Dynamic modelling and simulation for process design and engineering

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In today's oil and gas industry, companies are demanding more in terms of operational flexibility, plant automation, reduced project cycle and optimisation. Besides other approaches, Process Dynamic Simulation is also being employed as a technology-enabled solution to meet these challenges.

Traditionally, process engineers often face the possibility of FEED and detailed engineering designs exceeding limits due to unforeseen circumstances, for example, with complex control systems, operational philosophies and procedures. Potential problems during plant start-up, emergency shutdown and various turndown conditions may not be identified in advance due to insufficient information on plant behaviour. Similarly, the effect of various process controllers on plant operations during transient events may not be completely understood. The selection and operation of turbo machinery is another critical area. Rotating equipment is often carefully scrutinised to avoid setbacks, such as compressor surges or start-up difficulties due to undersized drivers that result in depressurization, etc. Dynamic simulation studies can successfully address these problems. The use of such studies is now an established best practice to accurately assess these transient scenarios and develop reliable and cost-effective solutions.

While the business benefits of dynamic modelling are widely accepted, many Engineering and Consulting (E&C) firms have not established in-house competency in this area. They typically rely on third-party service providers who often lack flexibility in terms of execution time, design evaluation, adherence to customer preferences and commitments. Such third-party studies are seldom inexpensive and lead to higher project execution costs.

To circumvent these challenges and improve project cycle time and costs, leading E&C and consulting groups have developed their own process dynamic

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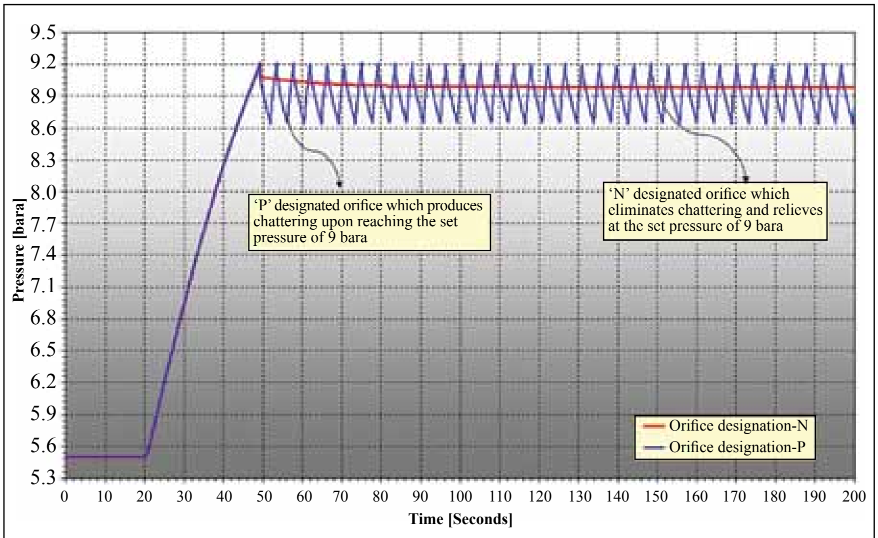

Figure 1: PSV upstream pressure variation: comparison between a steady PSV discharge flow and flow during PSV chattering

simulation capabilities and delivered solutions for their oil and gas clients. Benefits derived through these studies range from understanding plant process control schemes, improved flexibility through operational changes, cost savings through flaring avoidance, power savings with faster compressor start-ups without depressurisation, surge mitigation schemes, and reduced project execution time. This initiative reduces dependence on expensive third-party engineering service providers and fosters internal project execution and competitive pricing.

This paper illustrates the business leverage through dynamic simulation using AspenTech's 'Aspen HYSYS Dynamics' as a technology enabler, and the benefits derived from helping process engineers gain greater insight while making more prudent engineering decisions in terms of improved design, reduced project cycle time and execution costs. Process dynamic modelling and simulation is a paradigm shift in current engineering design practices. It adds a far-reaching and new dimension to engineering perspective and enhanced customer value, although it cannot completely replace traditional methods entirely.

INTRODUCTION

Front End Engineering and Design (FEED), which is done after process conceptualisation and feasibility studies, is a stage during which process engineers conduct investigations to identify and resolve technical issues. With regards to process plants and turbo machinery, today's process engineers are faced with simultaneously meeting the growing demands of optimising advanced process control schemes, ensuring operational flexibility to handle various raw material compositions, environmental safeguarding, and project execution cost savings through in-house execution.

