

ADVANCED PROCESS CONTROL AT AN INTEGRATED GASIFICATION COMBINED CYCLE PLANT

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Abstract:

IGCC (Integrated Gasification and Combined Cycle) plants are among the most advanced and effective systems for electric energy generation from refinery residuals and are becoming more and more popular in many regions worldwide. From a control perspective, IGCC plants represent a significant challenge: complex reactions, highly integrated design and variable feed composition come together requiring coordinated control to simultaneously satisfy production, controllability, operability and environmental objectives. While all these requirements seem clearly to demand a multivariable, model predictive approach, not many applications can be easily found in the literature.

This paper describes an ongoing Advanced Process Control project at the Isab Energy IGCC plant in Priolo, Italy, and aims to share design considerations, implementation details and preliminary results achieved on the first units. The project can be seen as the second step of a multi-stage plan for increasing process performance through automation improvements. After an overall DCS control revision performed in 2005, the project team was asked to introduce unit optimization on some of the most critical areas. This is going to be completed by means of several Multivariable Process Controllers which are contributing to reduce steam and utility consumption, stabilize H₂S removal and minimize environmental impact.

1. IGCC PROCESS GENERALITIES

An Integrated Gasification Combined Cycle, or IGCC (Integrated Gasification Combined Cycle), is a power generation system which produces synthesis gas (syngas), mainly composed of CO and H₂, converted from fossil fuel, such as vacuum residue, heavy oil, petroleum coke, coal and Orimulsion by a partial oxidation process and then burned to generate electricity from syngas by combined cycle. IGCC technology has become the center of public attention as one of the prime applications of technology for maintaining clean air for the world (see for example [1] and [2]). The reason for this is that it enables the production of clean gas, equivalent to natural gas even if at lower heating value, from inferior fuel with expected reduction of CO₂ emissions by use of high performance gas turbines.

IGCC technology offers a number of important environmental benefits: first because gasification allows the use of both a combustion turbine and a steam turbine in the power production process, an IGCC power plant can achieve an operating efficiency of about 45 percent, compared to pulverized coal (PC) plants which operate at efficiencies ranging from about 33 to 40 percent. Particulate matter, sulphur, nitrogen and mercury are removed from the gasified coal prior to combustion instead of from boiler exhaust gases post-combustion as in a PC plant. Up to now, refinery-based IGCC plants (mainly in Europe) have demonstrated good availability performance and are more established rather than utility-based coal IGCC plants, with availability in the range of 90%-95% consistently being achieved. Several factors are common to these plants that may be

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contributing to this good performance. It should also be noted that non-utility plants have recognized the need to treat the gasification system as the up-front chemical processing plant that it is, and have generally reorganized their operating staff accordingly. Because IGCC plants are highly demanding from a control perspective, they are ideal targets for advanced strategies (see for example [3 and [4]]). However literature about actual advanced process control applications for IGCC facilities does almost not exist.

2. THE ISAB ENERGY PRIOLO IGCC PLANT

2.1 Process Overview

The Isab Energy (IE) IGCC plant in Priolo, Italy, converts about 120 tons/h of heavy residual oil, provided by the nearby ErgMed refinery, into more than 500 MW of electric power. Isab Energy and Isab Energy Services are a joint venture between ERG Power & Gas (51%) and International Power Mitsui & Co. Ltd (49%). Isab Energy and Isab Energy Services represent, respectively, the Owner and the Operator of the IGCC complex.

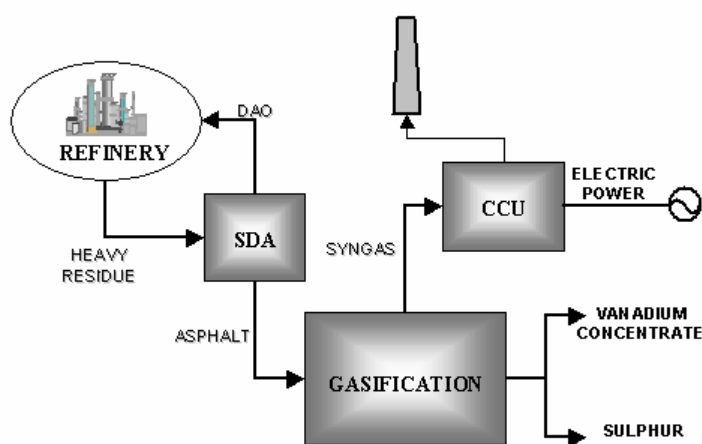


Figure 1 - IGCC general scheme

The Priolo IGCC plant started commercial operation in April 2000 and can be divided in three main areas:

- Solvent Deasphalting Unit (SDA)
- Gasification and Utilities Units
- Combined Cycle Units (CCU)

The SDA receives the heavy residue from the refinery and deasphalts it; the deasphalted oil is then sent back to the refinery while the asphalt is fed to the Gasification Units. The gasification area transforms the asphalt coming from SDA into clean syngas to be burned in the CCU. It is a wide complex which includes the following main units (see Figure 2):

- 2 Gasification Units
- 2 Carbon Recovery Units
- 1 Sulphur Recovery Unit
- 1 Heat Recovery Unit
- 1 Acid Gas Removal Unit
- 1 Heavy Metals Recovery Unit
- 1 Waste Water Pre-treatment Unit

