USING ESL IN AN INTEGRATED REAL-TIME COMPRESSOR SIMULATION APPLICATION

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ABSTRACT

An application, which was used for testing the integration of various components of a new gas compression station, is described. The application required simulations of a gas turbine compressor train and a unit control panel. The simulations had to be integrated into the testing and operating environments.

The simulations have been developed using ESL - the ESA Simulation Language - which was developed by ISIM International Simulation Limited for the European Space Agency - European Space Research and Technology Centre (ESTEC).

The objective of the application was to allow the functionality of the control hardware to be tested during the commissioning phase to ensure installation deadlines were met. To this end, the application was developed in a modular manner with the unit control panel and compressor train simulations implemented as separate processes communicating over the station data highway. In this way the simulations were integrated with the main SCADA system and had access to all system data. Initially, both the unit control panel and the compressor train were simulated. Once the unit control panel was installed, it simply replaced its simulation process in the application architecture, thus allowing the control unit functionality to be validated.

Graphical user interfaces for the simulation processes were developed in Visual Basic and the COGSYS product (developed and marketed by Cogsys Ltd) was used as a means of integrating the simulation processes with the SCADA system and graphical user interfaces.

The paper presents an overview of the compressor simulation project and describes the unit control panel and compressor train simulations.

OVERVIEW OF THE COMPRESSOR SIMULATION PROJECT

Gas Pipeline Compressor Station

BG Transco had contracted an international construction company to design and build a new compressor station, to contain two compressor units. The compressor units were sub-contracted to a leading Italian producer. Due to time-scales and bottlenecks in the plan of installation and commissioning, the client needed to perform the testing of hardware as early as possible.

Cogsys Limited, who are supplying the Compressor Operations Advisory System (COAS) (Cogsys 1998) for performance monitoring and emissions control, had been contracted to produce a simulation application to assist the hardware integration tests. This application simulates both the Unit Control Panel (UCP) and the Compressor Train and associated equipment for one of the compressor units

Purpose of the Simulation Project

The initial phase of the project was to produce a demonstrator, which has allowed the prime contractor to get a feel for how the simulated hardware components were integrated. This was extended to the point where it was used for the hardware integration testing while the compressors were being commissioned. In a final phase, the application was extended further to produce a Training Simulator for training the staff to use the compressor control equipment.

Compressor Station Components

The main components of the compressor station, shown in Figure 1, are:

- The Station Operation Interface - the SCADA system by which the station is operated.
- The Unit Control Panel (UCP) for the compressor units - that runs the compressor control sequences.

- The Compressor Units - the gas turbine compressor train and associated equipment.

Also shown on the figure are the Compressor Operations Advisory System (COAS) and the Simulation Application.

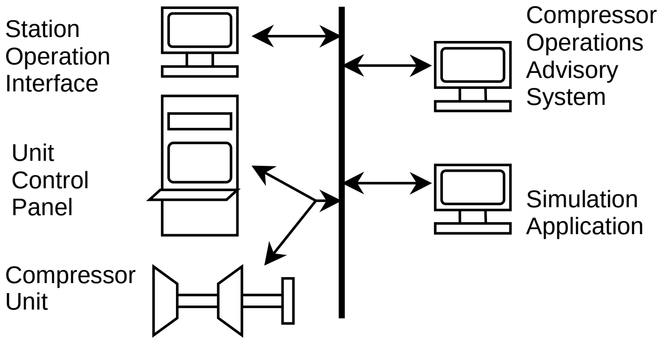

Figure 1

The Unit Control Panel runs compressor control sequences, initiated via the Station Operation Interface, such as:

- initialisation
- startup
- shutdown
- emergency shutdown

Signals and data are communicated between the components via PLCs linked to a data highway network.

Application Architecture

The software architecture for the simulation application is a modular structure in which several independent processes run and communicate with each other and pass data to and from the data highway. These processes may be configured in a number of different ways. For example, to test the integration of the Unit Control Panel independently of the compressor train, the UCP simulation can be removed and the UCP tested with the simulation of the compressor unit.

