Implementation of Predictive Functional Control on a high pressure distillation column

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Introduction

In the last decade the meaning of **M**odel **P**redictive **C**ontrol (MPC) for the industries has been significantly increased, particularly in petrochemicals industries, as well as within the chemical engineering field. These based on the fact that MPC is suitable for the regulation of complex systems.
One of the advantages of the MPC is the robust control behaviour in term of controlling processes with a distinct ratio between its time constant and its dead time. Another advantage of MPC is its adaptable control algorithm. This means MPC can handle processes with changing steady state point due to the fluctuation of the resource composition.
Furthermore constraints and other additional operational conditions can be applicated in the control algorithm with small effort.
However, the implementation of the advance control algorithm fails in practice because of lack of acceptance from the plant operator. The complexity of the advance control algorithm and the low understanding of the control behaviour are presumed to be the root of the lack of acceptance.
In this work, we introduce a first approach of the linear PFC implementation on a complex chemical process. A binary azeotropic thermal separation process on a distillation column is addressed. Moreover, an alternative method of concentration control to preserve a given product specification is used, based on the thermodynamic character of the mixture.
The main objective of this work is the development of the PFC algorithm for complex control tasks in consideration of the influencing variable (disturbance handling), constraint handling and using a linear / nonlinear model. In addition, visualization of optimization-based process data with the consideration of multicriterion objectives will be discussed based on the process considered.

Problem formulation

As we all know rektification / distillation process is a high non linear process. A small changes on one variable (e.g. feed-flow rate or pressure drop) will affected the dynamic of the whole column. Maintaing the product quaity and quantity in a distillation process is a common problem that can be solved with controllers. The question is how good does the controller work ? A good controller can maintain the given set point during operation, and a bad (poorly adjust) controller can also achieve almost the same result. So what makes a good controller difference from a bad controller ? A good controler can preserve the process output or **C**ontroled **V**ariable (CV) close to the reference value (set point) the entire time, with minimum cost of the actuator / **M**anipulated **V**ariable (MV).
For example we look at a case in which the controller (PI) should maintain the temperatur at the given value 110°C. As we can see, the controller can hold the CV at the set point for most

time, although there is some changes in the dynamic (pressure lost changes). The problem appreas at ca. t = 120 *min*, when the column has reached a new steady state point. Regarding that the controller is not designed for this new steady state point, it can compensate the model missmatch for a certain time, with a high cost of the MV(heat duty)