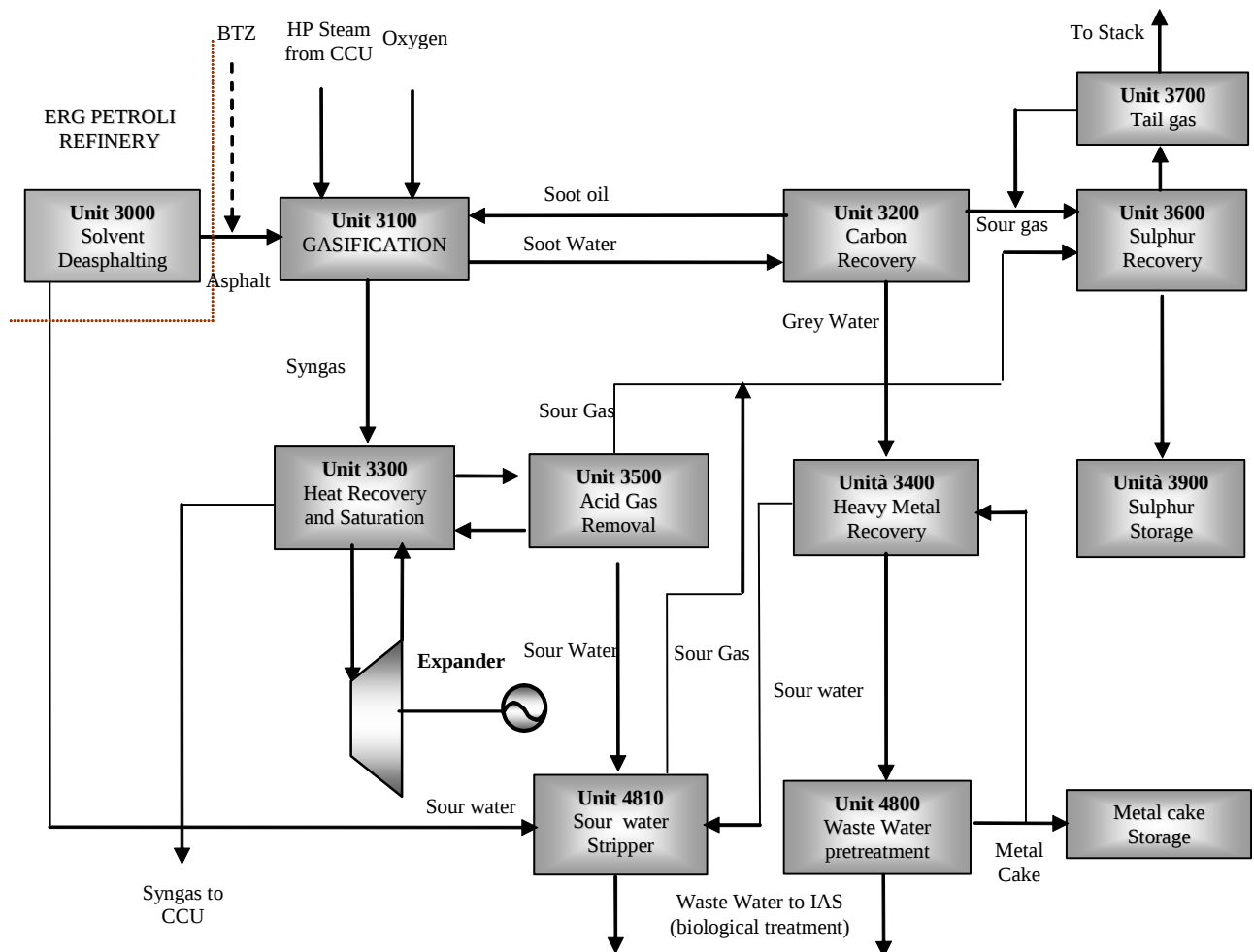


Figure 2 -- Gasification Flow Diagram

The CCU includes two trains, each of them with a gas turbine, a HRSG and a steam turbine.

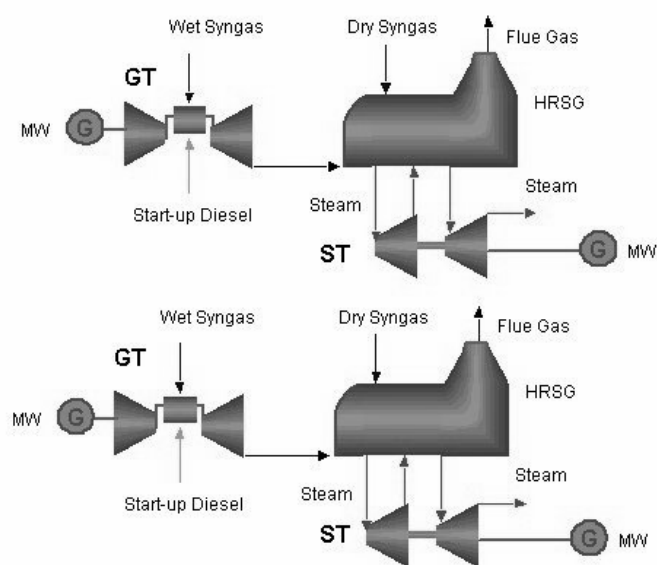


Figure 3 - Combined Cycle Flow Diagram

2.2 Automation System

The plant is equipped with an ABB DCS commissioned in 2000. About 65 Redundant Control Units manage around 90 000 tags. Control management is performed by means of 12 Operator Consoles. Turbine control is based on a dedicated Siemens Teleperm system. The total number of loop control schemes (PID) is more than 900. As an addition to the base regulatory control, late in 2006, Enhanced Alarm Management software, an innovative package for alarm recording, analysis and screening [5], has been installed in order to allow a significant reduction in the number of alarms so to free operators from the nuisance of false or redundant alarms and drive their attention to really meaningful events or opportunities.

3. THE ADVANCED PROCESS CONTROL APPLICATION

3.1 Background and Implementation Philosophy

After a few years of successful operation after plant startup, personnel at Isab Energy felt that the plant had the potential for additional margins and started to analyze possible strategies for improvements. In 2005 they started a collaboration with the vendor in order to review and improve the basic control scheme, hosted in the plant DCS. This activity led to the introduction of several improvements in the plant control schemes with the objective of improving process control in normal and transient operations.

The main changes implemented in the 2005 project were:

- Revision the coordination layer between the process unit (PPU) and the combined cycle unit (CCU), also known as Master Controller, to allow for:
 - Better control in steady state conditions
 - Faster response in transient conditions
 - Possibility to handle some specific operating conditions (e.g. in one CCU Unit have two trains in coordination mode, one train operated at maximum limit, etc.) that were originally not considered
- Implementation of pass balancing in the plant furnace
- Implementation of multiple new control loops (cascades, feedforward, ratio-control, etc.)

As part of this advanced regulatory control enhancement project, Isab Energy supported by vendor's specialists identified some key process units that had the potential to greatly benefit from the implementation of a fully fledged advanced process control system. Three key units were then selected by the customer as the objective for the first step of an advanced process control (APC) project which has been awarded to the automation vendor. These units were:

- Solvent De-Asphalting Unit
- Gasifier Units (2 trains)
- Acid Gas Removal Unit (AGR)

Figures 4 to 6 show the schematic diagram for each unit.

