ADVANCED PROCESS CONTROL FOR YARA UREUM PLANT BRUNSBÜTTEL

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1 Abstract

IPCOS, a market leader of APC solutions for the fertilizer industry, has successfully implemented its MPC system, INCA, on the urea plant of Yara Brunsbüttel. In this paper, a small introduction into the urea process and MPC systems is given. Further, an overview of the specific implementation on the Brunsbüttel site is described together with its proven benefits. It is shown that applying the INCA MPC system on the urea plant offers more stability to the plant, maximizes the throughput and increases the overall yield. Also, switching from 50% load to 100% load occurs faster and in a more stable way.

2 Urea process

The described urea plant at Yara Brunsbüttel, Germany is based on Snamprogetti technology. A schematic overview is depicted in figure 1.

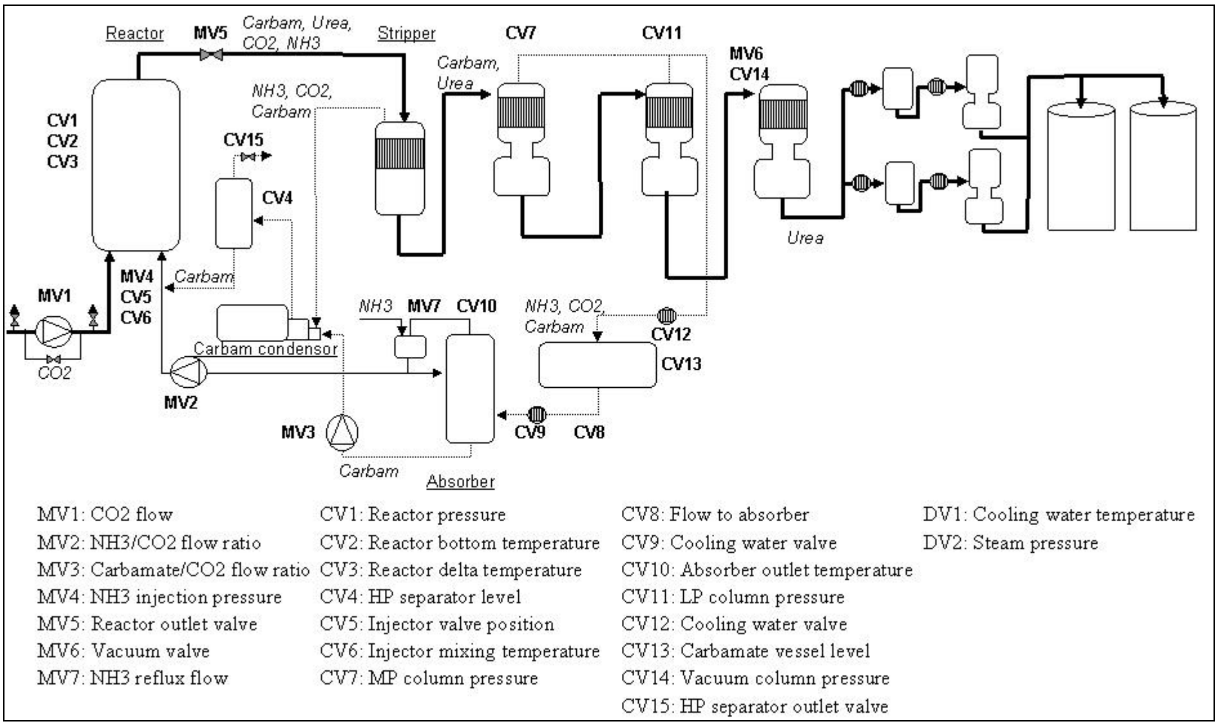

Figure 1: Schematic overview of a urea plant with INCA model variables

The commercial synthesis of urea consists of the reaction of ammonia and carbon dioxide at high pressure to form ammonium carbamate. This carbamate is subsequently dehydrated to form urea and water under the application of heat.

2 NH3	+ CO2 ↔	NH2COONH4 ↔	CO(NH2)2	+ H2O
Ammonia	Carbon Dioxide	Ammonium Carbamate	Urea	Water

Both reactions, the carbamate formation and dehydration, take place in the high pressure reactor. The first reaction is fast and exothermic and almost goes to completion under the conditions in the reactor. The second reaction, the carbamate dehydration, is slower and does not go to completion under the conditions in the reactor. In the stripper excess NH_3 and CO_2 is stripped from the outlet of the reactor and recycled back to reactor via the carbamate condenser.

