High Fidelity Dynamic Simulation of Compressor Systems

Realize the benefits of “20/20 hindsight” before commissioning a new compressor or new compressor controls

Authors: Jim Jacoby: Director, Turbomachinery Controls Portfolio, Triconex
Ian Willetts PhD: Global Consulting Director, SimSci-Esscor
Alan Wade, Department of Engineering Science, University of Oxford

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1. Introduction

In recent times, the integration of turbomachinery control functions and hardware into a single high reliability platform with robust control algorithms, such as the industry-leading Triconex® Tricon™ platform, has led to significant improvements in system performance and operability. In the past, a compressor train might have had separate controllers for suction pressure, recycle and turbine or motor speed as well as separate relay sequencing and alarm panels, a separate vibration-monitoring package and a separate over speed trip protection package. Now, to meet the requirements of today's industry standards, only the over speed protection system is required.

While improvements are continually made to turbomachinery control system hardware and software, it is important to ensure that the process side design that includes the compressor specification, anti-surge and throttle valves sizes and ancillary equipment is sufficient to allow the industry leading control programs to provide the required protection. No matter how superior the control platform, an incorrectly specified anti-surge valve and recycle loop can cost millions of dollars in lost production if discovered during the Site Acceptance Test.

Once the design is verified, focus can turn to the ensuring the control system is configured correctly and tuned prior to the commissioning process. For example, an overly conservative anti-surge control can lead to unnecessarily high recycle rates affecting operating efficiency, while protecting the critical equipment. On the other hand, a poorly configured anti-surge controller can fail to prevent compressor surge, leading to irreparable damage to the equipment and risk to personnel safety.

Therefore, the success of a project is often determined before the Site Acceptance Test begins, when an engineer has the tools to verify the system design and to test the control logic across the full operating range of the compressor system being commissioned.

2. Dynamic Simulation - An Enabling Technology

Dynamic simulation models were first used in the turbomachinery business more than 25 years ago to validate the sizing of the recycle valves on large LNG compressor trains. These studies required detailed data about the entire piping system and taking months to complete. Womack (1986) discussed this and other applications of dynamic simulation and noted at the time that although dynamic simulation was an “expensive, and slow-to use tool”, the ability to reduce the Opinion Engineering content of plant design, and to provide ‘twenty-twenty hindsight before start-up’ justified the required time and cost.

Today, computers support more sophisticated object-based simulation software (such as SimSci-Esscor's DYNSIM® platform) that allow far more detailed compressor models to be created in weeks rather than months. Furthermore, the DYNSIM software can be integrated and run directly with an emulation of the actual Triconex Tricon turbomachinery control (TMC) configuration program on a single computer. This integrated control and process-modeling platform allows rigorous system testing under all operating conditions in a safe environment, where faults can be discovered without creating enormous costs or posing a risk to human safety.

Four distinct areas of benefit can be realized using high fidelity TMC Integrated Dynamic Simulation models to check out the process design and control configuration around turbomachinery applications. These benefits can be realized at various stages of the process life cycle and can be applied to almost any project underway today.
3. Benefits

Four distinct areas of benefit can be realized using hi-fidelity TMC Integrated Dynamic Simulation models to review the process design and control configuration around turbomachinery applications. These benefits can be realized at various stages of the process life cycle and can be applied to most projects underway today, and include:

**COST SAVINGS**
- **Front End Engineering Design (FEED):** Avoid costly design errors by verifying, for example, that valve and vessel sizes and equipment configurations are correct early on when changes can be made at minimum cost. This integrated solution allows the engineering company to verify that the overall system will perform as designed.
- **Design:** The sizing and selection of the compressor can be tested against the actual process requirements, ensure optimum recycle flow rate under normal operating conditions, reduce power consumption and improve efficiency.
- **Pre-Factory Acceptance Test (FAT):** Running the actual control code integrated with a dynamic simulation model makes control programs easier to debug and improve.