The main processes are:

- User Interface (Station Operation Interface Emulation) - providing remote signals to initiate UCP control sequences and visualise their progress. It is written in Visual Basic. (This process is not required when the simulation application is used directly with the full Station Operations Interface on the SCADA system).
- UCP Simulation - providing simulation of UCP control sequences. It is written in ESL) (Pearce and Crosbie 2000; Hay et al 1994; Hay 1990). (This process is not required when the simulation application is used directly with the actual Unit Control Panel).
- Compressor Unit Simulation - providing simulated instrument data. It is written in ESL.

These processes are shown in figure 2.

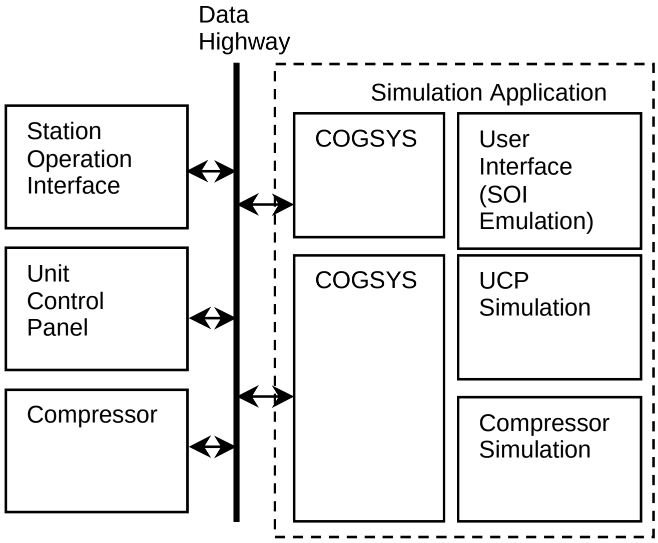

Figure 2

The COGSYS product (Davison and Kraft 1990) is used as the integration platform to provide a central communication point for all other components of the application. The COGSYS datastore is divided up into a number of areas, governed by functionality. It provides interfacing for the different Simulations and data from/to the Station Operation Interface (or its emulation). These include:

- UCP Controls - control signals issued by the SCADA to the UCP
- UCP Results - results or signals relayed back to the SCADA from the UCP
- Unit Controls - control signals being issued by the UCP to the Compressor Unit
- Unit Results - signals relayed back to the UCP from the Compressor
- Measurements - machinery measurements being simulated by the Compressor

There are two main ‘bridge’ programs, written using the COGSYS API (Application Programming Interface):

- ESL Simulation Application Program (ESAP) - providing interfacing between COGSYS and the simulations. Independent 'bridge' processes are used for the two simulations.
- PLC Driver - providing interfacing between COGSYS and the PLC Data tables and linking the simulation application computer to the data highway network.

This application architecture is shown in Figure 3.

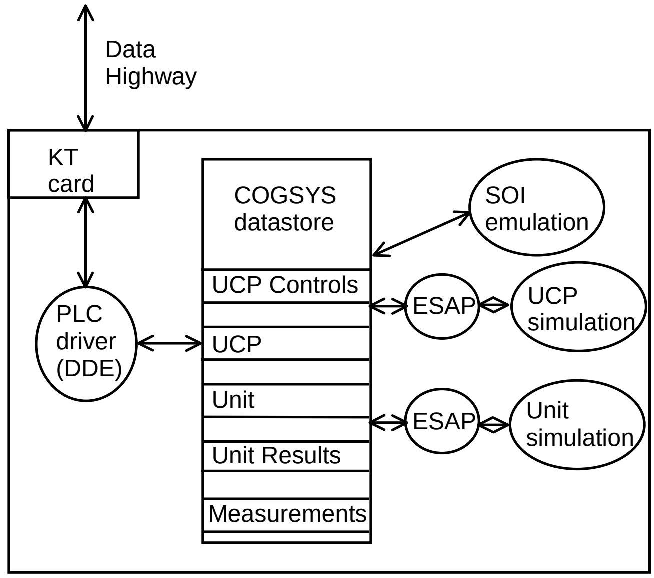

Figure 3

The COGSYS component

The COGSYS product (Davison and Kraft 1990) is used as the integration platform for the simulation application, and provides the means to re-configure it. Although used in this application purely for the purpose of integration, the COGSYS Knowledge Based System development environment makes it easy to capture and deploy best practice knowledge, in real-time, to assist in achieving optimal business performance. It is an advanced generic tool-kit for building applications to handle the rapid analysis of multiple data streams in real time. It can be applied in any problem domain which is characterised by the issues of high volume data and alarm input.

