The intelligent and simplified control solution for turbo- and motor-compressor trains

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Abstract
GE Oil and Gas has recently launched its latest version of compressor control technology that marks a significant upgrade to its current Compressor Control package - Intelligent Compressor Control.

One of the key achievements of Intelligent Compressor Control is to meet the final users need for increased production and higher reliability while protecting the machine. Intelligent Compressor leverages extensive engineering experience to deliver a model based control system with enhanced transient and process control capabilities. The Intelligent Compressor Control algorithm has been validated using the high fidelity modeling and simulation environment and test rig facilities for compressors available exclusively within GE Oil and Gas.

The Intelligent Compressor Control package can be installed in the Integrated Turbine and Compressor Control system (ITCC) by GE Oil & Gas, both on Mark VIe and PLC platforms (e.g., GE IP PLCs) for both new and existing units

This control system upgrade includes an enhanced anti-surge protection algorithm, allowing more efficient compressor map exploitation, an improved process controller, which minimizes upset effects on machines and offline/trip risks, optimized load sharing to maximize process efficiency and a more efficient surge predictor tool based on machine mechanical parameters.

Introduction
The compressor control system plays a crucial role in managing the train efficiently, minimizing upsets and keeping production at satisfactory levels with an eye on machine safety. The control system is a key component for improving a compressor’s ability to handle transients and disturbances and to operate at a desired point. This article describes GE Oil and Gas’ latest improvements in the control system architecture to ensure that compressors can be operated safely, reliably and efficiently. The article describes the current Integrated Turbine and Compressor Control (ITCC) Architecture and provides details on the latest enhancements in the solutions and implementation of the control system.

The Integrated Turbine and Compressor Control system (ITCC) is a well-established GE Oil & Gas product in the control portfolio, boasting more than 500 installations for different applications around the world.

This Integrated product offers a simplified, reliable and efficient control architecture and software for compressors (both centrifugal and axial) driven by electric motors, gas or steam turbines, and delivers the following benefits:

- Reduction in the number of hardware and software platforms/components
- Complete train control and protection with improved process, load sharing, anti-surge
and anti-choke controllers embedded in a single platform
- Enhanced maintainability and machine availability
- Simplified installation and commissioning
- Significantly lower total cost

**Total Train Control Integration**

The traditional control system approach is typically based on separate hardware to handle different functions in a compression train:

- Turbine controller to operate the driver and its auxiliaries and to control all variable geometries and fuel to give a specified load
- Anti-surge controller to prevent surge that could lead to serious compressor damage due to excessive stress and vibration
- Load sharing controller to share the load between parallel compressor trains
- Process controller to maintain a selected process variable at the desired value
- Vibration monitor to protect the compression train from atypical vibration levels, typically using non-contacting instrumentation

All of these features are highly interactive and need to work harmoniously as an orchestra to meet the plant specification and customer requirements. Often, each controller uses a different programming language and user interface, specific HW and dedicated SW maintenance procedures. The non-correlated actions of drivers and compressor controls can adversely impact the process and diminish the overall train efficiency.

The GE Oil & Gas integrated turbine and compressor controls system eliminates the need for independent controllers, thereby eliminating the problems highlighted above and in addition, results in fewer electronic components and spare parts, and simplifies operator training. The Integrated Turbo-Compressor system is able to handle in a single controller all the above-described algorithms plus a dedicated anti-choke controller to protect and operate axial compressors and obtain better performance while simultaneously avoiding risks to the machine.

All the control algorithms are installed in a single environment and they are developed using only one programming language, reducing system errors, and minimizing maintenance and future upgrading tasks. Moreover, operators deal with a single interface to monitor the driver, compressor, associated auxiliaries and the surrounding process by simply switching from one graphic video page to another.

GE Oil & Gas controls are built on state-of-the-art hardware, such as the MarkVIe and GE IP PLCs, and are designed to fully satisfy customer needs of high performance, improved availability and reliability, redundancy, flexibility and upgradeable functionality.

**Control software**

Established GE Turbo-Compressor control algorithms have been enhanced, tested and validated using a model based design method. Model Based design provides an effective approach to defining complex plant models, such as the one shown in Figure 1, which has advanced functional characteristics to allow fast and efficient software testing and verification through real time simulation. Moreover, the plant model behavior has been validated by comparing it with the same model validated by Hysys®. The resulting fully validated algorithms are designed following a modular architecture, facilitating the addition or modification of control features to handle future needs.