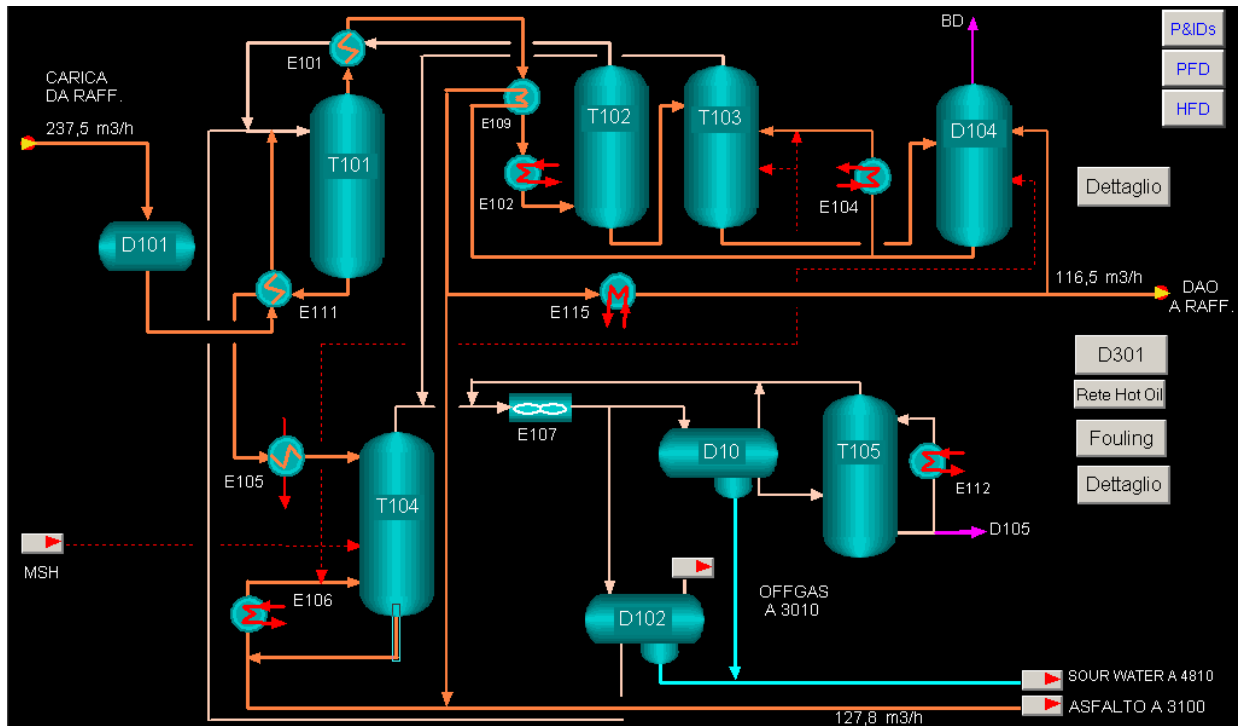


Figure 4 -- Solvent Deasphalting

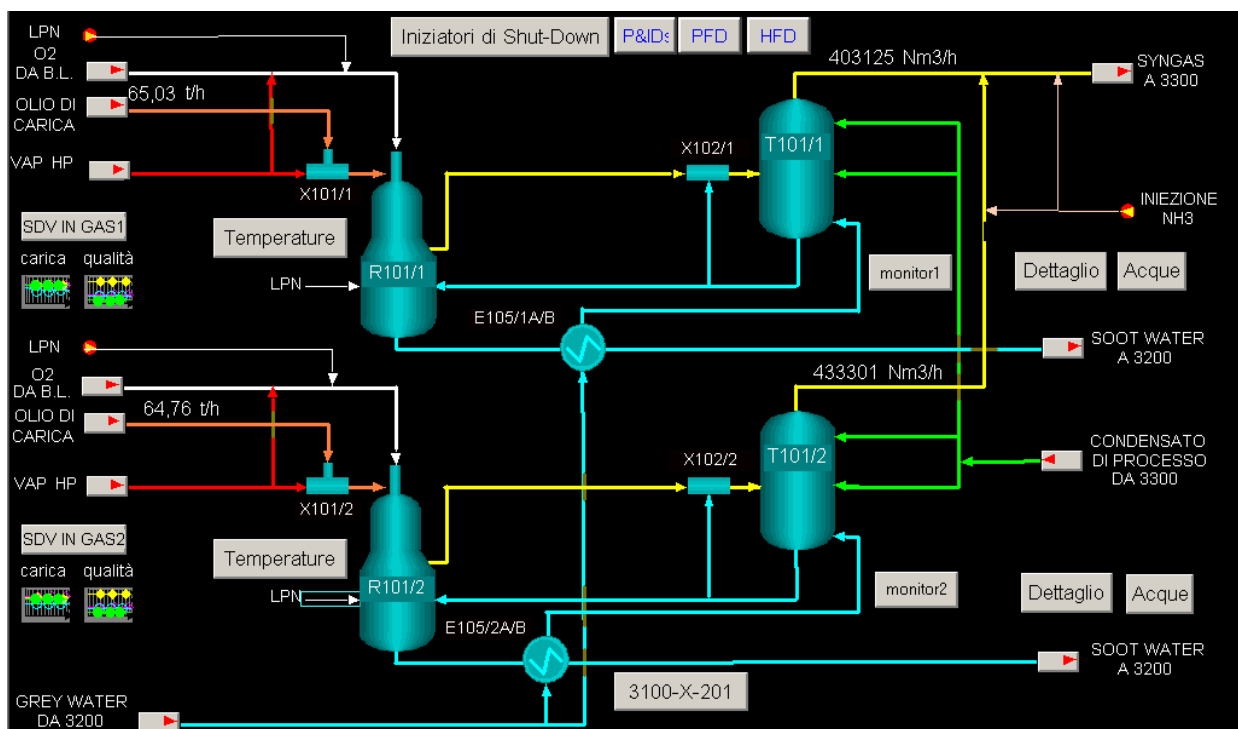
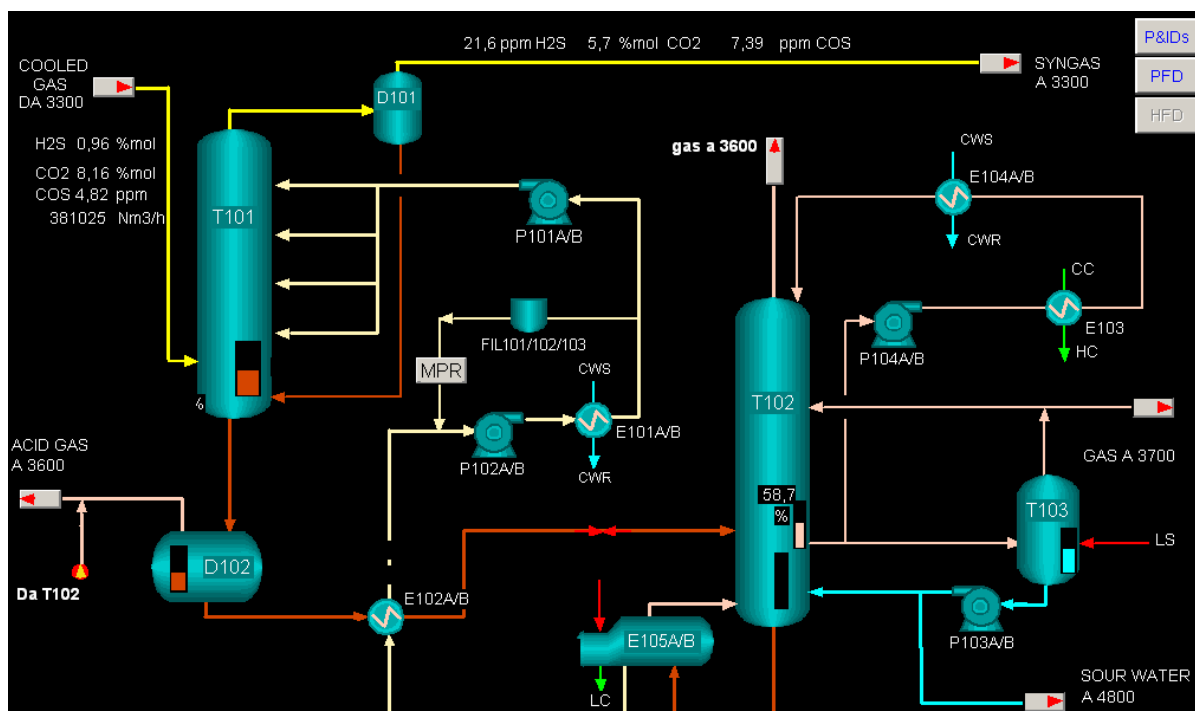