Process dynamic modelling and simulation is a technology that enables process design engineers to develop transient models of plants that respond to disturbances with respect to time. This can also be tailored to various applications throughout the project life cycle. Additionally, during early design stages of process plant control systems, these modelling methods can be used to ensure sufficient margins exist to handle process disturbances and assess a plant's optimal operation. This helps to avoid, or at least minimise, costly rework later.

Process dynamic modelling

Process dynamic modelling involves the use of fundamental and rigorous thermodynamics, heat and mass transfer, and fluid flow laws. The data required involves boundary conditions data, system volumes, valve characteristics, rotating equipment performance curves, type of controllers, etc. This allows process engineers to understand system behaviour, as well as capture the inertial effects or delays in the process times during process disturbances.

The commercial dynamic simulator 'Aspen HYSYS Dynamics' by AspenTech is used to perform dynamic simulation activities. Once built, the dynamic model is validated against steady-state data or field data to ensure that the model will provide the correct and accurate plant operational response, performance and overall behaviour when subjected to various disturbances.

The following sections discuss several actual dynamic simulation case studies from recent projects.

Case study 1: Eliminating oversizing of pressure safety valves

Case study 1 involved a gas compressor at a gas gathering station operating at a suction pressure of 1 Bara to a discharge pressure of 5.8 Bara, with a flow of 12.2-mmscfd. The discharge air cooler is operated at a temperature of 70 ºC.

During the design phase, a dynamic simulation study was performed using 'Aspen HYSYS Dynamics', incorporating full compressor details including compressor curves and all piping elements and equipment, such as air coolers, anti-surge valve, etc. One of the scenarios studied involved closure of a compressor discharge block valve. It was observed that the PSV (designated with 'P') orifice at the compressor discharge line was over sized for a flow of 12.2-mmscfd. As a result, valve chattering occurred with excess flaring. The study also revealed that the maximum flow through the PSV was only 9.6-mmscfd, as opposed to the steady-state sized flow of 12.2-mmscfd. The problem was solved by replacing the 'P' orifice with an 'N' orifice designated PSV that was smaller in size, which therefore significantly reduced the flaring flow by about 20% and eliminating the chattering effect.

Case study 2: Load sharing distribution during residue gas compressor trip

Case study 2 involved a gas treatment plant which consisted of three parallel residue gas compressors that operated on sweet gas with a load sharing philosophy. The (3 × 33%) configuration consisted of a single master pressure controller and three slave controllers that operated the three compressor systems at nearly identical operating points on the compressor curves.

The process conditions at each compression unit consisted of compressing 163-mmscfd of gas from a suction pressure of 31.1 Bara to a discharge pressure of 53 Bara at a compressor speed of 6,018-rpm. Each compressor's duty was approximately 4.2-mw. Figure 2 shows a dynamic model of the compression system built in 'Aspen HYSYS Dynamics' with a load sharing scheme.