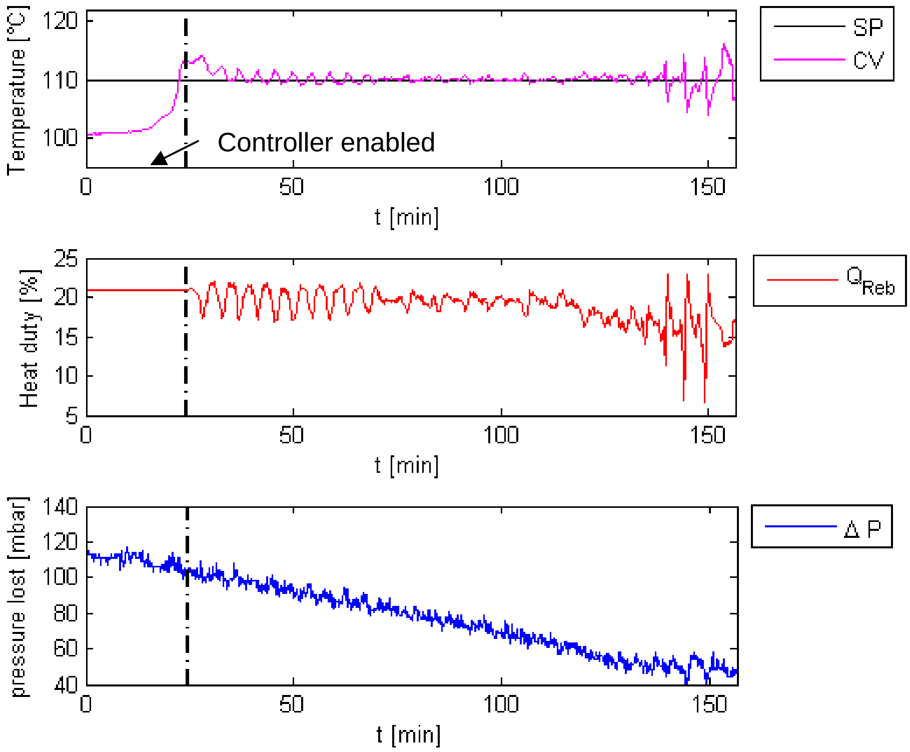

Figure 1. PI(D) control behaviour on a pressure drop change

MPC introduce an optimal control algorithm due its ability to predict the future behaviour of the systems and calculated a set of optimale MV.One disadvantage of MPC is its optimzation algorithm, which demands a high computational effort to predict the future and to calculate the MV. This lead to the second problem: how to modify the MPC algorithm, which is suitable for fast processes.
Finding a proper internal model for MPC is another problem that appears automatically with the implementation of MPC algorithm. In other words, this study focused on three main problems:

- Controlling product composition in a distillation process (concentration controlling)
- Investigation and analysis of the dynamic behaviour of the column (modelling)

However, the implementation of **A**dvanced **P**rocess **C**ontrol in the industry fails in the practice because of lack of acceptance from the plant operator.
The complexity of the advance control algorithm and not understanding the control behaviour presumed to be the root of the lack of acceptance. A further cause analysis has been done in [11].
While 80% of the conventional automation systems consist of standard blocks, however for the graphic integration of APC in operating specific control interface there are still no standard form established. As a consequence, the Human Machine Interface in the automation system has a limited usability, which is especially caused by the absence of process transparency and self explaining function.
The consequences of these problems lead up into two typical behaviours [10]:

- Distrust leads to neglect and/or non-usage of the systems.
- Excessive confidence can decrease the plant operateur's situation awareness, which lead up to losing his ability to take a proper action in case of a failure.

Solution

Predictive Functional Control (PFC)

In the late 80s, Richalet presented the Predictive Functional Control (PFC) method, which based on the model predictive control (MPC) principle. PFC has an undermanding algorithm, is faster, and offers higher control precision than normal model-based predictive control principles. Ability to use a linear or non linear model and the constraint handling are two from many essential advantages in comparison to the conventional controller. In praxis, PFC has been successfully applied to many different control areas [1],[2].
The main idea of PFC algorithm or the big difference between PFC and MPC algorithm is that, PFC calculate only one future MV, not like the common MPC , which calculate a set of future MV's behviour. So that the high cost of computation of the optimization algorithm and/or iterative methods, which is needed for the solution of QP-problems, is omitted [3]

Figure 2 shows, the structure of PFC in a control loop. It shows also that PFC algorithm consists of two main parts:

1. *internal model,*
   the internal model simulates the (future) behaviour of the process with the same given input MV_{lim}. A short introduction about the internal model will be discussed later in this chapter
2. *controller/control algorithm,*
   in this block, the controller calculates the optimal MV based on the current model output $Y_m(n)$, current system output $CV(n)$, past system output $CV(n-1)$ and set point $SP(n)$