Figure 5 - Gasification



3.2 Project Execution

The APC project team was composed of three engineers working full time on the project. This included two experienced engineers from the vendor side and one from Isab Energy. In addition, several Isab Energy engineers provided support for process analysis and simulation, DCS integration, network integration. The project had its kick-off meeting in October 2006.

The first unit taken into consideration was Acid Gas Removal, followed by Solvent Deasphalting and finally the Gasifiers. The first milestone task for the project team was the development of the basic design specification for all the APC applications. This specification provided an overview of the design, for all the applications and described in detail the implementation approach. Continuous dialogue and interactions between the project team was a critical factor in the development of a design basis that received a high degree of acceptability from the plant personnel and ensured efficient project execution.

The execution of this kind of project in phases brings several advantages. For example, each application can be designed, installed and tested in a completely independent way, resulting in a greater flexibility and more efficient use of resources. The project team was able to gradually introduce new concepts to the plant personnel and train them on the use of the new technology without any risk of information overload. By keeping its project team members closely involved with each phase of the design and configuration of these advanced applications, Isab Energy was able to reduce project costs while ensuring they received customized solutions that could quickly be put online and maximize their return on investments.

3.3 Technology Overview

Key technologies selected for the APC applications are multivariable model predictive control (MPC) and inferential modeling. In addition to that, advanced regulatory control was applied in several cases to provide better process control and faster disturbance rejection.

At the core of MPC technology is a mathematical model of the process that is used to predict future process behavior. Using this predictive model the controller is able to calculate an optimum set of process control moves which minimize the error between actual and desired process behavior subject to process constraints. Since the late 1970s, MPC technology has

performed reliably in the petrochemical and refining industries because of its ability to account for process interactions and constraints, thereby reducing process variability and driving the process closer to its limits.

For the power production control, MPC strategies are required for driving the gasifier to satisfy load demands while meeting IGCC plant integration, performance, and environmental objectives. Multivariable control applications are based on the Optimize^{IT} Predict & Control (P&C) technology from ABB. P&C is an innovative multivariable controller, based on state-space modeling technology. While referring to [6] for a detailed description, it is important to underline that P&C exclusive features allow to reach a superior control performances in an easy-to-use powerful environment.

The first APC step involved four P&C controllers (one for each unit, two for each train of gasifier) and a few inferential models. Inferential models were implemented through an ABB Optimize^{IT} Inferential Modeling Platform (IMP), whose software details are described in [6].

The controllers are hosted on a devoted workstation that also hosts an OPC Server. A second PC is used as development and testing environment and is not directly connected to the base automation system (see Figure 7). This second workstation performs data collection using the dedicated software Optimize^{IT} Data Manager. The APC LAN is connected to the plant LAN by means of a dedicated Firewall that allows access to the APC LAN only to the authorized personnel. ABB software allows remote monitoring and maintenance for both P&C and IMP software.

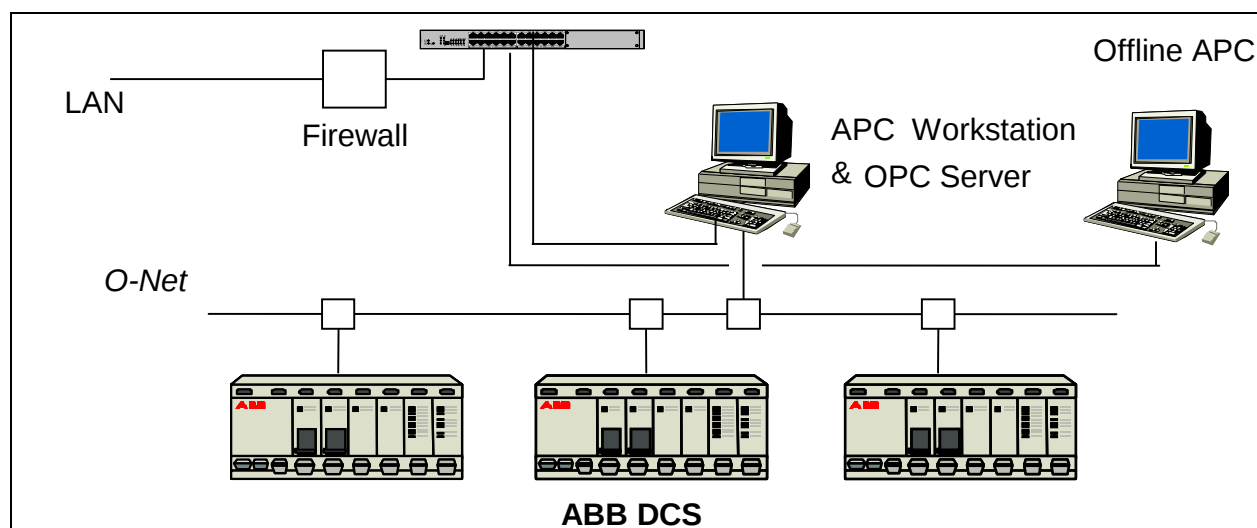


Figure 7 – System Architecture

While engineering monitoring and tuning of the APC applications is performed using dedicated HMIs, either remotely or locally, standard operations are performed directly by use of DCS graphic displays.