The concern raised during the de-

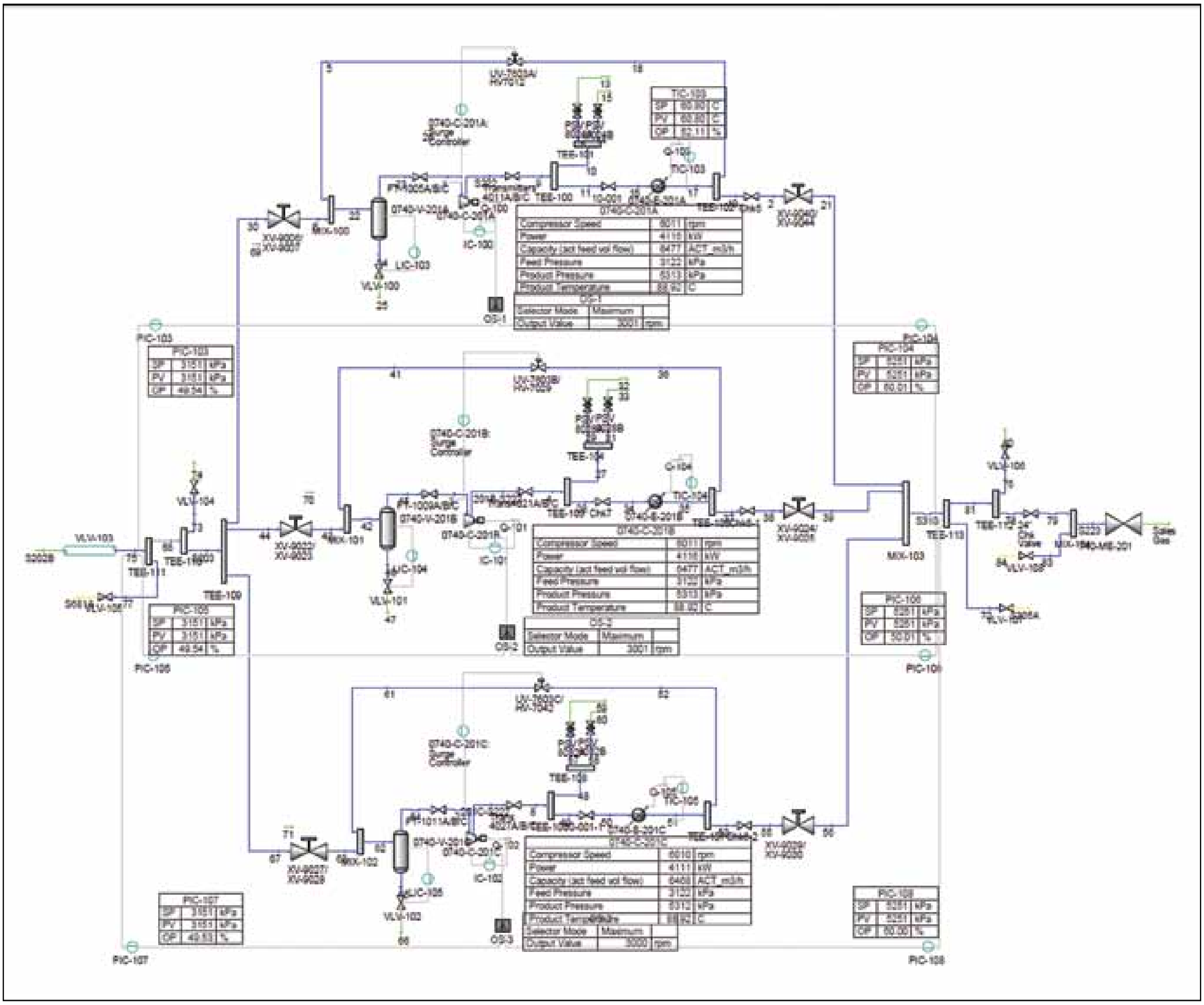

Figure 2: Aspen HYSYS Dynamics model of residue gas compressors

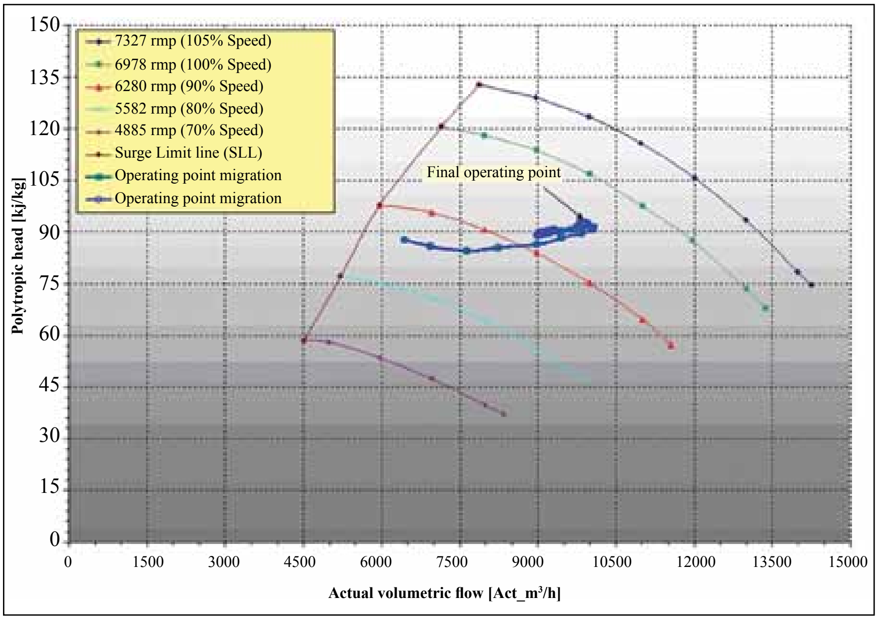

Figure 3: Operating point migration of Compressor A and B after trip of Compressor C

sign stage was whether, in the event of a single compressor failure, the remaining two compressors would be able to handle the total flow with no surging, when the two compressors are run at an expected higher speed. Upon performing the operability study, it was proved successfully that the remaining two compressors could sustain the total flow by running at higher speeds of 6,636-rpm each, without tripping. Figure 3 shows the migration of the compressor operating point and indicates clearly that the surge line was never violated during a single compressor failure.