COGSYS can be integrated easily with existing systems, for example; SCADA (Supervisory Control and Data Acquisition), DCS (Distributed Control Systems), NMS (Network Management Systems), and Relational Databases. This is achieved using its comprehensive API (Application Programming Interface).

COGSYS features include:

- an easy to use graphical editor
- high performance and scaleability
- advanced API for ease of integration (C, C++, Visual Basic)
- multi-platform operation
- full truth maintenance system
- generic rules and multiple inheritance
- fuzzy logic and uncertainty handling
- full debugging tools
- tools for integration, simulation and display
- run-time system for deploying completed systems cost effectively

The COAS Component

The Compressor Operations Advisory System (COAS) system (Cogsys 1998) is used on the compressor station for monitoring the compressor units. It is a sophisticated PC-based data acquisition and analysis software applications package suitable for installation on a range of rotating/reciprocating machinery and fixed process plant.

It has been developed specifically for use by BG for application to their gas turbine driven centrifugal compressor installations on the UK high pressure gas grid (the "National Transmission System"). The system acquires process data from the Gas Generator, Power Turbine, and Gas Compressor stages of each pipeline compressor train.

COAS is used for:

- on-line and off-line condition monitoring, including power capability & plant efficiency, vibration levels, bearing temperature and oil flows, & levels of gas turbine exhaust emissions
- performance testing
- on-line and off-line multi-machine optimisation
- predictive emissions monitoring for compliance with EU regulations

THE SIMULATIONS

The Unit Control Panel Simulation

The Unit Control Panel (UCP) simulation simulates the compressor control sequences which are initiated from the station control via the SCADA system. The simulation includes the following sequences:

- Start-up Sequence
- Normal Stop Sequence
- Pressurised Stop Sequence
- Emergency Shutdown Sequence
- Initialisation Sequence

Each of these sequences involves the UCP issuing commands to start and control various pieces of plant on the compressor train. For example, the start-up sequence as shown in Figure 4, comprises the following actions:

- start auxiliaries
- accelerate the gas generator by the hydraulic starter
- a purging sequence
- an ignition sequence
- accelerate the gas generator to idle speed
- ramp up the power turbine to minimum load speed

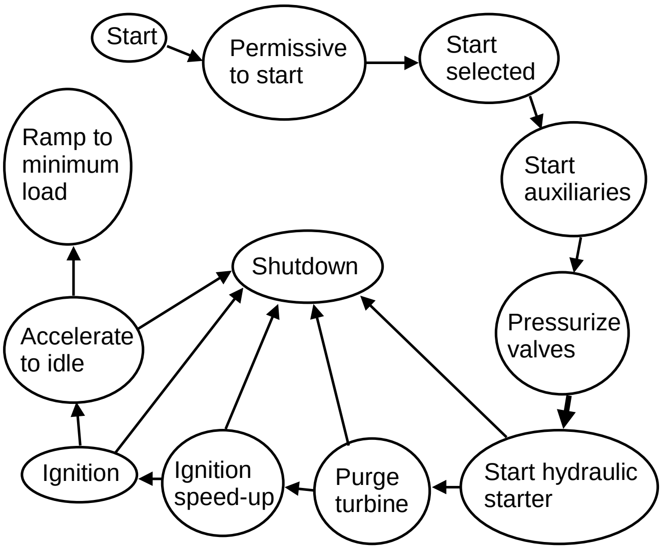

Figure 4

The simulation generates the appropriate command signals (UNIT Controls) which are passed via the COGSYS data store to the turbine/compressor UNIT simulation. The UCP simulation also monitors signals received back from the UNIT simulation (UNIT Results) and takes appropriate actions. The UCP simulation also detects and processes various alarms and trip conditions, e.g. failure of the gas generator to complete an acceleration within a specified time; ignition not detected within a minimum time; fuel valve not in minimum position for ignition.