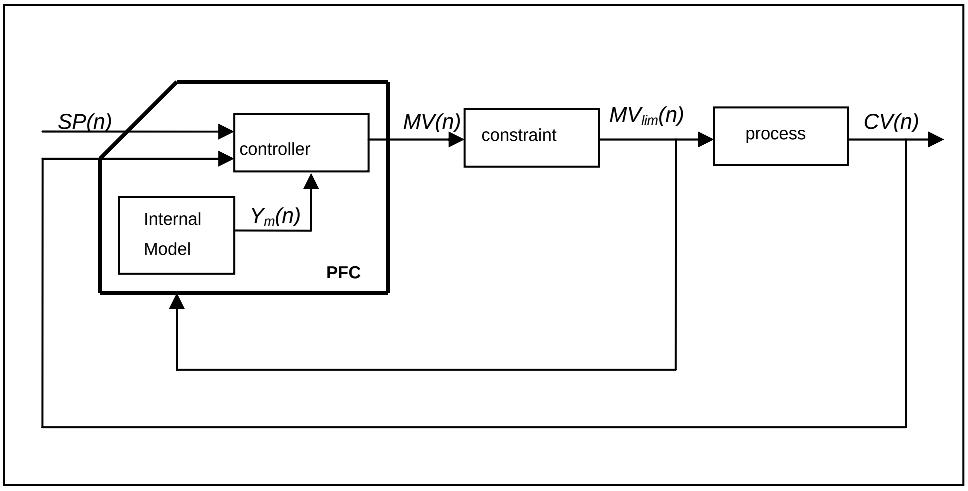

figure 2. PFC control loop

With:
SP(n) - setpoint
MV(n) - manipulated variable

$MV_{lim}(n)$	- limited / constrained MV
$CV(n)$	- controlled variable
$Y_m(n)$	- model output

internal model

PFC describes the internal model of the system as a discrete differentation equation. The main advantage of having the model in this state is, that the future behaviour of the system can be calculated/predicted using models's current and past output. In the example below a first order system will be described as ODE (**O**rdinary **D**ifferential **E**quation)

<u>Example:</u>

First order system in continuous state

$$\tau \frac{dy_m(t)}{dt} + y_m(t) = K \cdot MV(t) \tag{1}$$

Discretization through the Z-Transformation as a transfer function (eq.(2)) and as a discrete differential equation (eq.(3))

$$G(z) = \frac{Y_m(z)}{MV(z)} = \frac{K \cdot (1-\alpha) \cdot z^{-1}}{1-\alpha \cdot z^{-1}} \tag{2}$$

$$y_m(n) = y_m(n-1) \cdot \alpha + K \cdot (1-\alpha) \cdot MV(n-1) \tag{3}$$

with

$$\alpha = e^{-\frac{\tau_A}{\tau}} \tag{4}$$

Whereat τ_A the sampling time and τ the system's time constant

control algorithm

The assumption that the model output y_m by the time $(n+h)$ identical to the process output CV (eq. XX), is the initial point for calculating the future $MV(n+h)$, whereat the prediction horizon $h = 1$.

The current MV can be described as a function from the current set point, current process output CV, current model output ym and the decrement factor of the discrete reference trajectory β

$$MV(n) = \frac{[SP(n) - CV(n)] \cdot (1-\beta^h) - y_m(n) \cdot (1-\alpha^h)}{(1-\alpha^h) \cdot K} \tag{5}$$

For the specify calculation of the MV can be found in [3] and [4]

Prospective design of the Graphical User Interface (GUI)

As written above, the implementaion of APC fails in the practice due to low/lack of acceptance of the plant operateur, whose works should be actually supported by the APC. The initial point of this work is the hypothese

A transparent display of the system effects both the quality of process control and the plant operateur's acceptance positively

The goal of this work is to developt an innovative User Interface for a prospektive design of Human-Technology-Interaktion.
One important aspect in designing a Graphical User Interface is the trade of effect between the Workload and the Situation Awareness. Too high workload will lead the operatuers to neglect or abandon their second Task or even in a worst case, unaware of the incoming alarm. On the other hand, too low Workload indicating an excessive confidence in the control system, which may decrease the ability to react properly in case of system failure or emergency.
The first step in order to achieve this goal has been made. Figure 3 shows a prototype of an user interface for an advanced control system.
The development of the prototypes was limited to the Trend display, which give possibility for the plant operateur to see the future behaviour of the system at the given system input and its model uncertainty.
This kind of display has greatest usability for the interpretation of the dynamic behaviour of process variables [12].