The simulation also exhibited that the load sharing scheme was robust enough to maintain a nearly identical parallel operation, with almost no disturbance or anti-surge valve opening. Moreover, it was proved that no flaring of sweet gas in the residue gas compression system had occurred. This demonstrates, unlike traditional methods that involve overall lumped parameter calculations or thumb rules (e.g., designing anti-surge system) where accuracy cannot be predicted during transient plant operation, that it can be overcome with dynamic simulation analyses. This provides a detailed insight into the plant operation, thereby helping to understand the capabilities and limitations of the designed process plant.

Case study 3: Demethanizer column recovery profiles during turbo expander trip

Case study 3 consisted of two parallel natural gas liquid (NGL) units in operation that work on an ethane recovery process wherein a turbo expander is used to recover a mixture of methane and ethane. Figure 4 is a block flow diagram of this process. The turbo expander is controlled by a master pressure controller that senses the throughput at the slug catcher unit which receives the wellhead fluids and alters the turbo expander operating point in the NGL unit. The master pressure control also limits the maximum amount of well fluids through the gas sweetening absorber

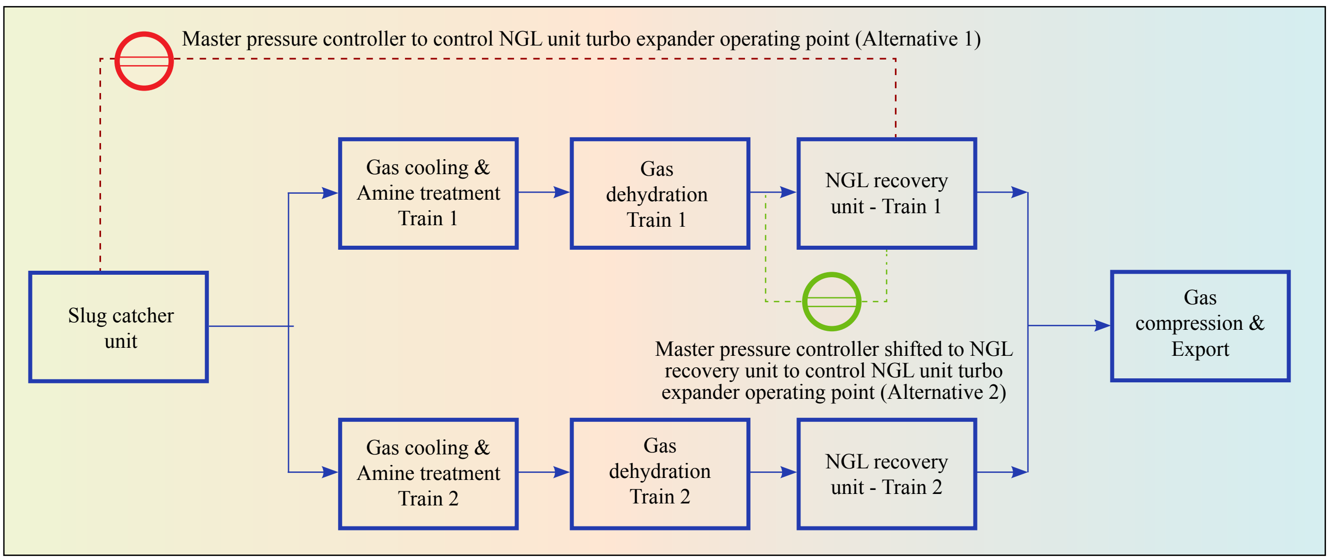

Figure 4: Block flow diagram of NGL recovery unit in the overall gas plant

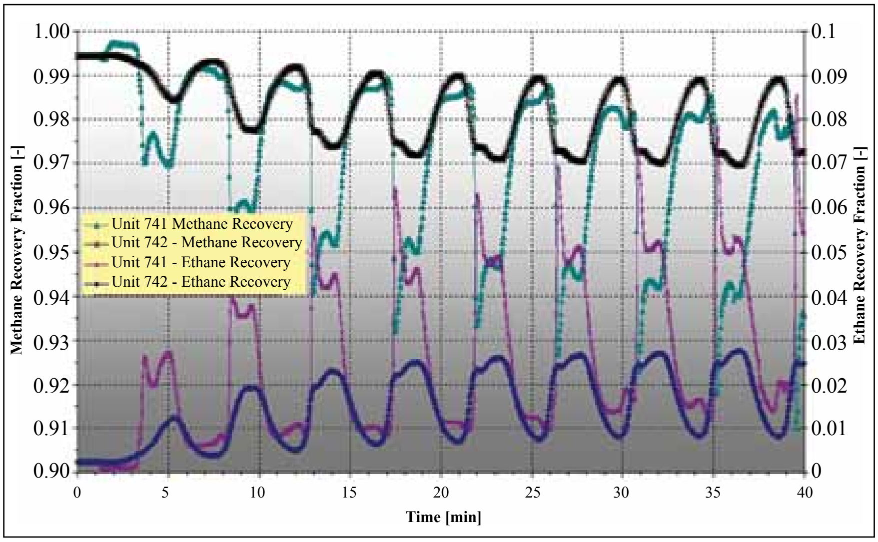

Figure 5: Oscillatory column behaviour with an overall master pressure control

section by limiting the turbo expander range of operation. The NGL unit consists of a demethanizer and the column recovers during the normal ethane recovery process at 99.4% C1 and 0.23% C2.

During the event of a turbo expander trip, the NGL unit would switch to Joule-Thompson (J-T) mode of operation in which all the dehydrated gas from the dry gas chillers would be diverted through the J-T valve. The demethanizer column recoveries in this mode of operation would be 96.1% C1 and 3.8% C2. The problem at hand was that during a turbo expander trip of one of the NGL trains, the column