is important to note that the project benefits have been sustained one year later, with no deterioration in performance or in operator satisfaction detected. Fig. 5 shows a comparison of production vs. technical maximum capacity. This project demonstrates how the appropriate use of APC technology can provide a tangible and sustained improvement in plant profitability and operability in a cost-effective manner. **HP**

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