The UCP simulation is concerned with sequences of discrete events and is implemented in ESL as a state automaton which progresses the simulation from state to state as the various signals are received from the SCADA and the UNIT simulation. This is readily implemented in ESL by the use of conditional checks carried out at each communication or frame time. This part of the simulation illustrates ESL's ability to model Combined Continuous and Discrete (CCD) systems.

The Compressor Simulation

The compressor simulation models the three major components of the machinery train, shown in Figure 5:

- the gas generator (an aircraft derivative gas turbine)
- the power turbine
- the centrifugal compressor

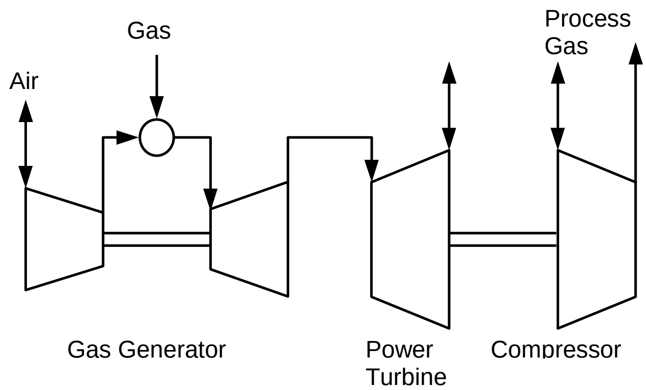

Figure 5

For the purpose of testing the UCP functionality, it is not necessary to have a high fidelity dynamic simulation, simply one that produces acceptably realistic responses to the UCP commands. Consequently, a *pseudo dynamic* simulation has been developed which basically models the steady-state performance of the gas generator, power turbine and compressor subsystems. The dynamic performance is approximated by first order differential equations, e.g. to represent the inertia of the gas generator and power turbine rotors and thermal inertia of the components. In the case of acceleration and deceleration of the rotating machines, appropriate rate limits are applied so that the simulation matches the real plant.

The centrifugal compressor performance is represented mathematically by two-dimensional polynomial functions derived from the manufacturer's compressor maps. This form of representation is identical to that used by the COAS system and ensures an accurate steady-state response.

The gas generator and power turbine models are based on predicted engine performance data and appropriate gas tables. These data are represented in the ESL model as multivariable function generators (a standard ESL feature).

When on load, the primary control of the compressor is through a power turbine speed set point which is determined by the station control algorithms in order to meet a required performance, e.g. discharge pressure or flow rate. Once on load, the speed set point, together with a specified gas flow rate, suction pressure and suction temperature form the main inputs to the UNIT simulation. Using the compressor map functions, the compressor pressure ratio and isentropic efficiency are determined from the specified power turbine speed set point and the gas flow rate. The efficiency and pressure ratio are used, together with data from the gas table, to determine shaft power. Hence the gas generator speed, gas generator exhaust temperature and power turbine exhaust temperature are estimated from the engine performance tables. The structure of the UNIT simulation is shown in block diagram form in Figure 6.

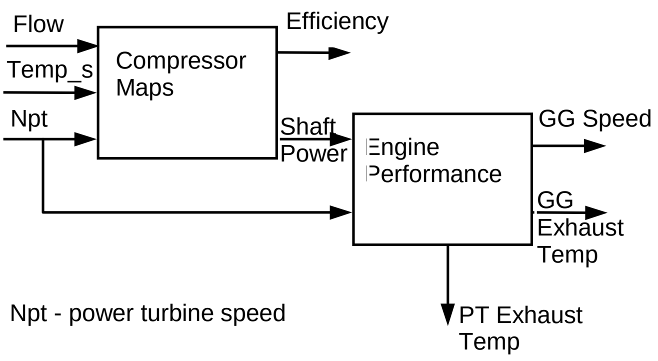

Figure 6

Individual instrumentation measurements (UNIT Measurements) are predicted from the raw data obtained from the above procedures. Small random variations between, for example, different exhaust temperature transducers, are added to improve realism.