Operators manage the advanced application with the standard operator console where additional pages have been added for this purpose. Figure 8 shows a typical page in the Acid Gas Removal section.

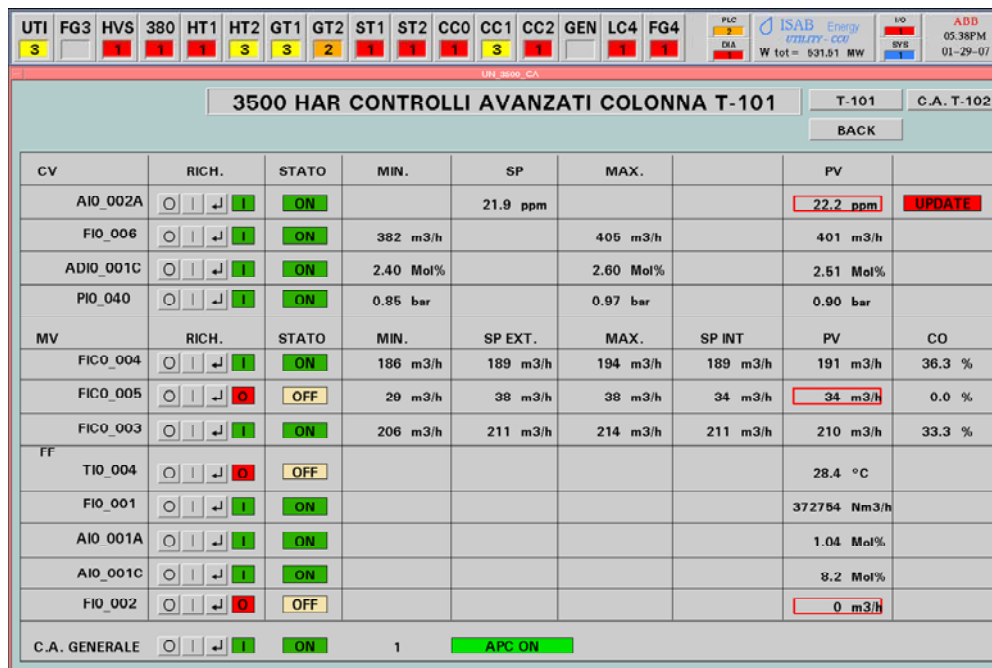


Figure 8 - Typical APC Operator Display

4. FIRST RESULTS AND PERSPECTIVES

As described in section 3 the four modules (1 for AGR, 1 for SDA, 1 for each train in the Gasification section) were commissioned one at the time so not to overload process personnel, starting with Acid Gas Removal commissioned in November – February 2007 and continuing with the SDA. Gasifiers will be completed within July 2007.

First results have been excellent with impressive returns of investment. To keep the description short we will illustrate first results on the Acid Gas Removal section, which is the one where the APC strategy has the longest running period (having been the first to be put on-line).

4.1 Control Improvement on Section 3500

The multivariable controller on the AGR section covers two columns: Absorber and Regenerator (see Figure 6). The Absorber column uses MDEA to separate H₂S from syngas. The Regenerator column uses high quantity of LP steam to strip H₂S from MDEA. This unit is very important both for environmental and energy usage reasons.

The H₂S left in the syngas out the Absorber column is one of the main contributors to emissions with specific respect to SO₂, and as such it is very important to stabilize and, where possible, minimize. From an energy standpoint, this unit is one of the main users of low pressure steam and, as such, there was great interest in reducing the steam usage. While the unit absorbs H₂S, there is certain slippage of CO₂ altogether with H₂S to the Regenerator column and then to the downstream Claus unit. This slippage has to be within certain limits due to the limited capacity of the downstream unit which acted in the past as the bottleneck for the entire section.

The objectives have been translated into the following objectives/constraints for the APC system:

1. H₂S in syngas in absorber overhead
2. CO₂ absorption
3. Overall MDEA circulation
4. Regenerator overhead temp
5. Regenerator pressure
6. Regenerator key tray temperature
7. Regenerator Reboiler bottom level

In addition, the following optimization objectives have been introduced:

1. Minimization of circulating MDEA in Absorber
2. Minimization of Steam/Rich MDEA ratio in Regenerator

The controller moves multiple MDEA injection streams to T101 and key variables like steam, overhead reflux, and bottom bleed for the Regenerator column. It is important to note that the multiple MDEA injection streams are located in different positions of the tower. The impact of a variation on each stream on H₂S and CO₂ is different depending on the injection position given the different kinetics of the reaction of MDEA with H₂S and CO₂. These differences in the dynamic response and steady state gains have been incorporated in the controller that can use any slack available in CO₂ absorption and emissions to minimize steam consumption.

The advanced control strategy has proven to be able to drastically reduce steam usage while maintaining controlled variables to their setpoints or inside constraints. The main advantage provided by the APC system was the possibility to avoid any risk of overloading the downstream unit by continuously assessing CO₂ absorption and allowing a shift of MDEA injection to a higher average position. To avoid unnecessary movements and filter the process and instrumentation natural noise, all setpoint control objectives have been implemented in the form of a setpoint with deadband form.