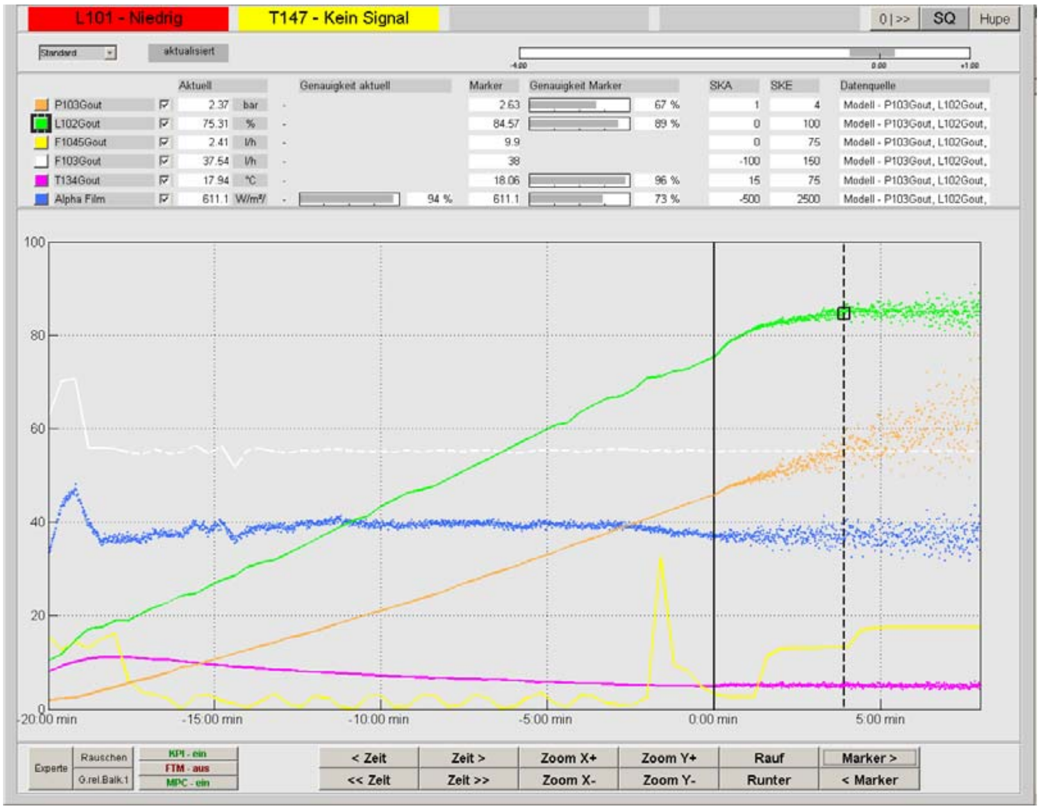

Figure 3. Graphical integration for Advanced Process Control [11]

Result and conclussion

Result

Some results of the PFC implementation on a distillation column to regulate the concentration of the bottom product can be seen in the figure 4, figure 5 und figure 6. Figure 4 shown the PFC control process with no disturbances. Meanwhile in the figure 5 and 6 is the result of the PI(D) and PFC to compensate a lasting disturbance, in this case feed flow rate changes.

Figure 4 below shows the PFCs control sequence during the pressure drop changes. The PFC can preserve the temperatur to the given set point for the entire time with a minimum cost of the heat duty. In direct comparison with the PI(D) control sequence, see figure 1, it is obvious the the PFC perform a better control performance during the operation without disturbances.