While the simplistic UNIT simulation is perfectly adequate for testing the control hardware and for the purposes of implementing the training simulator, a full dynamic simulation would be required if the simulation were to be used for quantitative prediction of performance and to compare different operational scenarios. Such a dynamic simulation, based on thermodynamic and mechanical models of the compressor train components, is well within the capabilities of ESL.

Graphical Interfaces

Three graphical interfaces were provided to operate the simulation and display results. These were written in Visual Basic and linked to the simulation through the COGSYS VB API. At the station control level, a control panel, Figure 7, emulates the issue of remote signals to the UCP and allows the compressor to be taken through the initialisation, startup, normal and emergency stop sequences. Further screens allow the progress of the sequences to be monitored. This provided a means of running the simulation in an off-line mode. The UCP interface, Figure 8, emulates the local control functions. The UNIT simulation interface, Figure 9, displays both numerically and graphically the state of the compressor train.

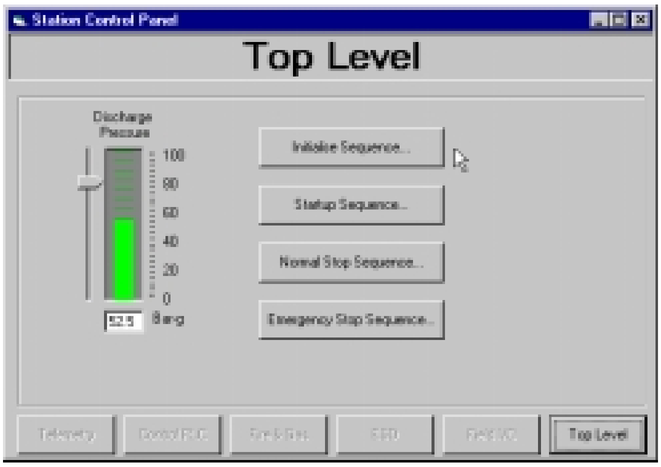

Figure 7

Figure 8

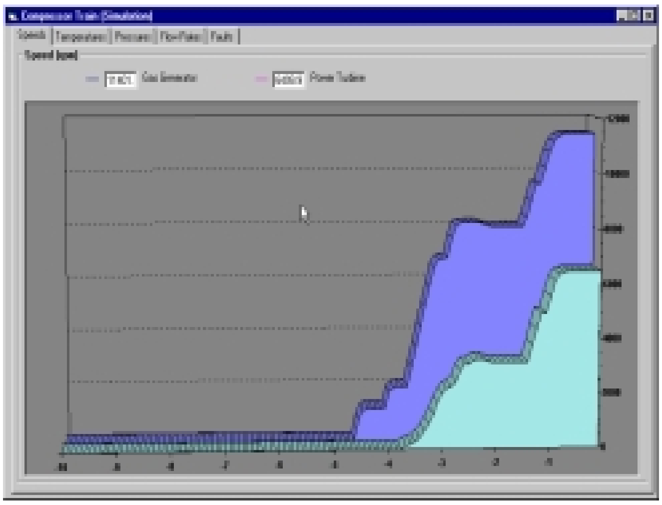

Figure 9

The ESL-ISE Simulation Tool

Both the UCP simulation and the UNIT simulation were written in the European Space Agency Simulation Language (ESL) (Pearce and Crosbie 2000; Hay et al 1994; Hay 1990). The language was particularly suited to this application because of its ability to model both the continuous behaviour of the compressor train and the discrete sequencing nature of the control functions. Another important factor was the ease with which the simulation programs (UNIT and UCP) were integrated with the other applications through the use of the ESL Simulation Application Program (ESAP). ESL has been recently provided with a new graphical interface - Integrated Simulation Environment (ISE), which allows graphical block diagram descriptions of systems to be entered. Although this feature was not used in this application (the simulations were written directly in ESL), ISE provided an excellent test environment.

CONCLUSION

A real-time simulation of a gas compressor station using the ESL simulation language has been described. The simulation was linked to the installation SCADA system using the COGSYS real-time data base as the means of integration. Graphical user interfaces were provided by Visual Basic programs. The simulation was successfully used during the commissioning phase of the project to test and validate the local PLC based control systems.

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