A brief explanation of available functions is provided below:

- **Driver Core Engine**: includes control algorithms and logic related to the compressor driver, which can be either an electric motor or a steam/gas turbine. In the case of a steam turbine, for example, it can control speed / inlet pressure / extraction
Driven Core Control: includes the control algorithms and logic associated with the centrifugal compressor, such as anti-surge and load sharing; mainly for axial compressors but available also for centrifugal compressor anti-choke protection.

Process Control: includes the algorithms and logic associated with the control of the selected process variable (for example, suction/discharge pressure/flow).

Auxiliaries: it includes the control logic and algorithms associated with all the auxiliary systems of the machine, such as for example, lubrication oil, starting motors, ventilation, etc.

Sequencer: this is in charge of the main start/stop sequences of the machine and issues commands to all the elements mentioned above.

The following section of the article describes the advanced control functions associated with Driven Core Control and Process Control.

Anti-surge module
If the stability limit of the compressor is violated, a breakdown of flow occurs leading to surge. During surge, the flow reverses until a stable pressure condition across the compressor is momentarily resumed, allowing forward flow again (Figure 2).
If no control action is taken, the surge instability can cause serious compressor damage due to excessive stress and vibration. By preventing machinery surge, repair and replacement hardware costs are minimized.

The GE Oil & Gas advanced anti-surge control module integrated with the overall control software provides maximized protection of the compressor from harmful surge conditions, while enhancing process efficiency and availability. By minimizing the opening of the anti-surge valve together with managing the risk of surge, the algorithm helps to get the most out of the plant.

The objective of the anti-surge controller is to protect the compressor stage from surge by insuring that the compressor operating point (A) does not reach the SLL (Figure 3). In order to achieve this goal, a protection line called the SURGE CONTROL LINE (SCL) is defined to the right of the SLL. The distance in terms of flow between the SCL and the SLL represents a safety margin for the controller, and is defined by a percentage K.

When the compressor operating point moves to the left of the SCL, the controller takes action and begins to open the anti-surge valve. The opening of the anti-surge valve increases the actual suction flow, moving the operating point along the speed characteristic curve from the critical condition back to the SCL. Then, when the valve is fully closed, the point will move to the stable operating area.

Thanks to the model based approach, GE Oil & Gas has been capable of improving its anti-surge controller with the following advanced features:

**Margin anticipation** – activated in case of rapid approach of the operating point to the surge line. In this case, the flow margin parameter K is multiplied by a factor, effectively shifting the SCL towards the approaching point. The original margin is then restored when the approach rate is again below a threshold.

**Quick correction** – activated if the operating point approaches the surge line closer than the correction line (COR in Figure 4) OR if the prediction of its position in a fixed time horizon reaches the SLL. In this case the anti-surge valve is positioned in such a way as to move the operating point back to the SCL.

**Safety protection** – activated if the operating point reaches the surge line. In this case, a fast opening ramp is initiated on the recycling valve. Safety protection terminates when the operating point is again to the right of the COR.

In addition, the anti-surge controller can de-energize the solenoid valve for safety reasons, forcing the anti-surge valve to immediately open without tripping the machine. This has been implemented to take into account the possibility of failure of the valve actuator.

**Dead-Time Compensation (patent pending)**
A dedicated algorithm is used to compensate for the effect on the flow of delays measured
Dead time compensation (DTC) by the controller between the command to the anti-surge valve and the actual modification of the compressor flow (Figure 5). These delays are specific to the plant and are due to the characteristics of the piping layout, instrumentation delay and valve actuation response.

Stage decoupling In case of multi-stage systems, as per figure 1, where each stage is equipped with an anti-surge loop, the controller is able to effectively decouple the actions of the loops, pre-positioning the valve(s) on the basis of the predicted compressor flow variation. This improves the efficiency of the loops and limits any load imbalance effects.

Surge detection system (patent pending) Surge detection is typically accomplished by analyzing thermodynamic parameters of the gas (discharge pressure/suction flow). During a surge event, a sudden drop of, for example, the compressor discharge pressure followed by a rapid pressure recovery is expected due to a temporary gas flow inversion (Figure 6).

In addition to this, the advanced controller includes a detection system based on mechanical parameters (axial displacement variation). Following the detection of the surge, corrective actions are executed to avoid its recurrence.