The remaining carbamate and urea solution is subsequently fed to the decomposers which are operated at lower pressure. This lower pressure will cause the carbamate to decompose into ammonia and carbon dioxide, which is collected in the carbamate vessel. In the absorber, the ammonia is separated from the carbamate mixture and fed with make up ammonia to the reactor again. The carbamate mixture is recycled to the reactor via the carbamate condenser and the high pressure separator.

The remaining concentrated urea melt from the decomposers is further purified by removing remaining water in two parallel evaporation stages. The purified urea melt is then granulated in two prilling towers.

3 INCA MPC technology

3.1 INCA MPC: what is it?

A urea plant is a complex unit with a lot of internal heat recovery, recycle flows and external disturbances (cooling water temperature, heat exchanger fouling, etc.).
Due to this high level of interactions and external disturbances in the plant it is very difficult for operators to predict what the exact effect will be of changes they apply to the plant. As a result, operators tend to operate the urea plant in most cases in a stable but suboptimal working point. Once stable operation is achieved, operators will not be very eager to push the plant towards the optimal working point. Indeed, due to the highly interactive properties of the plant, the operator can easily make incorrect plant changes that introduce upsets instead of bringing the plant closer to the optimal working point.

The INCA Model Predictive Controller (MPC) is capable of increasing overall plant stability and at the same time pushes the plant towards the most optimal working point.
INCA uses a complete model of the plant including all the interactions and disturbances. Based on that model INCA predicts every minute how the plant can achieve the most stable and optimal operation point.

- Therefore INCA calculates and changes the set points of certain PID controllers in the plant, which are called the Manipulated Variables (MV).
- INCA defines the plant stability and optimal working point based on the Controlled Variables (CV) such as qualities, energy consumption, reaction conversion, etc. that have to be controlled and optimized by the controller. CV's can be controlled within a zone or at an ideal value and can have a different priority within the INCA controller depending on whether the zones are linked to safety, quality of economic issues.
- Process disturbances such as changing ambient temperatures, fouling of heat exchangers, etc. are taken into account by INCA as Disturbance Variables (DV). Disturbances will have an effect on the stability and working point of the plant, and therefore are taken into account by the INCA controller as well.

The INCA MPC controller will compute the optimal required MV changes to achieve optimal control of the CV's taken into account all relevant plant disturbances DV.
The INCA controller is installed on a PC that is connected to the DCS system via an OPC interface. Robust fallback strategy is implemented on the DCS if the connection between the DCS and the INCA PC is disrupted.

3.2 INCA MPC project phases

The implementation of an INCA MPC system involves several project phases. After a site visit it is decided whether base layer controls have to be optimized before he actual MPC project can start.
Good performance of the base layer control is a prerequisite for a MPC implementation since the MPC controller will be implemented on top of this base layer control. Base layer control optimization includes optimal tuning of PID controllers and PID control structure redesign at the DCS level.

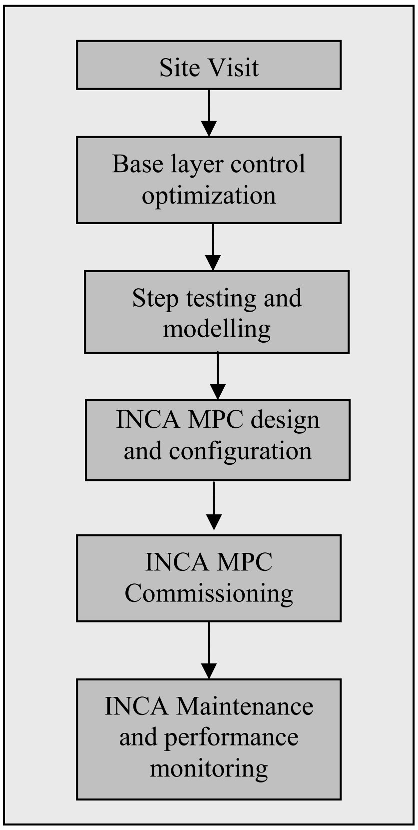

Figure 2: APC project structure

After the base layer optimization step, the IPCOS and Yara engineers elaborate the general model structure and a step test plan. The step tests on the plant are required to identify the correct relationships between the MV's and the CV's and thus to construct the model. These tests are performed in close cooperation with the plant operations staff and they are designed to be non-intrusive to the process. This means safety and product quality are ensured at all times.

