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The operability & control solutions – the technology to achieve stability for plant start-up

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Abstract. Process start-up of a liquefied natural gas (LNG) plant, refinery or a petrochemical facility is often equated with some level of process instability. The root cause for these instabilities is the lack of work-processes that manage the dynamic behaviour of the entire facility during the detailed engineering design phase. This has been found to be pervasive in all the international design companies assessed during the development of this program. As a result of these instabilities, Control Room Operators/Panel Operator will typically be challenged during the start-up of the facility, with the potential for human-errors, start-up delays and in some instances, mechanical failures. These in turn contribute to losses in production, significant energy wastage and extended flaring duration (a significant environmental concern). The concerns had prompted the Process Control team to come up with mitigation, the Operability and Control Solutions (OCS) technology, developed based on experiences gained from the start-up of a number of Oil and Gas facilities over a 20-year period. This paper will describe an innovative design-review technology that addresses the gap in effective process behaviour management. This unique technology provides assurance that new process facilities are designed to be inherently stable during the critical start-up phase till the normal operations phase. In doing this, the technology also addresses design gaps in addressing the potential of human-error and design gaps, which had prevented the facility to at its optimum point in a sustainable manner. The Operability and Control Solutions (OCS) is the technology, which has been applied in more than 10 large multi-million dollar plants. The technology has been accepted by design contractors and gives estimates of reduction in start-up periods of up to 3 days per facility.

1. Introduction

The Operability and Control Solutions (OCS) programme was developed based on experiences gained from the start-up of a number of Oil and Gas facilities over a 20-year period. The ability to control a process system is subject to the understanding of the inherent dynamics within the components that make up the process system, coupled with many other factors including the design of the regulatory control system, the integrated dynamics and the operating condition of the system. Most process units that are well run and are operated close to their normal operating points have traditionally been the subjects of much structured and unstructured tuning exercises. Both of these exercises would have resulted in the processes approaching some level of stability. Where these process units are of economic significance, the standard approach thereafter, has been to implement Advanced Process Control (or APC) algorithms, which further enhance the stability of the unit while driving the unit to some predefined economic optimum.
There is a significant number of materials that has been written about the stabilisation of process units during normal operations. However, very little has been discussed about the issue of stabilising processes during start-up of a facility. The issue of process start-up is complex from the perspective of dynamics while that of a fresh start-up (i.e. right after construction and commissioning) raises the complexity level even further. The reasons for the complexity are:

i) Operation that is substantially away from design/normal operating points  
ii) Substantially different process dynamics during start-up process  
iii) Inability of standard control systems to handle both normal operations and start-up scenarios without retuning  
iv) Significant number of disturbances  
v) Lack of familiarity by control room operators with dynamics (especially with first time starts)

These complexities typically result in process instabilities that challenge the Operations personnel of a facility, increase the potential for human-errors, increase start-up delays, and increase the potential of mechanical failures and the inability to drive for sustainable and optimised operations. These in turn contribute to losses in production, significant energy wastage and extended flaring duration (a significant environmental concern). Instabilities can be aggravated by poor design and the failure to consider integrated dynamic behaviour of the process system during the detailed engineering design phase. As highlighted by [1], one must control processes to overcome the effects of disturbances, and the inherent variability that occurs in all processing operations.

Over a five-year period, assessments were carried out on a number of designs from several international design companies. During discussions with these companies, one common finding was the absence of experienced personnel familiar with process behaviour and its management. While experienced personnel (in the form of experienced Control Engineers from an Instrumentation background, Process Control Engineers, APC Engineers) are common in operating facilities, only one company (of ten assessed) maintain a small group of such engineers to support in design and commissioning phases.

As a result of these, most design companies focus on steady-state behaviour as opposed to dynamic behaviour management. For specific processes, these companies will develop dedicated dynamic simulation models to understand and address specific issues. However, in any major project, such models tend to cover less than 5% of the total number of dynamic systems in a facility. In addition, while most projects will scope in a full-scale dynamic simulation in the form of a Training Simulator, these are usually made available several months after detailed engineering is completed (prior to commissioning).

With all of these issues, PETRONAS was faced with the issue of delivering several projects while ensuring that integrated dynamics were managed effectively. This paper will describe an innovative design-review programme called the Operability and Control Solutions (or OCS) that addresses this gap in process behaviour management. This unique programme provides assurance that new process facilities are designed to be inherently stable during the critical start-up phase till the normal operations phase. In doing this, the programme also addresses design gaps in addressing the potential of human-error and design gaps preventing the facility to run its optimum point in a sustainable manner.

