A STEP CHANGE IN LNG OPERATIONS THROUGH ADVANCED PROCESS CONTROL

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1. ABSTRACT

"A STEP CHANGE IN LNG OPERATIONS THROUGH ADVANCED PROCESS CONTROL"

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Shell Global Solutions has been implementing and supporting Advanced Process Control (APC) projects in several LNG plants worldwide, including ones in Oman, Brunei, Malaysia, Nigeria, Indonesia and Australia. This presentation focuses on work carried out with some of the LNG producers.

APC is a model based predictive tool that enables automatic online control of a total unit or LNG train. Within the oil and gas industry APC was firstly applied in refining but over the past decade, also has become widely recognized as a value-adding technology in LNG processing.

The production process in LNG plants is sensitive to a wide range of disturbances, notably, the variations in the air ambient temperature and feed conditions / composition. APC technology reacts constantly, and very quickly, by making automatically countless small changes to the process parameters. With such tight control, a process may be operated closer to its limits. In fact, APC continuously pushes the process against its constraints while keeping at the same time a proper distance of the safeguarding (trip) and relief settings which leads to financial rewards.

APC in LNG processing has been applied to a variety of units. Results noted are:

- 1 to 3% higher throughput,
- Higher efficiency,
- More LPG or NGL,
- Less flaring.

APC stabilizes plant operations resulting in less upsets and higher plant availability. Also, operations between various shifts become more consistent. APC is flexible to different objectives e.g. under certain conditions LNG extraction is maximized where under other conditions efficiency is maximized.

The levels of benefits achieved depend on local conditions such as cooling-system type, compressor driver type and product prices. Gas-turbine-driven sites tend to enjoy higher benefits because of the strong impact of air ambient temperature on gas-turbine efficiency.

APC covers one whole LNG train including:
- Liquefaction sections (main cryogenic heat exchangers [MCHE] and refrigerant loops)
- Fractionators
- Scrubber columns
- Stabilisers

Recent developments in Shell Global Solutions look at APC over a number of trains where the fuel gas balance is optimized and overall efficiency is further enhanced to further boost the benefits.
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A STEP CHANGE IN LNG OPERATIONS THROUGH ADVANCED PROCESS CONTROL

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2. SUMMARY
The application of Advanced Process Control (APC) on LNG plants has shown to be very beneficial. APC pushes a plant continuously to maximize LNG production, improves energy efficiency and/or maximises LPG production. Results noted are 1-3% more throughput. Project payback is typically within six months of commissioning.
In the example of Oman LNG the plant throughput went up with 270,000 m$^3$/year LNG which represents two additional cargoes.

3. INTRODUCTION
Shell Global Solutions has been implementing and supporting Advanced Process Control (APC) projects in several LNG plants worldwide, including ones in Oman, Brunei, Malaysia, Nigeria, Indonesia and Australia. This article focuses on work carried out with some of the LNG producers.

APC is a model based predictive tool that enables automatic online control of a total unit or LNG train. Within the oil and gas industry APC was firstly applied in refining but over the past decade, also has become widely recognized as a value-adding technology in LNG processing.

The production process in LNG plants is sensitive to a wide range of disturbances, notably, the variations in the air ambient temperature and feed conditions/composition. The sensitivity to ambient temperature is due to the presence of air coolers, gasturbine drivers and cooling towers in the process. APC technology reacts constantly, and very quickly, by making automatically countless small changes to the process parameters. With such tight control, a process may be operated closer to its limits. In fact, APC continuously pushes the process against its constraints while keeping at the same time a proper distance of the safeguarding (trip) and relief valve settings which leads to financial rewards.

APC applications cover one whole LNG train including:
- Liquefaction sections (Main Cryogenic Heat Exchangers [MCHE] and refrigerant loops)
- Fractionators
- Scrubber columns
- Stabilizers
- Feed gas treating

4. OPPORTUNITIES FOR APC IN LNG PROCESSING
There are several characteristics that make LNG plants excellent candidates for applying APC:

- Variations in optimum operating conditions – it is challenging for any panel operator to handle all the changes in operating conditions such as in ambient air or cooling-medium temperature, throughput or feed composition. There are complexities and interactions between the many process variables that require continuous attention (for example, LPG re-injection affects LNG composition). The typical ambient temperature fluctuates during the day (the diurnal effect) and thus requires continuous alterations to be made to the optimum operating conditions (see Figure 1). The changes in air temperature affect the cooling-water temperature and thus disturb the process. APC can handle such changes in operating conditions 24 hours a day, 365 days a year
- Product specifications – not maintaining tight control of the specifications for LPG and LNG can result in either off-specification cargoes or product giveaway. The penalties for off-specification products can be severe. Consequently, most plants operate above the minimum specification (in the comfort zone). APC stabilises the plant and enables operation closer to the minimum specifications (see Figure 2)
- Production schedules and objectives – most LNG plants have to meet an annual delivery plan for cargoes. During peak demand, LNG plants need to maximise production; at other times they run
at lower throughput. In addition, product prices change, and so sometimes maximum LPG production takes priority but at other times maximum LNG production does. Frequent changes in operating strategies can be easily managed by APC

- Equipment constraints – the compressor capacity in a plant is limited and some equipment deteriorates over time, both of which factors impact on production capacity. APC is model-based and uses predictive techniques to control the plant. By continuously pushing the process against varying constraints, APC keeps the plant operating at the optimum conditions.