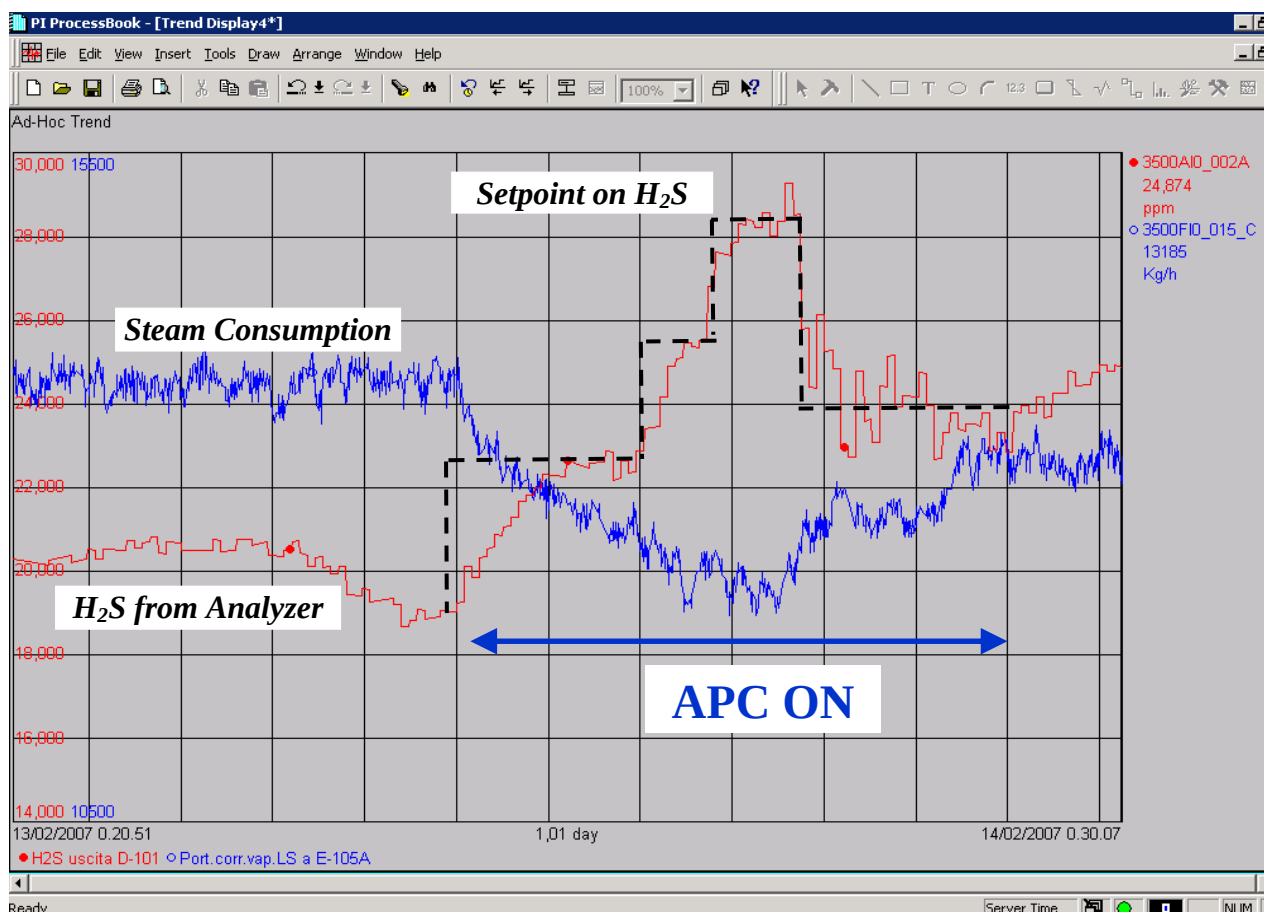


Figure 9 – APC Management of H₂S content in T101 Overhead

APC control of H₂S in the Absorber column overhead has proven to be very accurate and reliable. In Figure 9 a chart of the APC system response to step changes on the H₂S setpoint is presented. These setpoint changes were all achieved by the APC system in a short time, without overshoots and excessive perturbations of unit operation. This is a remarkable result given the magnitude of the variation of the steps – equal to about 10 ppm in a few hours – something that very rarely occurs during normal operations. As a result of the step changes, the consumption of steam in the regenerator column decreased very heavily, as shown by the curve in blue (for a

single reboiler – there are two twin reboilers). The overall decrease in steam usage was up to 3.5 t/h.

Although such a drastic change in setpoint for H₂S often not possible in a few hours, it is quite common that changes in factors like:

- Feed composition
- Feed flow
- Cooling water temperature
- Other units contribution to emissions
- Gasifier efficiency

Impact on H₂S content was of a similar quantity over 1-2 days. In that case, the presence of a APC system capable of minimizing steam while maintaining H₂S content at target provides large economic benefits. The figure below shows the steam consumption reduction achieved during a night test, when changes in feed composition and cooling water temperature together with a small increase of the H₂S setpoint (2ppm) allowed for a reduction in steam usage of about 2t/h.