The Operability and Control Solutions (OCS) Programme has been applied in more than 10 large multi-million dollar projects. The programme has been accepted by design contractors, and estimates reduction in start-up periods of up to 7 days per facility.

2. Methodology
The Operability and Control Solutions (OCS) Programme was initiated as a result of an analysis of more than 10 plant/process start-ups, delivered by several large international engineering contractors. This analysis showed design gaps which resulted in process instabilities during the start-up process and the inability for these plants to operate at the optimum-point as shown in figure 1. These issues were
exacerbated in some cases by complex operational procedures that introduced the potential for human-error, thereby further increasing the likelihood of process instabilities.

![Figure 1. Typical Start-up trend vs Ideal trend](image1)

The OCS programme comprises of three different studies with one common objective, i.e. to ensure that new facilities could undergo a start-up that was free of instabilities, where automation and other means are utilised to minimise human-error and finally, where technology is applied to achieve an optimized and sustainable production. The OCS programme developed 3 dedicated studies to address these different areas as depicted in figure 2. These are the:

- Stable Start-up and Dynamic Stability Study (SSDS)
- High Intensity Sequential Operations Study (HISO)
- Process Control Optimised Operations Study (PCOO)

The study approach is quite different for each of these studies because the objectives are significantly different. These will be explained in the following sub-sections. Internal references were developed and enhanced over the years to ensure consistency in methodology regardless of the process technology/type.

![Figure 2. Different targets for each studies](image2)

2.1. *Stable Start-up and Dynamic Stability Study (SSDS)*
The first study in the OCS programme is called the Stable Start-up and Dynamic Stability (or SSDS) study. This study identifies points of potential instability during the start-up process. The objective of the study is to stabilise the facility while bringing it up to its normal capacity. It achieves this through a rigorous desktop study of process technology, design and anticipated dynamic behaviour. Where applicable, operational experience of identical or similar units is brought in to support understanding the behaviour.

In one case, the study was carried out on a Crude Distillation Unit, and it was identified that control loops on the Atmospheric Residue line for a series of recovery heat exchangers were designed individually and not collectively. The analysis revealed the various control loops would have dynamic-conflicts resulting in an unstable product flows that would impact a downstream unit. Both issues and recommendation of control simplification was acknowledged by the engineering contractor. A similar finding was identified in an RFCC Main Fractionator Light Cracked Oil pump-around. A number of other designs were found with dynamic conflicts, as there was little perception of the impact of controlling multiple integrated processes.

Because of its rigor in assessing the operational aspects, the study has been able to identify numerous other non-dynamic issues. For instance, early in 2016, the study identified a design oversight in a fluidized catalytic cracker, which disabled the operation of a critical air purge facility. This would have resulted in several days of start-up delays. Once again, the engineering contractor immediately rectified this at the design stage. As the projects moves from detailed engineering to commissioning, any re-engineering of a design gap becomes more difficult and costly. The OCS Program prevents the need to carry out re-engineering at a later phase.

In cases where a novel process is studied, experience is typically unavailable to provide comprehensive understanding of individual and integrated dynamics. In order to provide a more wholesome solution, in limited cases, dynamic simulation is recommended in order to understand the effect any major operational scenarios (e.g. impact of multiple LNG train start-ups with common cryogenic equipment, impact to complex multi-feed fuel gas network, etc.). This SSDS study, combined with a dynamic simulation, provides recommendations to overcome certain difficult scenarios, as provided from the results of the simulation.

In addition to identifying potential dynamic issues and providing the associated recommendations, the SSDS study additionally includes a section to support commissioning of control loops. Recommendations for every control loop are provided for every control loop in the facility. This includes how to approach control loop tuning during the start-up phase and during normal operations. It also provides focus on complex controllers that needs to be rigorously designed and tested. The study identifies critical controllers that need to be automated during start-up in order to ease the Operations team during the start-up phase.

As a result of over 40 years in experience, PETRONAS has developed references for control design, as well as a program of continuous capability development in the area of operability and control. This complements the execution of the OCS Programme and makes it more effective.

2.2. High Intensity Sequence Operations Study (HISO)

The second study within the OCS Programme, called the High Intensity Sequence Operations (or HISO) study addresses how complex / unfamiliar operational steps can promote human-error. This study assesses each gross operational step and applies a consequence-probability matrix to identify the impact of human-error. The aim is to reduce excessive operator intervention and leverage on automation as much as possible.