5. **RESULTS**

APC in LNG processing has been applied to a variety of units. Results noted are:

- 1 to 3% higher throughput,
- Higher efficiency,
- More LPG or NGL,
- Less flaring,
- Flexibility and consistency in operations (different throughput modes, etc.)
- Reliability (fewer temperature shocks, less wear and tear, etc.)
- Stability of process operations

APC stabilizes plant operations resulting in less upsets and higher plant availability. Also, operations between various operation shifts become more consistent. APC is flexible to different objectives e.g. under certain conditions LNG production is maximized where under other conditions overall efficiency is maximized.

The levels of benefits achieved depend on local conditions such as cooling-system type, compressor driver type and product prices. Gas-turbine-driven sites tend to enjoy higher benefits because of the strong impact of air ambient temperature on gas-turbine efficiency.

Process units that benefit most from APC are:

- Main cryogenic heat exchanger and refrigerant loops
- Fractionators
- Stabilisers
- Scrubbers
- Flash vessels and fuel-gas compressors
- Boil-off gas compressors

5.1 **APC project steps**

There are several essential steps in any APC project:

1) Base-layer control review – for effective APC, instrumentation such as analysers and valves must be performing well. In particular, attention must be given to the reliability and accuracy of those analysers that play key roles in the control strategy (e.g. LNG composition, mixed refrigerant composition). APC usually sends targets to existing base-layer controllers that must be on automatic control. A review of base layer control performance will identify weak players and improvements may be necessary before APC can be implemented.

2) Functional design – the objectives of the advanced control strategy and the number of controllers must be defined including lists of manipulated and controlled variables. This requires involvement of technology and operations. At this step also opportunities for optimisation should be identified.

3) Plant testing – the dynamic behaviour of the plant is then identified by applying test signals to the manipulated variables. The responses (measurement data) are collected for further analysis. Part of this process can be automatic.

4) Detailed design – the collected data are transformed into dynamic models that are used to build the model predictive controllers and quality estimators. Performance of the controllers under various conditions is tested using dynamic simulation.

5) Implementation (in the distributed control system) – the tested controllers are installed by connection to the distributed control system, the human interface and the database. The controllers must have safeguards against process or equipment upsets.

6) Commissioning – the controllers are checked in action on the process before being handed over to operations.
7) Post-implementation review – after a few months’ operation, operational data are collected to compare the actual performance of the advanced process controllers against the expected results.

Before a project starts it is important to establish a joint team of competent and experienced local staff and staff from the APC supplier, so that all contingencies can be covered. Key factors for success are management commitment, operational involvement, and the use of experienced staff and proven products.

Implementing an APC project on one LNG train takes about a year for the first train and about nine months for subsequent trains. Project payback is typically within six months of commissioning.

5.2 Shell APC technology
The technologies used to implement APC in LNG plants are:

- Shell Multivariable Optimising Controller – SMOC\textsuperscript{PRO} - for model based predictive control.
- Robust Quality Estimator – RQE\textsuperscript{PRO} - for estimating qualities of products.
- Advanced Identification and Data Analysis - AIDA\textsuperscript{PRO} - for building the models of the controllers.
- Monitoring and Diagnosis – MD\textsuperscript{PRO} - for performance monitoring of controllers.

Figure 3 shows the relationships between these products. The results of the plant test and data collection are input for AIDA\textsuperscript{PRO} and RQE\textsuperscript{PRO} where the models are built. Subsequently the models are given to SMOC\textsuperscript{PRO} for controller design and simulation. The SMOC controller is implemented using ExaSMOC/ExaRQE in a Distributed Control System that is connected to the real process.

5.3 Case study – Oman LNG has increased its production by applying APC
The Oman LNG plant has been operational since 2000 and has two trains, modern instrumentation and a distributed control system (Yokogawa).

5.3.1 Oman LNG-train (U1400)
See Figure 4. The plant uses once-through seawater for ambient cooling. The natural gas stream enters the scrub column where heavy components and aromatics, which would freeze in the Main Cryogenic Heat Exchanger (MCHE, E1415), are removed and sufficient quantities of propane are recovered to produce refrigerant makeup. Overheads are routed to the MCHE.

The pressure of the LNG stream leaving the MCHE is reduced through a liquid expander (GT-1420) before running down into atmospheric storage tanks. The maximum capacity of the LNG train is limited by the amount of refrigeration capacity available. A mixed refrigerant compressor (K-1420/1430A/1430B) and a propane refrigerant compressor (K-1440) power the refrigeration cycle. The refrigeration capacity is determined by the maximum shaft power that can be delivered by the gas turbines on the two compressors. Each of the compressors has a helper motor that can deliver extra power to the shaft. Once the Turbine is at its maximum power, the maximum allowable helper motor power determines the maximum power that can be delivered to the shaft. At maximum LNG production one of the helper motors usually reaches its maximum allowable power before the other. The total LNG production is therefore limited by the most limiting of the two compressor powers.