After the testing, the IPCOS engineers elaborate the MPC model. The INCA MPC controller is designed and configured in a simulation environment. Different scenario's can be simulated to verify the correct behaviour of the controller in these different situations.

In the next step the INCA MPC controller is connected to the DCS. Before the commissioning of the INCA MPC controller starts, all the fallback logic implemented on the DCS are carefully tested to assure safe and correct operation of the INCA MPC controller. Subsequently the INCA MPC controller is set to control step by step. During this phase the MPC controller requires some tuning as well.

The controller performance is evaluated during the next weeks. During this evaluation period additional fine tuning is performed as well.

4 INCA implementation for urea Yara Brunsbüttel

4.1 INCA MPC objectives

The urea plant at Yara Brunsbüttel in Germany is one of the largest of the Yara group.

The objectives for the INCA MPC controller were defined in close cooperation with the plant operations staff:

- Increase overall plant stability: due to the typical complexity (high degree of interactions and recycles) of a urea plant, the INCA controller is the perfect tool to reach the optimal, stable operating point in a straightforward way.
- Maximize throughput: once the desired stability is reached, the INCA controller will be used to smoothly maximize the CO2 flow (MV1) without violating any of the CV constraints. A typical constraint can be the maximum pressure of the reactor or cooling water temperature at the inlet of the absorber.
- Increase yield: by increasing the yield in the high pressure reaction section, less recycle of unconverted carbamate will be required which will result in minimization the energy consumption.

- Optimally switch operating points: at the Yara Brunsbüttel site, the CO_2 is fed to the reactor by means of two compressors that operate in parallel. On average the compressors require maintenance once a month. Therefore approximately every two weeks one of the two CO_2 compressors is shut down for maintenance. This will cause the plant to work at 50% of the standard load. Once the maintenance is performed the plant has to be ramped up from the 50% load conditions to 100% load again. When performed by the operator this ramp up from 50% to 100% is performed very slow in order to avoid process disturbances. This slow ramping up by the operator however implies production loss. The last objective defined for the INCA MPC controller was to speed up this ramp up without disturbing the plant in order to minimize the production losses of operating at loads lower then 100%.

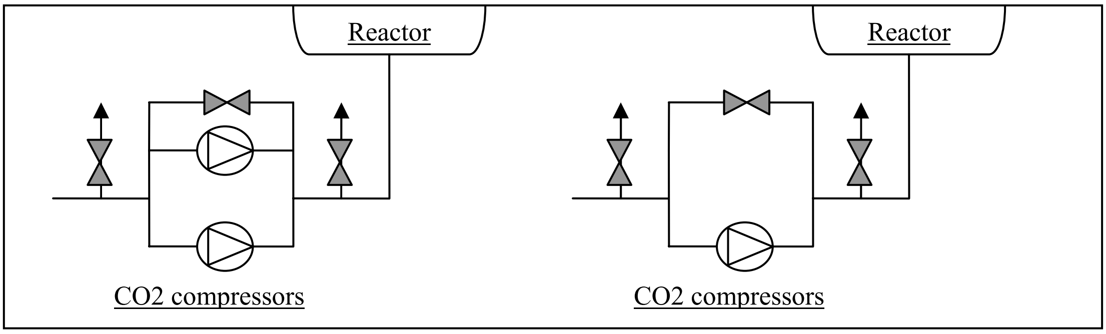

Figure 3: CO2 compressors at 100% load (left) and at 50% load (right)