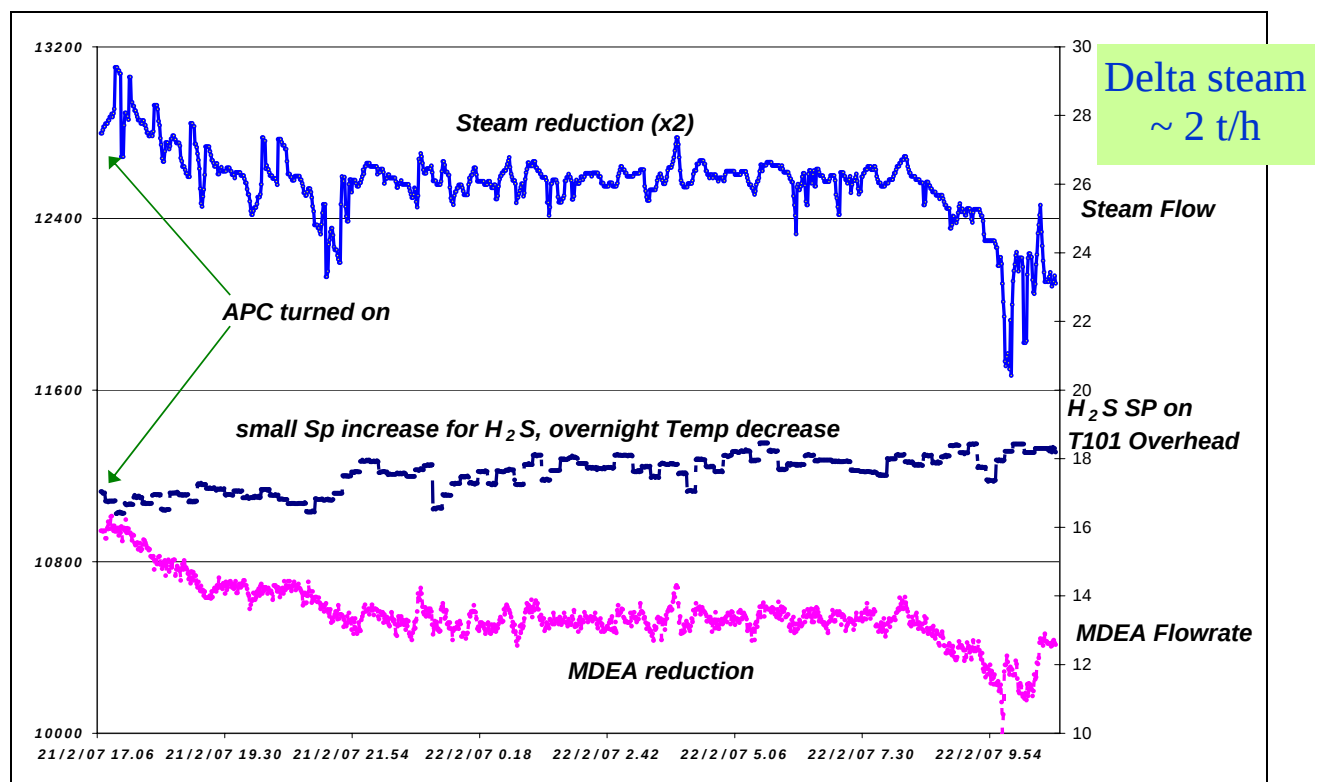


Figure 10 – Steam Consumption Reduction

Overall, the APC application allowed running the unit in a different operating region. The following figure presents the steam specific usage (expressed as a ratio between the steam and the MDEA circulation rate) over a long period of time, from the startup of the APC commissioning to the finalization of the APC system for the AGR unit. As can be seen by the chart, the reduction in the steam usage is quite relevant.

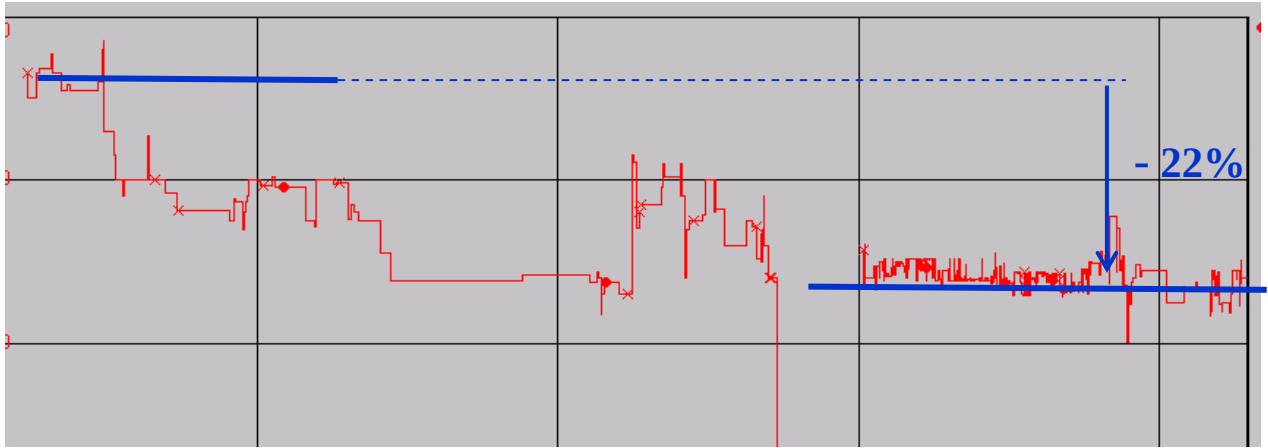


Figure 11 – Steam/MDEA Ratio Reduction

The overall benefit in terms of energy saving is quite considerable. Steam consumption went from 35.1 t/h to 26.1 t/h equivalent to a reduction of about 9 t/h.

This reduction is due to changes in operating conditions that can be described as follows:

- First, steam specific usage was reduced by optimizing the regenerator operating conditions
- Then, the overall MDEA circulation rate was reduced by optimizing the Absorber column operating conditions in two ways
 - Operating closer to H₂S specifications
 - Moving MDEA steam injection to a more favorable position (average)

As a result, the unit operating conditions have moved as depicted below in terms of steam usage and MDEA circulation rate.