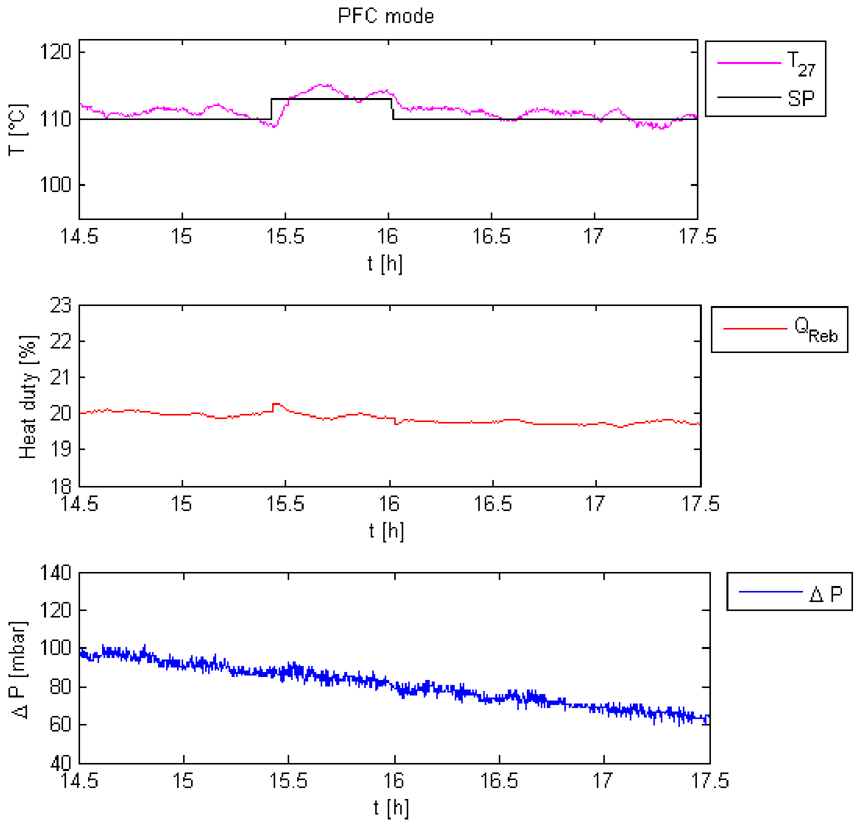

Figure 4. PFC: Temperature control with $CV = T_{27}$

Another interesting comparison shows the performance of both controllers in term of handling steady state changes during operation through increasing the feed load.

Figure 6 shows the control sequence from PI(D) controller. At approx t = 68 *min* the feed load increased from 16 *l/h* to 18 *l/h*. With higher feed load, the temperatur in lower parts of the feed tray will decreasing, beacause of the lower inlet feed temperatur, thus the heat duty should be increased, to maintain the temperatur at the given value.
Basically PFC can compensate the disturbance by increasing the heat duty to the new steady state point(from 14.5% to 17.5%), but it failed to fulfil the main task. It took about 60 minutes for the PFC to reach the new steady state point, and during this “action” the temperature couldn’t be preserve to the given value. This cause concentration changes which lead to benefits lost.

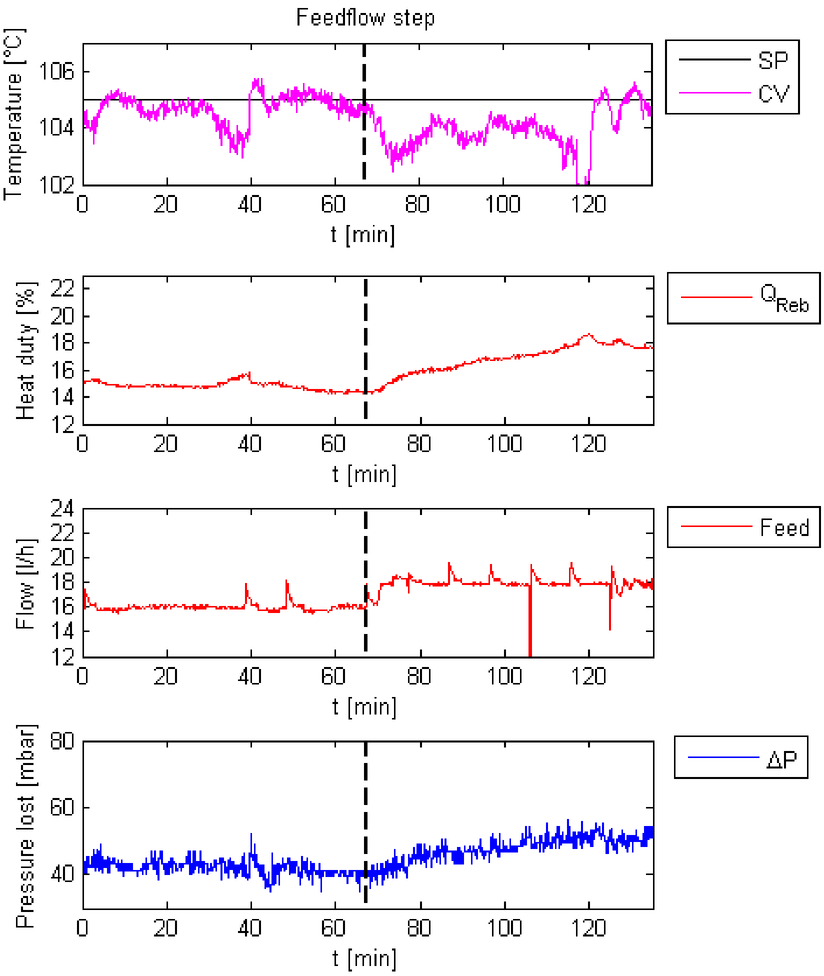

Figure 6. PI: steady state point changes

The same working condition as the PFC test-scheme is also applied to investigate theperformance of PFC.
As we can see in figure 6, PFC increase the heat duty a lot faster then PFC, it only takes about 3 minutes for the heat duty to reach the new steady state point. This action can be explained, because the PFC predict how the feed load change will influence the temperatur in the future and how to compensate this disturbance. In other words PFC acctually doesn't react based control error, but rather *prevent* the controlled variable leaving the setpoint