4.2 Project execution

Before the actual APC project, the IPCOS engineers studied the plant and made some base layer optimizations necessary for the INCA implementation.
In the urea plant in Brunsbüttel ratio controllers were implemented to keep the NH_3 and carbamate flows in ratio with the CO_2 feed flow. Furthermore temperature control was introduced in the stripper and mass balance throughout the complete plant was maintained by introducing additional level PID controllers.
This initial base layer control optimization already increased the stability of the plant significantly.
The plant was now found ready for APC and subsequently, the control model framework was developed in close cooperation with the Yara Brunsbüttel operations staff.
The list of selected MV's, CV's and DV's can be found in figure 1. Because of the high degree of interactions in the plant, whole parts of the plant needed to be incorporated into the model. Emphasis was put on the high pressure part of the plant but the medium pressure, low pressure and evaporation part of the plant were added to incorporate these constraints when the INCA MPC controller start to push the plant towards more optimal working points.
Subsequently non-intrusive step testing was performed in close cooperation with the operations staff and the model input/output relations were identified. The main part of the step testing was performed in less than 1 week.
Subsequently the controller configuration and tuning were performed by the IPCOS engineers in simulation environment to test different scenarios.
In parallel the fallback logics and at the DCS and operator interfaces were prepared and tested carefully. The INCA MPC controller was set to control step by step and tuning was performed. Due to the careful preparation and good cooperation with the Yara Brunsbüttel staff the INCA MPC controller was commissioned in approximately 1 week time. During this week of commissioning the operators received hands-on training in how to use the INCA controller.
Via a remote connection between the IPCOS offices and the Yara Brunsbüttel plant, the performance of the controller was monitored during the weeks after the commissioning and fine tuning applied where required.
Six weeks after the commissioning the project was finalized with a kick down meeting in Brunsbüttel.

5 Results

5.1 Increase plant stability

After installation of the INCA MPC system, the stability of the whole plant increased substantially. A good example is the High Pressure separator level (CV4). Without the INCA MPC controller it was very hard to control due to very sudden changes in the level that required many manual interventions of the operators. It is however very important that this level is kept low enough to avoid high level alarm triggering a plant shutdown

for safety reasons. Rise of the corrosive carbamate in this vessel might damage the downstream subunits connected to the top of this High Pressure Vessel.
When INCA was switched on, the level could be controlled very well within the defined zone, as can be seen in figure 4.

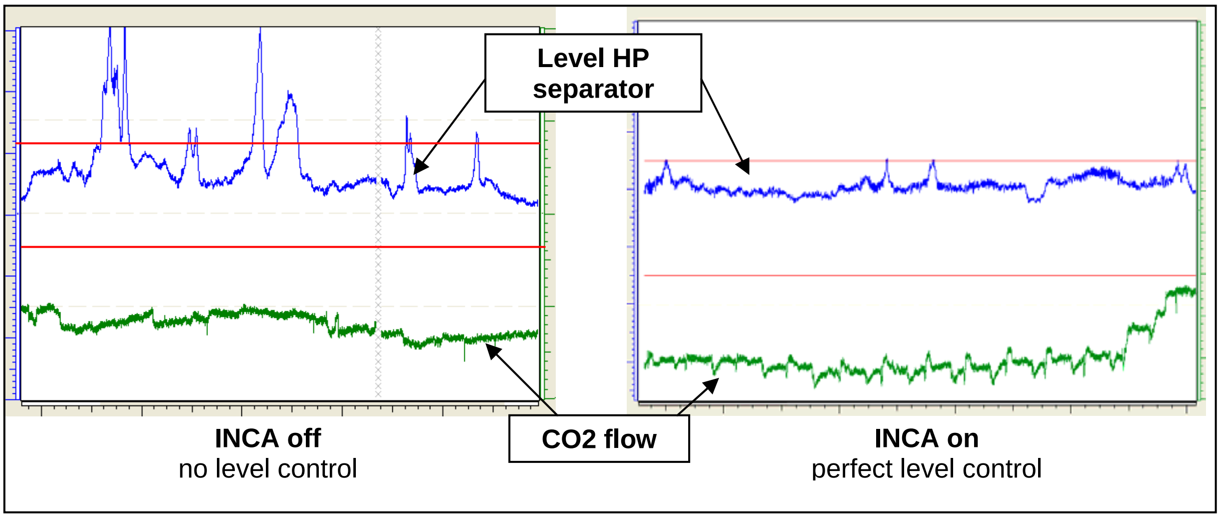

Figure 4: HP separator level with INCA turned off (l) and INCA turned on (r)

5.2 Maximize throughput

The INCA controller maximizes the throughput. This is mainly done by increasing the CO_2 flow until one or more of the constraints are hit. In figure 5, this throughput maximization is illustrated.
Initially the cooling water constraint (CV12) is kept at its lower limit and the INCA MPC controller can not increase the CO_2 flow (MV1) any further. When the cooling constraint is released after a couple of hours, the INCA controller automatically increases the CO_2 flow smoothly until another constraint is hit. In this way, maximum CO_2 flow is guaranteed continuously without upsetting the plant and taking into account all constraints.