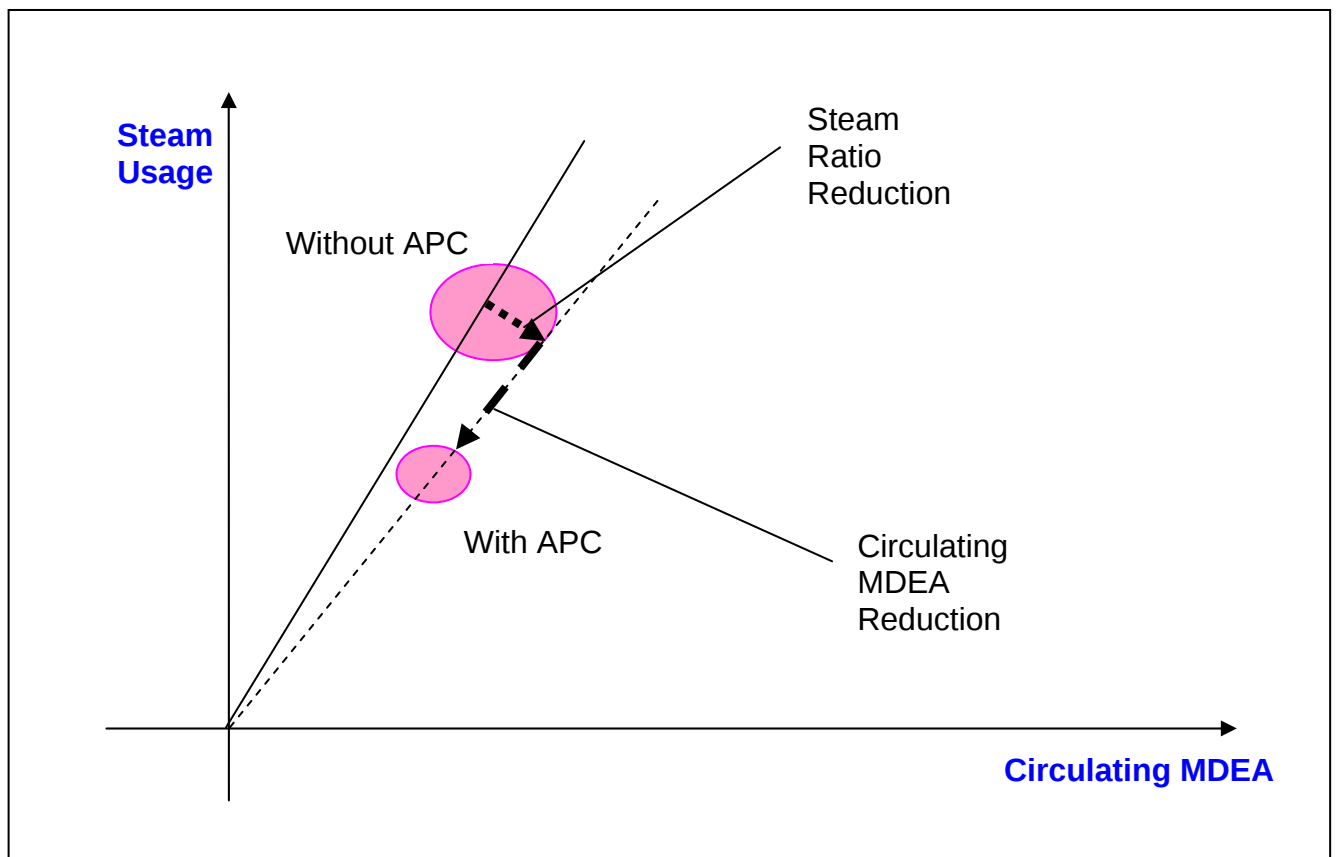


Figure 12 – Unit operating conditions before and after APC

As a further confirmation, Figure 13 shows the trend of the reflux stream over more than six months of data. Analysis shows that the reflux flow has decreased of about 50%. This is quite remarkable given the fact that the original reflux flow was not far from the design value for the unit.

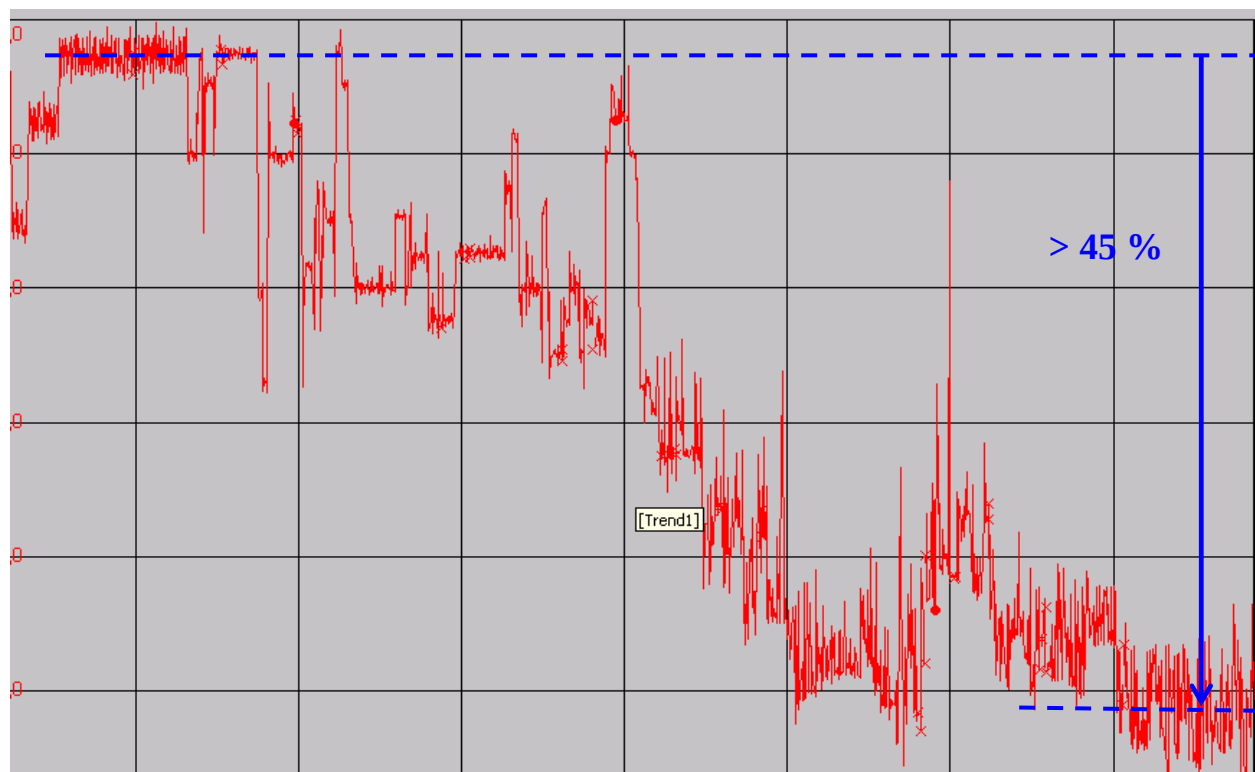


Figure 13 – Reflux Flowrate Reduction

4.2 Comments on Results

The positive results shown above (and the similar ones achieved in other sections) have been achieved through a proper combination of advanced control technology, process expertise and deeper insight. The APC project has proven to be the opportunity to explore a number of possible operating conditions, sorting out actual process and control limitations from “control myths”. The improved control tools allowed the engineers to move the plant into non familiar conditions, pushing the envelope and discovering hidden profit margins that basic control schemes don’t allow to harvest. This is not different from that verified on any other process (no matter if it’s refineries, petrochemical or upstream plants) where APC is applied as a technology enabling operators to manage the plant more aggressively without compromising on safety but with much higher economic performance.

4.3 Conclusion and Future Perspectives

This paper has presented a very successful application of Advanced Process Control technology to an IGCC plant. The application dealt with three sections (Acid Gas Removal, Gasifier and Solvent Deasphalting) that have been identified as interesting benchmarks for return-of-investment evaluation. The results after the first running period are extremely positive and clearly show that APC has the potential of providing relevant savings on IGCC plants, mainly through its capability to greatly increase energy efficiency and reduce steam consumptions.

As a consequence of the successful results of the APCs project, Isab Energy is evaluating the possibility of extending them to other units. In particular, the highest benefits could be obtained in the following plant sections:

1. Carbon Recovery
2. Tail Gas Treatment and Sulphur recovery
3. Combined Cycle
4. Waste Water Treatment

A proper plan for APC extension to additional units is under evaluation and will be finalized in the second half of 2007.

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