recovery profiles exhibited an oscillatory behaviour, as shown in Figure 5. Moreover, the oscillatory disturbance in the column recovery profiles in one train propagates to the NGL unit of the second train to experience an overall upset condition. This happens due to the inertia caused by the large piping network that delays the response time drastically from the slug catcher unit through the master pressure controller (MPC) and then to the turbo expander. The oscillatory column recovery problem during a single train turbo expander trip was eliminated by shifting the master pressure controller action from the slug catcher unit to the NGL recovery units, thereby reducing the response time. Figure 6 shows the elimination of the oscillatory behaviour in one of the NGL train expanders, resulting in the expected values of 96.1% C1 and 3.8% C2 while the second train continued to operate at 99.4% C1 and 0.23% C2 without any disturbances in the column profiles. As a result, dyna-mic simulation proved to be an invaluable technology to identify and root out such control system related issues.

Technical merits

The aforementioned case studies illustrate the critical role played by process dynamic modelling in a project life cycle, whereby numerous design issues were identified and solved effectively. The design changes made during the front end engineering and detailing phase also enabled engineers to eliminate process bottlenecks, process rework and develop faster start-up and shutdown procedures.

The studies have also benefited customers by analysing plant performance with various feedstocks and helped optimise equipment sizes for efficient operation. Turbo machinery related studies, such as compressor start-up, shutdown, turndown, load sharing, and related issues were addressed prior to commissioning, during the design phase itself. This enabled resolution of surge-related and start-up power problems to optimise plant equipment sizes and piping parameters. Importantly, the process control scheme envisaged for plant operations could also be studied with utmost criticality to check for process stability during plant disturbances, and in response to plant production