**TIME SAVINGS**
- **Factory Acceptance Test (FAT):** The TMC Integrated Dynamic Simulation model allows for detailed testing of the actual control program logics and sequencing. A relatively clean and tested control code at FAT saves critical time during the FAT.
- **Site Acceptance Test (SAT):** Changes to the control program can be tested against the model and corrections made prior to going live on a system, saving commissioning time.

**SAFETY**
- **Operator Training:** The TMC Integrated Dynamic Simulation model can be used to conduct operator training before and after start-up.
- **Safer Operation:** Compressor surge can result in costly equipment damage and potential relief scenarios can be dramatically reduced by initially implementing a tested, well designed and tuned controller.

**AVAILABILITY**
- **Commissioning and Start-up:** Since the control program has been evaluated against a dynamic simulation of the local process, start-up proceeds in a straightforward and timely manner, bringing the process online quicker.
- **Cost Savings:** The simulation can pay for itself on the initial start-up. Furthermore, the simulation can be used as a training tool for operators and engineers and enable operational improvements on an on-going basis, including future control upgrades.

The following section discusses four project types recently executed by Invensys Operations Management and using TMC Integrated Dynamic Simulation models, various benefits were realized in a cost effective and safe manner.

4. Cost Savings - Ensuring Equipment Sizing and Selection

Typically, drums, piping and valves associated with a compressor system are sized based on flows calculated by steady-state heat & mass balances and engineering judgment (such as ‘full recycle’ for the sizing of anti-surge piping). By definition, surge is a transient event. As dynamic simulation calculates time-variation in all variables of interest from first-principles equations, it can determine if the layout and equipment size are adequate to cope with the transient conditions.

The following is an example where a TMC Integrated Dynamic Simulation was used in the design phase that lead to identifying issues in the original system design. The system involved a 4-stage compressor system, where all the stages were driven at the same speed by a single electric motor. The original design included a cold gas recycle stream between the fourth stage discharge and the suction drum upstream of the first stage. While initiating a test case where the electric motor was tripped, it was discovered that the original designed cold recycle was insufficient to stop the first and second stages from surging. This happened for all anti-surge valve sizes that were installed, even when the valve was fully opened before the trip. The issue was likely due to the loss of the motor, causing a sudden drop in pressure across the fourth stage, quickly moving towards a stall (see Figure 1).
The fourth stage pressure, after the trip, was insufficient to supply the necessary flow through the anti-surge valve, preventing the first and second stages from surging. Figure 2 shows each compressor stage surge margin versus time. Surge margin is a measure of the approach of the compressor operating point toward the surge line. A negative surge margin indicates the compressor is surging.

Alternative solutions to mitigate this issue were tested on the simulation model and the best solution was to add a hot gas bypass around the first two stages of compression. With proper sizing of the valve in this line and the addition of the required logic in the control program, the controls kept all four-compressor stages out of surge after the motor trip (see Figure 3). The issue was identified and corrected at a minimal cost early on during the project using the TMC Integrated Dynamic Simulation model.
5. Time Savings – Reduced Commissioning Time from Pre-Tuning

TMC Integrated Dynamic Simulation models can be used to optimize the tuning of the PID controllers within the turbomachinery controls. Traditionally, tuning is performed in the plant, post-startup of the turbomachinery. However, these tests run the risk that if the controller is originally ill-conditioned; the step changes could cause an undesirable response, placing the compressor into surge.

Alternatively, these tests can be run in a dynamic simulation, where fault discovery does not have serious repercussions. Tuning is completed on the dynamic simulation model by reviewing the response to step changes in the operating point of the plant, and modifying the parameters of the controller (such as varying the overshoot or rise time) and the desired response. Once the actual plant is initiated, only fine-tuning of the controller is required. This mitigates the risk of undesirable behavior and reduces the time between start-up and commencement of production, allowing the new compressor system to generate revenue sooner.

Triconex’ TMC Integrated DYNSIM Simulation model was successfully implemented on a steam turbine driven Ethane Recycle compressor. The project goal was to verify the Triconex control logic and tuning prior to commissioning, which included determining the best control strategy and assessing the value of De-coupling Control between the kickback valve and the Inlet Guide Vanes (IGV). Start-up sequence assessment included determining the optimum IGV loading and understanding the flow transition time from flow-through the bypass check valve to flow-through the compressor.