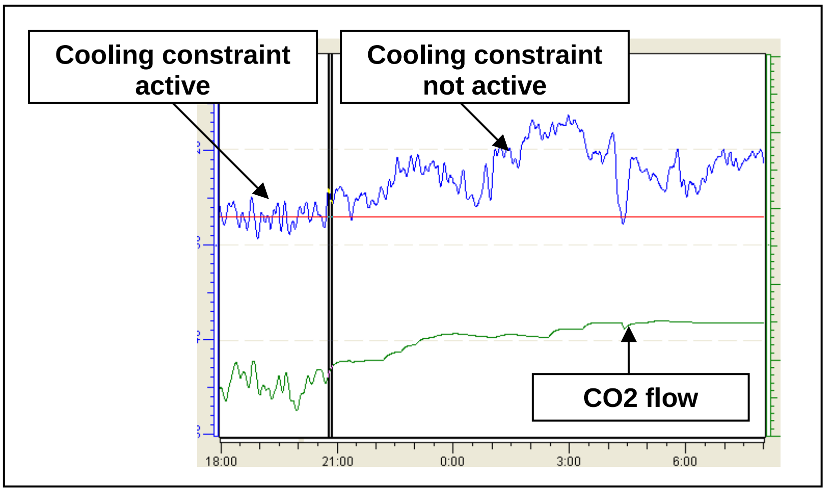

Figure 5: Maximizing throughput until a constraint is active

5.3 Increased yield

Several strategies are implemented in the INCA controller to increase the yield of the plant. The most actively used strategy to increase the yield in the reactor is to maximize the reactor pressure (CV1). The main MV to influence the reactor pressure is the reactor outlet valve (MV5). An example how INCA can increase the reactor yield is shown in figure 6. INCA always pushes the reactor pressure against its upper boundary. When the operator/engineer decides that this boundary may be set higher, INCA will push the process against this new boundary. An increase in pressure increases the yield and as a result decreases the steam consumption per ton CO2 in the steam stripper.

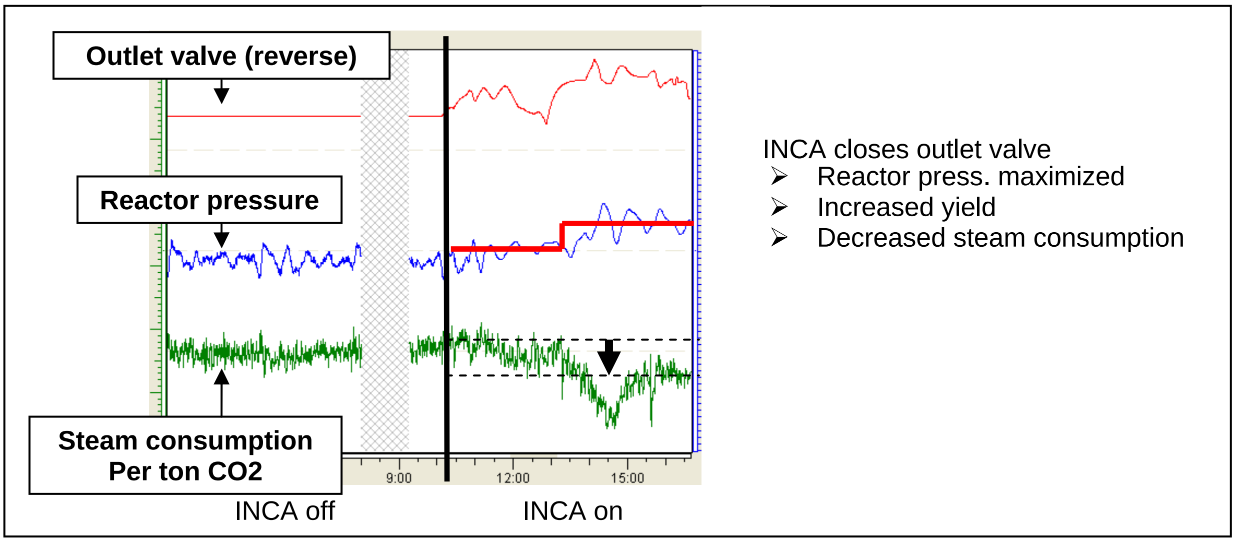

Figure 6: Increased yield by turning on INCA. Closing the outlet valve causes the reactor pressure and the yield to increase.