A common issue at start-up for non-identical/unique facilities is that the low experience levels promote a situation of a high Human Error Potential (high HEP) as in figure 3. It is important to note that human error at this stage can cause significant delays in start-up duration. As opposed to this, the availability of experience levels can actually limit the potential of delays and even limit damage when there are process/equipment/design issues, due to the ability of the operator to leverage on his prior experience.
Figure 3. Human Error Potential with respect to experience level

A typical refining or petrochemical facility will spend less than 10% of its time in transient operations — yet more than 50% of process safety incidents occur during these operations [2]. Deficiencies in procedures and employee training often are cited as root causes of these incidents. The increased reliability and extended turnaround intervals of plants result in less familiarity with tasks outside of normal operations. So, while it's critically important to follow procedures during transient operations, a high percentage of procedural violations are found to occur during them.

The Abnormal Situation Management® Consortium funded a study to investigate procedural execution failures during abnormal situations. The study team analysed incident reports to identify root causes associated with procedural operations failures. The main finding from this investigation was the majority of the procedural operations failures (57%) of the incident reports involved execution failures in abnormal situations as shown in figure 4 [3].

![Diagram showing time in abnormal operations and incidents during abnormal operations](image)

Figure 4. A disproportionate percentage of safety incidents typically occur during abnormal operations

One method to reduce the probability of human error is to introduce rigorous mechanisms to limit or prevent Human Error Potential (HEP). HEP-Reduction (HEP-R) techniques are varied but used in
varying degrees in the industry. To a large extent HEP-R techniques are subjective and usually dependent on experiences that have fostered similar HEP-R in previous start-ups.

Most HEP-R techniques originate from the aviation industry that have utilised items such as manual checklist successfully. Overtime, these have evolved into procedures that have been integrated into the flight systems. This has proven to be successful within the airline industry and have over years been incorporated into the Process industry. Such “Online Procedures” and “Procedural Automation” have already been used successfully in PETRONAS for several years (in selected facilities). In line with IR 4.0, automation is necessary to assist in preventing human errors.

The ISA Technical Report ISA TR-106.00.01-2013 Procedure Automation for Continuous Process Operations[4], provides a guideline on how to implement Procedure Automation effectively within the Process Industry. Part of the recommendations for HIS utilises the ideas or concepts that are presented in the TR-106. However, this is expanded enormously by incorporating several other simple and intuitive concepts such as repeat-alarms (for critical systems), rate-of-change of process variables, graphics enhancements and several other options.

2.3. Process Control Optimised Operations Study (PCOO)

The third study in the OCS Programme is the Process Control Optimised Operations (or PCOO) study. This study carries out a design review of a process unit to determine if it is ready for online and automated optimisation. The aim is to ensure that the plant can be brought immediately to optimum production in a sustainable manner. This is usually achieved through the application of Advanced Control strategies, once the facility has been stabilised.

The study per se would be similar to an Advanced Process Control feasibility study, which typically is done for an already running plant. Doing it ahead in time during the project stage is to ensure the plant system infrastructure and equipment/instrumentation is already designed for optimisation. The cost of carrying out modifications during early design is significantly cheaper that doing this during commissioning and/or during operations.

PCOO provides early identification of the means to optimize the facility. This introduces the approach of a plant that is ‘designed-for-optimisation’ from day one, as opposed to a plant that is just ‘designed-to-run’. In one study on a Propylene column, the study identified insufficient analytical instrumentation that prevents sustainable and efficient process operations using advanced automation post-stable operations.

3. The first section in your paper Case Study: Study for Floating LNG facility

The first implementation of the study was carried out on PETRONAS’ 1st floating LNG production facility. The study was deemed necessary, as this is the first of its kind in the world and requires more scrutiny in order to ensure the success of the facility. The controllability of the nitrogen liquefaction process is the main concern due to the large number of rotating equipment as well as load balancing the parallel Nitrogen refrigerant trains. Specific analyses need to be conducted on the liquefaction system due to the complexity and highly interactive nature of the process, leading to possible process instability.

Main objective of the study is to assess the dynamic stability of a facility, as well as identifying specific operational activities that are highly complex and sequential and therefore requiring extensive panel operations intervention. Dynamic stability of the facility refers to the stability of the process under a steady state and transition conditions. During the study, it was necessary to identify its operating modes, operating conditions during abnormal and normal operations, and subsequently the impact to stability during the abnormal and normal operations, including mode changes. Additionally, control schemes were assessed on their capability to achieve the desired levels of stability.