Figure 3: Surge Margins of Compressor stages with Hot Gas Bypass
Once the optimum control strategy was developed, the model was used to test the surge control responses, the speed control and make appropriate tuning changes.

Upon project completion, the customer reported that the compressor start-up was one of the smoothest ever experienced with the commissioning occurring three days faster than originally scheduled.

6. Safety – Improved Operator Training

TMC Integrated Dynamic Simulation models have many benefits when used as a tool to train operators on the turbomachinery operation and controls. These models implement the actual control code to be used in the plant and the models; operators can be trained within the simulator where their actions have the same impact as in a real plant. Using the simulation, operator mistakes do not risk safety or cost, and the model can be easily reset to the starting conditions from any state. These features make the TMC Integrated Dynamic Simulation models a valuable tool when training operators to use a new piece of equipment, provide new operators with experience that could previously only be learned with years on the job, or coach out bad habits. Models can be programmed with malfunction scenarios (such as a valve failure within the actual plant), where the response of the operators could be crucial for keeping the system in safe operation. Additionally, the model can be setup to use the same HMI (Human Machine Interface) as the controls system in the plant, to complete the feel of the simulator, and skills learned within the simulator are easily transferred to the actual plant.

Figure 4 shows a TMC Integrated Dynamic Simulation model that was set up for a new 4-stage compressor as part of a case study with the actual HMI. Using the TMC Integrated Dynamic Simulation model to train operators on new equipment before installation and in combination with the pre-tuning of the compressor controls, the client was able to smoothly start-up and have the compressor system running at maximum efficiency in less than half of the scheduled time for this type of normal installation. These unanticipated extra days of production led to millions of dollars in additional revenue for the operating company.
7. Availability – Verifying Startup/Shutdown Procedures

TMC Integrated Dynamic Simulation models can implement the exact control code to be used in a plant, and be used to verify that the control system can adequately handle start-ups and planned shutdowns of the system prior to the initial start-up of the plant during the SAT. Scenarios can be programmed to step through the startup and shutdown sequencing. Procedure can be validate and help avoid any surprises upon initial start-up and improve the reliability and availability of the turbo-machines by shortening commissioning time and preventing equipment damage.

In this example, the air blower system for a Fluid Catalyst Cracking Unit (FCCU) was particularly sensitive to the startup and shutdown sequencing. The system consisted of four compressors arranged in three circuits as shown in Figure 5, along with corresponding recycle valves and snort valves that discharged to the atmosphere and kept the units from surging.
Units 1-3 were centrifugal compressors driven by an electric motor and unit 4 was an axial compressor driven by a steam turbine. Because the downstream units had to be operating before there was sufficient steam supply to run the fourth compressor, it had to be started last. The previous start-up method had been to start the units up in numerical order, taking each of them up to their maximum capacity in order to provide the maximum margin from surge possible and control the required flow by venting the snort valves to the atmosphere. This approach was extremely inefficient with the operators erring on the side of safety over efficiency without any available system.

Part of the dynamic simulation performed on this setup was to verify the start-up sequence of the compressors operating with decoupling controls to balance the capacity controller and anti-surge controller. Triconex proprietary decoupling algorithms help ensure maximum efficiency with safe surge margins. Figure 6 shows the flows of all four compressors during startup. A master flow controller with load sharing was designed and added to the control configuration to control the target flow required by the process. The flow is steadily built-up to the target flow, while keeping all compressors out of surge. The study also identified the minimum position required on the suction valves of the compressors in order to keep the motors from tripping due to high current spikes.
8. Summary

The four proceeding case studies clearly show dramatic benefits that can be realized using SimSci-Esscor’s Turbomachinery Controls Integrated Dynamic Simulation solution and services. These benefits can be realized throughout the life cycle process for companies doing preliminary design work or upgrading turbomachinery controls on existing equipment.

Today, where industry demand is to provide more value-relative to the money spent, this solution stands out as one of the most exciting and new offerings available today, providing a wide variety of tangible and intangible benefits with very high rates of return.

9. References