5.4 *Optimally switch from 50% load to 100% load*

Prior to the installation of the INCA system, switching between the 50% load and 100% load was a complicated operation that required a lot of manual interactions of the operator at the panel and in the field. Often upsets were introduced during this ramping up due to incorrect changes applied by the operator. Therefore the ramp up was performed slow and conservatively resulting in a lot of hours production losses.

The INCA controller can however perform these ramp ups in a very smooth way and upset free way. This is due to the fact that the INCA can predict what the fastest allowable ramp up is that can be applied to the process taking into account all the constraints. If one or more constraints are hit, the INCA controller will slow down or stop ramping to avoid violation of the constraints. Once the constraint is not active anymore the ramp up continues or speeds up again.

This way, the controller has the power to make the ramp-up fast with and with a guaranteed stability. The operator only has to push the start button of the ramping and from then he can focus on optimizing other parts of the plant that would have been neglected when a manual ramp up was performed. In this way ramp time reduction up to 50% can be achieved with the INCA controller.

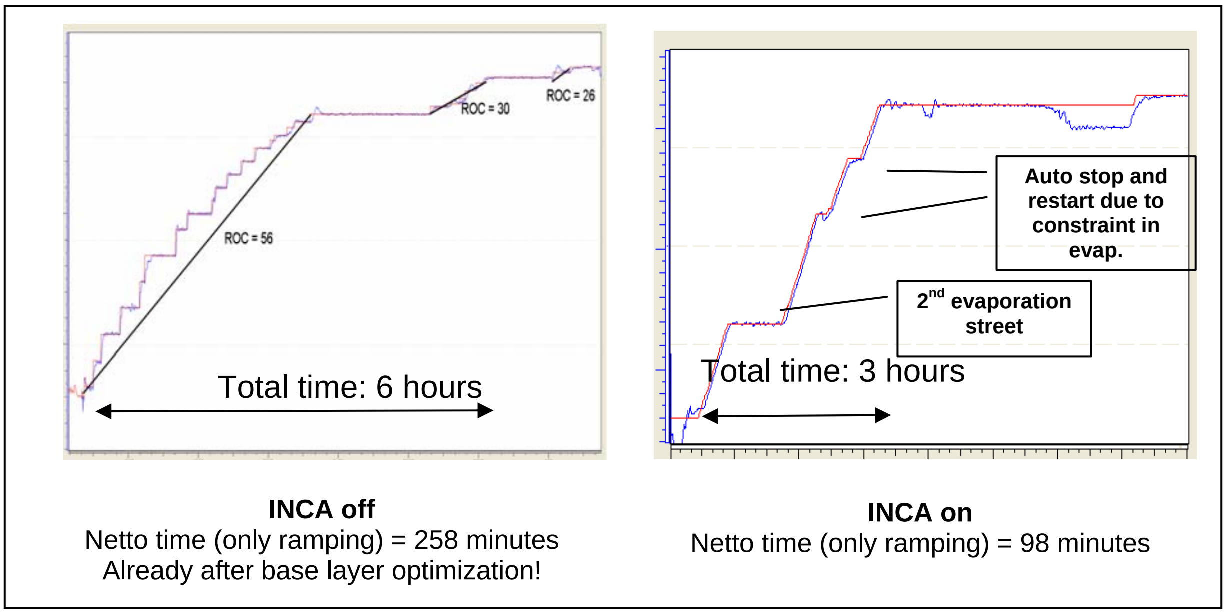

Figure 7: Ramping of CO2 flow from 50% to 100% load with INCA turned off (l) and INCA turned on (r)

6 Conclusion

INCA, the MPC system of IPCOS, on the urea plant of Yara, Brunsbüttel has been implemented in a straight-forward way. First, the base layer was optimized by the IPCOS engineers and Yara operations staff. Later on, only non-intrusive step testing was necessary for the design of the INCA controller. Applying the MPC controller has proven several benefits. The whole plant is shown to be more stable, the throughput is maximized and the yield has increased. Also, the switching time from 50% load to 100% load has decreased over 50% and occurs in a more stable way.