MPC as an APC Tool in an Industrial Environment

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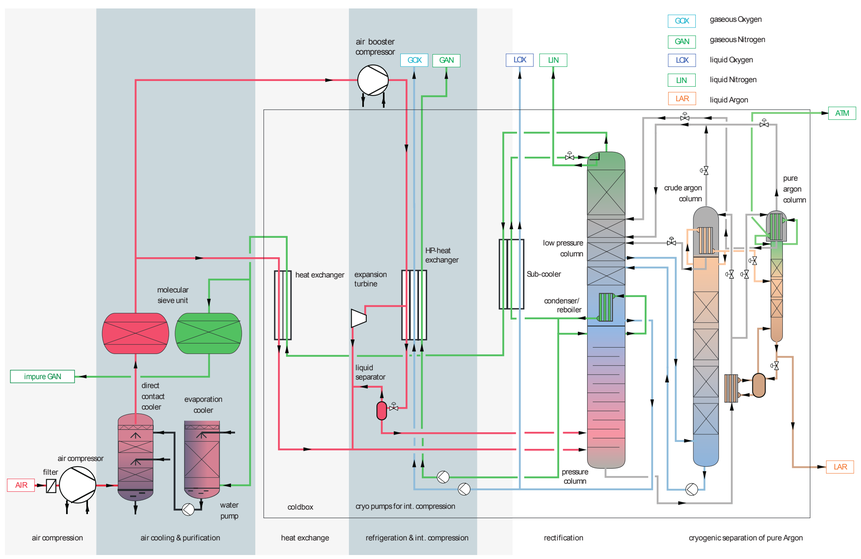
Introduction

- APC in the process industry
  - Has become essential for economical plant operation
  - Is an important tool for operator assistance
  - Required product are kept more tightly reducing overproduction
- Linear MPC, binary operations and adaptive load changing
  - Make plant operation more foreseable
  - Optimize the capabilities of the plant
  - Reduce down time
  - Exhausts most of the plant product domain