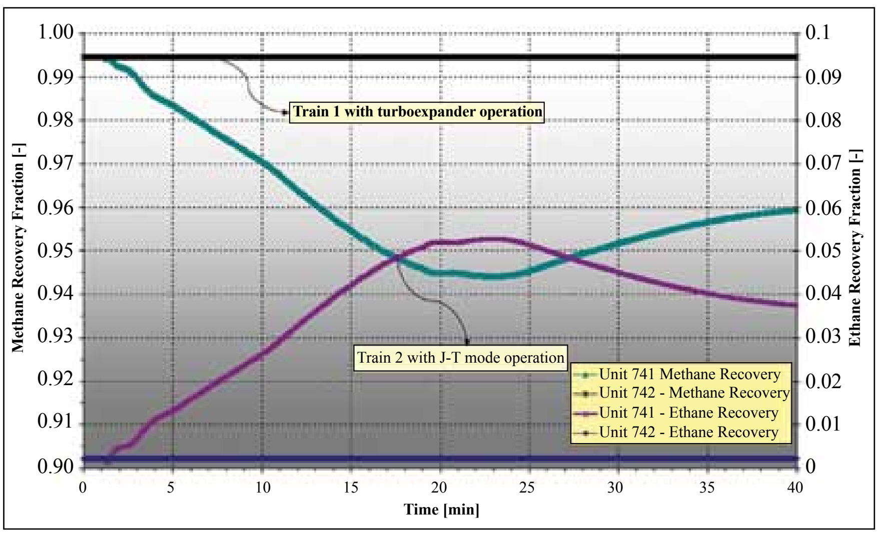

Figure 6: Stable column recoveries by localizing the master pressure control

throughput and compositional changes. Projects that require environmental considerations to be respected in an emergency event, such as inadvertent flaring, can be attended to effectively by estimating the amount of flaring. In situations where flaring would be inevitable, flaring of sweet gas in preference to sour gas could be effected with an operational change. Process dynamic modelling and simulation is a valuable tool to recognise these opportunities and to make appropriate, cost-effective and reliable changes. This technology has dramatically advanced in accuracy and ease-of-use in recent years, and has improved engineering decision making as well as building customer confidence.

Commercial benefits

Dynamic simulation studies are sometimes subcontracted to third party engineering service providers/vendors by engineering contractors. This practice is quite expensive as the work is gauged by the complexity of the analyses, and in some cases due to competitive disadvantage from a lack of technical and commercial resources within engineering contractors. In addition, customer expectations are becoming more demanding and there is need to felt for a greater perspective on plant performance for various operating scenarios. With third party subcontracting there is risk of exceeding projected budget costs in cases of increased case studies and re-work due to project document revisions. Another aspect that implies a cost increase for such studies is dynamic model customisation. This involves additional custom thermodynamic modelling, including sensitivity studies between thermodynamic packages often required to match project specific requirements. This represents an additional increase in project costs.

Costs associated with engineering contractors can vary from US$20 to 50 per man-hour in India – based on the authors' experience, while third party subcontractors typically charge between US$ 80 to 120 per man-hour depending on the complexity of the study and schedule. Considering an average cost of US$40 per man-hour as a base price offered by engineering vendors against an average cost of US$100 per man-hour by third party subcontractors, the man-hour price variation is more than 150% (i.e., US$60 more per man-hour) with respect to base price.

A typical study performed by most engineering contractors is a compressor dynamic simulation for surge analysis of gathering centre compressors. Prices quoted by a third party vendor for various operating scenarios can be higher by nearly 90% (~US$380,000) for an execution period of eight months when compared to a typical engineering contractor's quoted price. This instance clearly indicates the expensive nature of third party services. The end customer may require the study to be made for the as-built plant, i.e., until pre-commissioning. This means when using a third party vendor, project costs could rise significantly as scenarios are reworked as the project progresses. On the other hand, the same project executed internally by engineering contractors using dynamic simulation techniques would be highly cost effective and provide flexibility in responding to customer preferences.

A similar situation can be expected during the engineering phase for a fertiliser project where a dynamic simulation study needs to be performed to check for the PSV response during various process upset scenarios. Studies usually include analysis of plant safeguarding philosophy where the set pressures of the PSVs also have to be analysed. The price quoted by a third party vendor can be expected to be higher by nearly 33% (~US$45,000) for an execution period of six months. Such examples point to the expensive commercial nature of dynamic simulation services.

From the comparisons made, it can be inferred that there are significant cost implications for dynamic simulation studies when offered by third party vendors. This affects the engineering contractor's profit margins during project execution. To reduce dependency and to avoid such high price services, internal execution of dynamic simulation studies by engineering contractors can be implemented easily using available and proven tools such as 'Aspen HYSYS Dynamics'.

CONCLUSIONS

The case studies presented in this paper demonstrate the critical role played by process dynamic simulation in a project life cycle. Although such advancements in engineering design practices cannot completely replace traditional methods of engineering, it represents a paradigm shift in the current design methods and practices which provides a new dimension to engineering design and analyses.

This paper also highlights how innovative process dynamic modelling and simulation techniques can be leveraged by engineering contractors to add value to clients, achieve significant time and cost savings, and avoid use of third party engineering service providers and thereby improve competitiveness.

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Aspen HYSYS Process User Manual.

AspenTech Support Site and its Knowledge Base at:

http://support.aspentech.com