High pressure Heavy Mixed Refrigerant (HMR) is sub-cooled in the warm and middle bundles. The pressure of this stream is reduced through a liquid expander (GT-1410) and then flashed across the flow ratio control valve into the shell side of the MCHE between the middle and cold bundles. This stream is then is mixed inside the MCHE with the low pressure Light Mixed Refrigerant (LMR) from the cold bundle. High pressure LMR is condensed and sub-cooled in the MCHE and then flashed across the “cold JT” valve into the shell side of the MCHE above the cold bundle. This low pressure LMR stream provides the refrigeration for the cold bundle and is then redistributed with the HMR over the middle bundle by an internal phase separator and liquid distributor. The combined MR stream is totally vaporized and superheated in the warm bundle of the MCHE before being recompressed in the MR cycle.
5.3.2 The APC project

During 2002/2003, Oman LNG and Shell Global Solutions installed and commissioned APC on both the LNG trains. The main objective of the project was to drive the plant towards its economic limits and physical constraints using SMOC and RQE technologies.

The SMOC controllers for the main cryogenic heat exchanger (MCHE) were designed to cope with different operating conditions and had to be fully acceptable to the operations staff. Since commissioning, these controllers have been online with an uptime of more than 90%. On both trains, the MCHE SMOCs have been pushing for maximum production against changing constraints, mainly in the helper-motor power on the mixed-refrigerant (MR) and propane compressor shafts.

Figure 5 illustrates that when using a SMOC, LNG production increases when the air temperature decreases. Pushing against the maximum helper-motor power would require an operator's full attention. If the maximum power were exceeded, the gas turbines would lose speed and would trip. Following fluctuations in ambient-air and cooling-water temperatures manually would require the operator to make virtually continuous adjustments to maintain the levels that are achieved with a SMOC.

When a SMOC is used, there is an average increase in power usage of about 5 MW for the two-helper motors. This is possible through the tighter control enforced by the SMOC. At Oman LNG, this control has led to additional throughput capacity of between 3 and 4%.

Figures 6 and 7 show the turbine’s helper-motor power for the baseline period (SMOC not running) and the period with SMOC running. The increase in propane helper-motor power was used to increase production (Figure 8) and MR flows, and thus give higher loading on the MR machine. In such cases, the increase in total power consumption was very high. There is a difference between the LNG increase when MR helper-motor power is limiting and that when propane helper-motor power is limiting:
- If propane is limiting, then 1 MW of extra propane power gives 3.1 MW in total extra to liquefy LNG.
- If MR is limiting, then 1 MW of extra MR power gives 1.5 MW in total extra to liquefy LNG.

During some periods, the propane compressor power was limiting production and gave the largest benefit for pushing helper-motor power and increasing production. In periods when the MR compressor power was limiting production, a smaller but still significant increase in production was achieved, typically around 10,000 m³ of LNG per month. Contrary to expectations, detailed analysis of the plant's performance has shown that MR and propane compressor power limitations often occur in rapid succession during the same month, or even the same day. SMOCs have proven extremely capable of handling such constantly changing conditions.

The annual throughput increase that has been achieved is 270,000 m³ LNG which represents two additional cargoes. In addition to these quantified financial benefits, Oman LNG has seen other benefits from APC:
- a generally more stable and controllable process
- when SMOC is running one operator can operate two LNG trains, even during transients.
- fewer alarms
- reduced wear and tear on plant equipment
- base-layer configuration enhancements that have resulted in less boil-off gas-compressor recycle
- reduced flaring
- fewer trips
- higher efficiency of the MCHE–MR system
- improved teamwork between operations, control and technology staff, and management
- all specifications met without giveaway.
6. CONCLUSION

The application of APC can be of significant benefit for LNG plants. Projects have shown a six-month return on investment or better. Shell Global Solutions has experience in APC on LNG plants, which is illustrated by its operational know-how, APC expertise and field proven products (SMOC PRO and RQE PRO). As seen in the Oman LNG example, the results are projects on time, within budget and exceeding predicted results.

Shell affiliates own patent rights on certain APC applications on the MCHE, compressors and cooling cycles.

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Figure 1 Cooling Water temperature (diurnal effect)

Figure 2 APC stabilises process and moves operations closer to limits.

APC reduces standard deviation of controlled variables typically by 50% which can be turned into benefits.
Figure 3 Integration of APC products

Figure 4 Throughput as function of air temperature and cooling water temperature
Figure 5  Throughput as function of air temperature and cooling water temperature

Figure 6  Helper-motor power during periods in 2002 when a SMOC was not running
Figure 7  Helper-motor power with a SMOC running

Figure 8  LNG production increase after APC start (t=19 days)

LNGPRODUCTION_COR  =  Production calculated as function of air temperature and cooling water temperature (correlation).
LNGPRODUCTION  =  Flow measurement