**Introduction to course (module) on Advanced process control.**

**What is APC?**

**Let’s start by seeing what Wikipedia says about APC (August 2021).**

In [control theory](https://en.wikipedia.org/wiki/Control_theory), **Advanced process control** (APC) refers to a broad range of techniques and technologies implemented within industrial process control systems. Advanced process controls are usually deployed optionally and in addition to *basic* process controls. Basic process controls are designed and built with the process itself, to facilitate basic operation, control and automation requirements. Advanced process controls are typically added subsequently, often over the course of many years, to address particular performance or economic improvement opportunities in the process.

Advanced process control (APC) refers to several proven advanced control techniques, such as feedforward, decoupling, and inferential control. APC can also include Model Predictive Control. APC is typically implemented using function blocks or custom programming capabilities at the DCS (distributed control system) level. In some cases, APC resides at the supervisory control computer level.

**In summary, there are two main approaches to “advanced process control”**

1. **Conventional APC (this course).** This includes the “advanced” standard control elements that typically are provided at the DCS (distributed control system) level and which industry commonly uses to enhance control when simple single-loop PID controllers do not give acceptable control performance. Examples of such control elements are cascade control, selectors (override), split range control, input or valve position control (VPC), multiple controllers (and MVs) for the same CV, and nonlinear calculation blocks (including nonlinear feedforward and decoupling and linearizing adaptive gain elements).

Note that conventional APC includes what Wikipedia calls advanced regulatory control (ARC).

1. **Model predictive control (MPC).** This requires a mathematical model of the (whole) process to be controlled, and is implemented using on-line optimization where the cost J is minimized subject to satisfying constraints.
* **Economic MPC (Academia).** The most general (and popular) approach is to use “economic MPC” (usually based on a first-principle nonlinear process model) where J is the economic cost. This approach, also known as dynamic real-time optimization (DRTO) is very popular in academia, but is so far little used in industry (except maybe in some polymer applications).
* **Conventional MPC (Industry).** When we talk about MPC in relation to “advanced process control” then we usually have in mind the industrial implementation, which uses a linear model (often obtained from step response experiments) and the cost J represents setpoint deviation. In industry they usually have a two-level MPC where the setpoints are obtained based on a steady **state solution that takes into account constraints.**

**Why look at conventional APC when we have MPC?**

Control engineers rely on many tools, and although some people may think that in the future there will be one general universal tool that solves all problems, like model predictive control, this is not likely to happen. The main reason is that the possible benefits of using more general tools may not be worth the increased implementation costs (including modelling efforts) compared to using simpler "conventional" advanced process control (APC) solutions. In particular, this applies to process control, where each process is often unique. In addition, for a new process, a model is usually not available, so at least for the initial period of operation a conventional scheme must be implemented.

Since its introduction in the 1940’s, about 80 years ago, conventional APC has largely been overlooked by the academic community, yet it is still thriving in industrial practice, even after 40 years with MPC. So it seems safe to predict that conventional APC (including PID control) will not be replaced by MPC, but will remain in the toolbox along with MPC. The main reason is the lower cost for implementation and maintenance with conventional APC, because it requires less model information and less external expertise.

**The goal of this course is to take a systematic view on how to design a conventional APC system. The starting point is the plantwide optimal steady-state economic operation, with focus on constraints.**

**Some more details about what you will learn in the course**

Since conventional APC it is not going away any time soon, it is definitely time to strengthen its theoretical basis and train students on how to use it in an effective manner.

The goal of this course is to take a systematic view on how to design a conventional APC system. The starting point is to consider the plantwide optimal steady-state economic operation, with focus on identifying active constraints, for example, closed valves. For the remaining unconstrained degrees of freedom, we need to identify “self-optimizing” variables, which are variables which when kept constant (typically using PID controllers), indirectly keep the operation close to the optimum.

The next issue to consider is inventory control, where the concept of throughput manipulator (TPM) is central as it determines the structure of the inventory control system. Following this, one needs to consider how active constraint switching can be implemented and this leads to selectors (for CV switching) and split range control, multiple controllers or VPC (for MV switching). Other issues are disturbances and nonlinearity, where cascade control and calculation blocks may be helpful.

The main disadvantage with conventional APC compared to MPC is that it is based on single-loop controllers, so one needs to pair outputs (CVs) with inputs (MVs). For most processes this works well, but for more complex cases with many constraint switches one may get significant benefits and simplifications with MPC. Other cases where MPC may offer significant benefits compared to conventional APC is for interactive processes and for cases with known future disturbances

**Finally, some economic justification for when to use MPC and when to use ARC.**

**The objective of any advanced control solution is to make more profit (while maintaining physical, safety and environmental constraints). The overall cost Jtot must also include the cost for implementing maintaining the solution-**

The “problem” with the “academic solution” (MPC) is that it aims for the ultimate (optimal) solution

* which in general requires a detailed mathematical model of the whole system and a complex implementation. The cost of implementation and maintenance (repair) is often high and requires external expertise.

 whereas engineers (suing ARC) aim at an improved (generally sub-optimal) solution

* which is easy to understand and implement. The benefit must outweigh the implementation cost

Here is an attempt to include also implementation cost into the overall cost, Jtot:

J = economic cost during normal operation of proposed solution [$/s]

Ji = cost of making implementation [$], which usually for MPC requires external expertise.

Jr = cost when implementation is out of service = J0 + Jir (where J0 is cost with “base” control system and Jir is cost for repair)

r=Tr/T = fraction of time when system is down for repair

The total cost to be minimized is then

Jtot = Ji + J \* T \* (1-r) + Jr\*T\*r

**In summary, MPC has the lowest (optimal) value for the economic cost J during normal operation, but the other terms (Ji, Jr and r) are usually larger than for ARC.**

A little more on what Wikipedia says about APC and ARC

Types of APC:

* Advanced regulatory control (ARC) refers to several proven advanced control techniques, such as override or adaptive gain (but in all cases, "regulating or feedback"). ARC is also a catch-all term used to refer to any customized or non-simple technique that does not fall into any other category. ARCs are typically implemented using function blocks or custom programming capabilities at the DCS level. In some cases, ARCs reside at the supervisory control computer level.
* Advanced process control (APC) refers to several proven advanced control techniques, such as feedforward, decoupling, and inferential control. APC can also include Model Predictive Control, described below. APC is typically implemented using function blocks or custom programming capabilities at the DCS level. In some cases, APC resides at the supervisory control computer level.
* MPC…
* Nonlinear MPC…
* Inferential…
* Sequential control…
* Intelligent control….

x