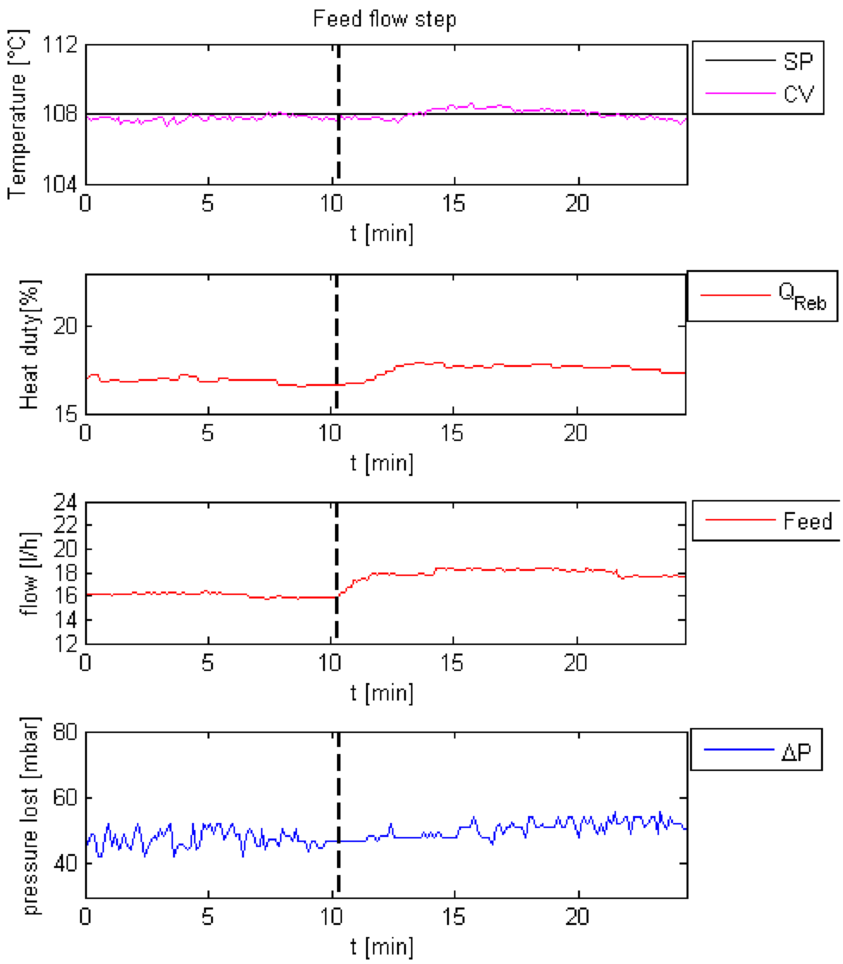

Figure 7. PFC: steady state point changes

This work shows that the implementation of **A**dvance **P**rocess **C**ontrol in order to optimize the porcess control strategy of complex system is successful. These results show also that with APC not only the bottom concentration can be maintained, which increase the benefits, but also the prodcution cost can be reduces due to manipulate variable'performance.

conclusion

The works shows, that the implementation of Predictive Functional Control has satisfied the expectation in optimizing the process control strategy. PFC not only maintain the bottom concentration at the given setpoint, but also reduces the operation cost due to manipulate variable'performance

On the other hand, model based control algorithm, particularly its model uncertainty has special contribution in developing a graphical integration of an Advanced Process Control. With the model uncertainty as an indicator, the plan operateur is demand to examine the process continuously, which affect the situation awareness of the plant operateur positively. With the display's transparency, which decrease the workload, and "in the loop" effect, which increases the Situation awareness the Graphical User Interface has completed its task to support and increase the performance of the plant operateur.

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