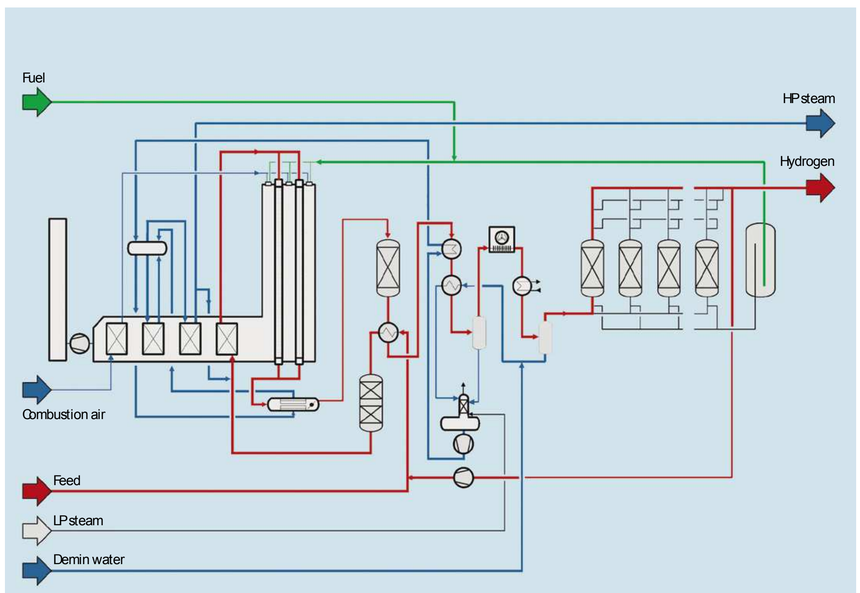
Process

APC at Linde is used in many different type of plants

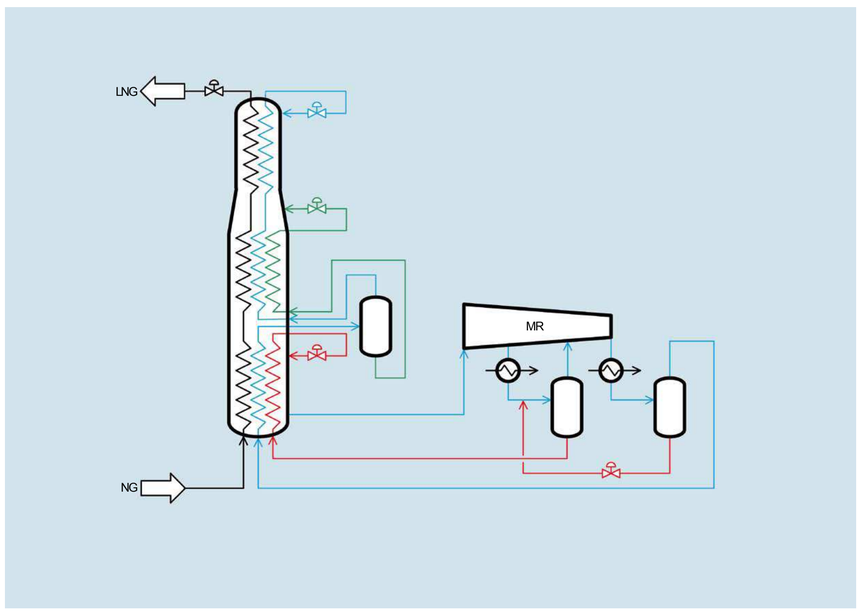
- Air separation unit (ASU)
  - The cryogenic process of separating air into O_2, N_2, Ar plus minor substances is based on the rectification principle
  - The process is highly energy intensive.
  - Blow off due to highly dynamic consumers influence the operating point of the ASU
  - Up to 30 MVs, 15 CVs



- H_2 and synthesis gas plants
  - Adsorbtion process to produce hydrogen or synthesys gases
  - Presure swing adsorbtion and cathalitic steam reforming are the main steps of production



- Liquid natural gas plants
  - Mainly by means of a cryogenic cycle, natural gas is liquefied for transportation logistics



Linde Advanced Process Control Tools

The Linde APCS consists of different modules for individual advanced process control tasks. The following modules are available:

- Interfaces for a large number of Distributed Control Systems (DCS) including an OPC client.
- Realtime Data Base, this database stores all data being exchanged with the DCS as well as data calculated by the APCS modules.
- OPerator Interface for the operation and supervision of the APC tasks
- Control is used for high level process control functions and calculation of unmeasured process data such as efficiencies and material balances. The central applications are:
  - LMPC (Linear Model Predictive Control)
  - ALC (Automatic Load Change) performs the automatic transition to new plant operation points.
  - AST (Automatic STart) restarts the Air Separation Unit or starts/stops plant sub-units.
  - APA (Automatic Product Adaptation) performs demand following for selected products, typically the Oxygen flow to a steel mill.
  - PRBS (Pseudo Random Binary Signal) is used to generate random signals and exitation of the plant of system ID.
  - EFC (EFficiency Calculation) performs efficiency calculations for machinery, e.g. compressors and turbines.
- MSG is the message module, for recording and retrieving events and alerts from all other APCS modules.
- TRE (TREnd) for the long-term storage of plant data.
- TRE-Plotter for the graphical and numerical evaluation of stored plant data.
- SIM, the DCS interface simulator for the off-line test of advanced process control tasks.
- OSV is the APCS internal OPC Server which transmits data inside RDB to and from external OPC clients.

Model Predictive Control (MPC)

- Linde [1] uses an online linear MPC, e.g. the quadratic optimization with linear terms is executed at every interval.

$$u = \arg\min_u J(x(0), u)$$

$$J(y(0), u) = \sum_{k=0}^{N} \|r(k) - y(k)\|_Q^2 + \|\Delta u(k)\|_R^2 + \|\Delta u(k)\|_{L_{pu}}^1,$$

$$s.t. \quad y(k) \in \mathcal{Y},\ u(k) \in \mathcal{U},\ \Delta u(k) \in \Delta\mathcal{U}$$

u: Model Input
y: Model Outputs
r: Reference Values
J: Quadratic Cost Function with Linear Term
Q: System Output-Reference Penalties
R: System Input Penalties
L_{pu}: Linear Penalty for System Inputs
$\mathcal{Y}$, $\mathcal{U}$, $\Delta\mathcal{U}$: Constraint definitions. i.e. linear system dynamics, input constraints.

- Mainly used for
  - ASUs
  - H_2 plants

Conclusions

- Linde has seen that by suiting all its plants with APC major cost savings can be achieved.
- APC reduces work load of operators, thus increasing their availability for other plants.
- APC enhances the operation envelop of the plant.
- PCS reduces the chances of accidental shutdowns of the plant
- APC has become not just a "nice to get" application.
- APC saves energy and thus money.

References

[1] Linde AG. *Linde Advanced Process Control System*. Linde AG, 2010.

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