The study analysed in detail the Start-Up of the facility from purge to pressurisation and continued with a Normal Operations analysis, which looks at behaviour under normal operational disturbances. This was done on mostly on paper and in the 2 parallel trains start-up and trip case, a dynamic simulation supported the study. This was necessary to identify the transient behaviour during these abnormal
situations and quantify the effect in order to identify whether any remedial actions are needed in the design of the facility.

In general, the study identified that majority of the process sections can undergo a safe start-up and sustainable normal operations. However, the study identified some constraints/limitations to the start-up process and to continuous and sustainable operations. These constraints and limitations are deliberated within the units’ start-up sequence in the various sections. Examples of such constraints/limitations include basic system configuration thought-process to enable safe start-up, venting/drainage in congested environment, inability of some process lines to undergo purge and safe pressurisation, lack of utility connections in some areas, inability to commission certain instrumentation, incorrect location of instrumentation, potential for total plant failure based on a single transmitter failure, etc. The remedial actions were able to be carried out during the engineering design stage and supported the successful start-up of the facility. This success convinced others to utilise this methodology as it supports other standard and mandatory safety studies.

4. Benefits of this program

The Operability and Control Solutions (OCS) Program has identified and provided recommendations for hundreds of issues in the facilities where it has been applied. The program estimates reduction in start-up periods up to 7 days per facility.

The OCS Program provides several benefits in addition to the reduction in start-up days. The OCS Program identifies operability issues not just related to specific equipment but to an entire facility. This broad focus of overall process operability and controllability addresses questions on whether the process is able to start-up and run in a sustainable manner. The OCS Program also complements flawless/smooth start-up programs, by providing focus and the required level of support to a key individual during the start-up process, the control room operator.

The other benefit is it reduces instabilities, indirectly implies that equipment are subjected to less thermal and flow cycling. This increases the life of the equipment and process mediums (such as catalysts, etc.). With reduced instabilities, the plant can be started up faster resulting reduced flaring/venting (which reduces the amount of greenhouse gases emitted into the atmosphere). The percent reduction in flaring is significant and can be as much as 30% of the total estimated flaring. The OCS Program provides the avenue to reduce the total flaring by addressing the effectiveness of the operational steps and minimizing the time taken to reach ‘product-on-specification’ by stabilizing the facility at an early stage. This is also in-line with initiatives by non-profit organisations such as the International Petroleum Industry Environmental Conservation Association (or IPIECA) which recommends methods for reducing flaring during start-up.

On the safety side, it increases hazard awareness and mitigation during start-up. It does not replace the mandatory HAZOP or LOPA, or other hazards identification assessments but works in tandem to provide automated or semi-automated solutions. The HISO study identifies the risk associated with each operational step, creating this awareness at a very early stage. For such high risk items, it recommends several possible solutions to mitigate the hazard effectively.

The OCS Program also supports sustainability with regards to reduction in wastage of materials and natural resources. It achieves this by stabilizing the start-up and reducing the start-up duration, while also ensuring (through the PCOO Study), that the process is able to operate at its most energy efficient point. An earlier start-up implies reduced economic losses from wastage of feed and energy. In addition, by bringing the facility on-line earlier, the economics of the project improves from earlier cash flow. The program provides early identification of the means to optimize the facility. This introduces the approach of a plant that is ‘designed-for-optimisation’ from day one, as opposed to a plant that is just ‘designed-to-run’.

An in-direct but extremely valuable benefit is improved operational awareness of the facility, 2 years before the start-up of the facility. This has been observed and acknowledged consistently by participants in the OCS Program in the past. As the OCS Program is a multi-discipline exercise, the stakeholders from the Operations, Technical Services and Maintenance disciplines will become aware of the method
of operation, the complexities and the various constraints of the facility at an early stage. The program then allows the various disciplines to make plans for effective operations, including the preparation of appropriate procedures, development of appropriate maintenance strategies, redefining critical spares purchase and other activities.

5. Conclusion
The Operability and Control Solutions (OCS) Program provides a means to address the issue of instabilities during the start-up of any new facility. It provides a holistic solution covering aspects of process and control complexity, human-error potential and the ability to sustain production of a facility at its most optimum point. It does this at a very early stage of the project allowing for design corrections to take place cost-effectively. The program will minimize the start-up duration of a facility while allowing for sustainable and optimized operations. Several international engineering contractors have acknowledged the value of the program.

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