Incipient surge detection system The advanced controller can foresee a surge event by monitoring radial displacements of the rotor. The idea behind the method is that, before surge occurs, a rotating stall develops in the compressor, generating asymmetric load conditions in the radial direction. The stalled fluid cells rotate inside the compressor at a speed generally lower than its rotating speed, and the resulting vibrations are characterized by a frequency below the first synchronous of the compressor (Figure 7). When an incipient surge situation is identified, an alarm is sent to the user and if necessary, corrective actions are executed to avoid the occurrence of surge.
Load Sharing Module
When multiple centrifugal compressor trains are operated in parallel between common suction and discharge lines, the Load Sharing function distributes the load between them in the most efficient way, maximizing surge protection and process efficiency. The Load Control module is integrated into each process compressor train unit control system.

The controller optimizes the overall process load distribution, avoiding unnecessary recycle.

When the compressors are being brought on/off-line, load redistribution is carried out automatically (Figure 8).

Sharing module Starting from the plant flow demand, this calculates the flow demand for each train and then converts it to speed using a model of the train.

Recovery actions These are additional features that allow, among others, fast recovery in case a train trips. The load is redistributed between the operating trains, keeping the flow equalized between producing parallel trains.

Train Efficiency Management In case of changes in process demand, this takes the most favorable action on each train based on the operating status of the available compressors.

Process Control Module
The process controller (PC) attempts to control the selected process variable (suction/discharge pressure/flow) using as a control variable the driver speed and/or throttling valve and/or IGV. It maintains the process variable at the selected set point during variations in plant conditions using a PI control scheme (Figure 9). The following features are included:

POC The PC uses a POC (Pressure Override Control) as a fast pressure limiting action and to limit pressure overshoot (Figure 10). In case of multiple parallel trains, POC action on each anti-surge module is balanced.

Decoupling In order to decouple the action of the PC and of the anti-surge, the same logic used to decouple the anti-surge controllers on multi-stage machines (Figure 10) is implemented to maximize control performance and system stability.
Priority Logic. The anti-surge controller is always active and overrides the process controller to drive the compressor out of the surge area if the operating point approaches the SLL anti-choke control module.

For axial compressors, the operating map is restricted by surge at low volumetric flows and by choke at high flow rates (Figure 11). Operating an axial compressor in the choke zone could lead to mechanical stress that could reduce the operating life of the machine and increase the need for maintenance.

The GE Oil & Gas anti-choke control module, specifically tailored to GE axial compressor characteristics, but also available for centrifugal compressors, provides punctual protection from potentially dangerous surge or choke conditions, keeping a constant eye on efficiency and availability.

The operating point is calculated and mapped taking into account possible changes to the gas composition and thermodynamic conditions. In case the operating point is determined to be outside the safe operating envelope at the current IGV angle position, the operator is alerted and, if automatic IGV management is active, the controller regulates the IGV to keep the compressor in the safe zone.

The anti-choke controller action together with all the other GE software modules improves the overall plant operability by responding rapidly to sudden process upsets, optimizing the tuning of the entire compression train.
Plant Valve Sequencing
Another feature of integrated controls is sequential operations management. All train sequential signals are available and are shared within the same programming environment. An example is the sequencing related to process valves, required to pressurize/depressurize compressors in coordination with the gas turbine driver startup and shutdown phases. A specific software module is designed to be integrated with the overall gas turbine and process compressor software and implements the sequential control of process valves.

Conclusion
The Integrated turbine and compressor control system delivers perfect coordination and superior overall process performance using a compact and simplified control architecture. It employs a common hardware platform for the compressor, driver and auxiliaries, and is unique to ITCC+ICC and available only from GE Oil & Gas.

Thanks to the model based approach, the driven machine core control has been improved to offer the customer enhanced process stability and efficiency, responding effectively to process upsets, minimizing train shutdowns, recycle and blow-off, and managing quick and smooth startup and safe shutdown. This state-of-the-art compressor control system in addition to improving the transient response of the compressor, provides the ability to optimize multiple units in parallel and in series.

For more information
Global Headquarters
Via Felice Matteucci, 2
50127 Florence, Italy
T +39 055 423 211
F +39 055 423 2800
customer.service.center@ge.com
Nuovo Pignone S.p.A.

Americas Regional Headquarters
4424 West Sam Houston Parkway North
Houston, Texas 77041
P.O. Box 2291
Houston, Texas 77252-2291
T +1 713 683 2400
F +1 713 683 2421

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