Slovak University of Technology in Bratislava
Institute of Information Engineering, Automation, and Mathematics

PROCEEDINGS

17$^{\mathrm{th}}$ International Conference on Process Control 2009
Hotel Baník, Štrbské Pleso, Slovakia, June 9 – 12, 2009
ISBN 978-80-227-3081-5
http://www.kirp.chtf.stuba.sk/pc09

Editors: M. Fikar and M. Kvasnica

Georgiev, B.: Practical Aspects of Boiler Performance Optimization, Editors: Fikar, M., Kvasnica, M., In *Proceedings of the 17th International Conference on Process Control '09*, Štrbské Pleso, Slovakia, 114–118, 2009.

Full paper online: http://www.kirp.chtf.stuba.sk/pc09/data/abstracts/107.html

PRACTICAL ASPECTS OF BOILER PERFORMANCE OPTIMIZATION

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Abstract: This paper discuss some practical aspects of implementing Model Predictive Control project in real plant. First part presents in brief the background of application of model predictive control and linear programming optimizer of multiple boilers load in boiler house with general description of requirements and expectations. This introduction to real plant problems is followed by model predictive control project life cycle description. Next chapter contains selected topics which are not directly related to the control algorithms but are crucial factors of project success. Overview of possibilities of Connoisseur follows as an example of the commercial tool which supports main part of the project life cycle and is able to perform model predictive control and linear programming optimization tasks in real process environment. Last chapter describes possibilities of external tool integration with basic process control system.

Keywords: industrial application, MPC, LP, boiler load optimization, Connoisseur.

1 INTRODUCTION

Every owner of the production unit expects its stable operation with maximum performance, minimal costs and flexibility to react to changing conditions in real-time. Regarding control point of view he has very often to treat with dead times, long process response times, MIMO systems with interactions, measurements with low scan rates (e. g. analyzers), changing process constraints and costs of raw materials and energy. To reach above mentioned expectations the conventional / basic control strategies are often not enough and more complex and relatively complicated approaches e. g. Model Predictive Control (MPC) must be used. Those approaches also called as advanced control has evolved during years and are successfully implemented over the world.

In present every vendor of Basic Process Control Systems (BPCS) has its own solution to perform MPC, Linear Programming (LP) optimization task, fuzzy logic controllers etc. While this tools are for wide range use, the theory behind is usually more or less hidden to the process engineers. Therefore the level of user friendly interface, ease of integration with existing BPCS and rich support functions are features which matter.

The topic of these days is not “How to make MPC work” but “How to execute MPC project effectively”.

Topics mentioned in this paper are partially related to the ongoing project on which our engineering office is participating as well as general issues which usually appear in every project of this kind.

2 REAL PLANT ENVIRONMENT AND GOALS

Our project was situated in the boiler house in refinery which produces steam for power generation and supplied the steam distribution system for other production units. Boiler house consisted from several boilers supplying common header with different steam power, different efficiency and different emissions caused by different age of boilers and burning of different type of fuels (heavy oil, refinery gas and natural gas).

Customer’s main concerns were to produce enough steam at lowest possible costs and follow emissions limits monitored by legal authority.

Amount of required steam changed with the changing requirements of power generation unit, weather and requirements from refinery. Also the type of fuel was connected to the situation in refinery while the requirement to burn the refinery gas (the side product) was defined by factory's dispatcher according to present situation which negatively influenced the emissions therefore more expensive natural gas had to be burnt to decrease emissions below limits. The load of boilers changed also during periodic turnarounds of each boiler during the year or during unexpected shutdowns.

Above mentioned differences of boilers resulted to different control strategies of each boiler. At the top of BPCS control strategies was the common header pressure controller controlling the output steam pressure from header with the load of all boilers. The principal scheme of original boiler control is shown in Figure 1.

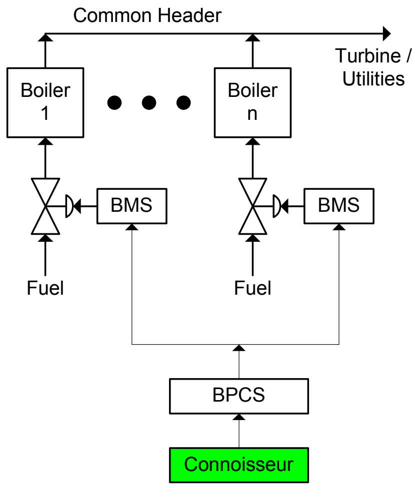

Fig. 1. Boiler load control diagram (BMS – Burner Management System)

Header pressure control loop is SISO system therefore the desired load (manipulated variable in %) was same for each boiler which was not the optimal situation.

The main goal of the project was to perform the real time optimization to distribute desired load of boiler house to each boiler according to its actual efficiency and process constraints to gain the best price for GJ of energy in produced steam.

According to described character of process the tool which combines MPC and LP optimization was selected. Expected outputs of project are shown in Figure 2. MPC should stabilize important operational indicators, while the LP optimizer should move the process to the steady state resulting in optimal efficiency while taking into account changing constraints.

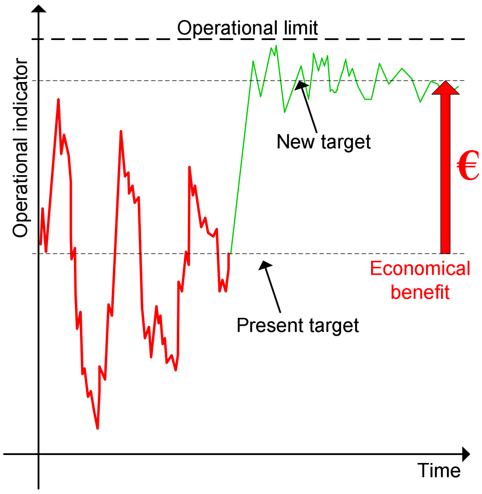

Fig. 2. Economical result of MPC and LP Optimizer

"The average process engineer can make from process value a line, while the good engineer can move the process / the line closer to the operational limits achieving higher efficiency."

3 PROJECT LIFE-CYCLE

Typical phases of project which is solely focused on implementation of MPC and optimization are:

1. Introductory study of potential benefits.
2. Negotiation of agreement.
3. Data acquisition from normal plant operation (for future comparison).
4. Realization phase of project.
5. Data acquisition from normal plant operation for declaration of achieved benefits.
6. Support of application during its service.

During the introductory study the existing state of process is evaluated to analyze the potential impact of improvements on economical efficiency of plant operation. Usually more potential improvements with different impacts are found. Selection which of them will be used depends on customer preferences. Outputs of this phase also help to make realistic claims in future negotiation phase.

The most important part of agreement is about promised benefit to the customer. What benefit will be achieved, under what circumstances i.e. the process operational area and conditions and how will be the benefit measured. This must be absolutely clear from the very beginning while usually the financial side of project is strictly connected to achieved benefits. Therefore the data acquisition phases before and after the project is very important. In the sake of objectivity they should be performed by third independent party.

The own realization phase of project is in Figure 3 further decomposed on individual tasks. Presented sequence of steps is generally always the same but they can vary e. g. according to the possibilities of used tool. The critical phase is the Process Response Testing. Conditions under which the process will be tested must be agreed in contract while it's a point of two contradictory requirements. Process testing is done during normal operation of the plant. To get rich data for modeling we need to upset the process to see the response and to test the plant close to its operational limits where it's planned to be operated to achieve optimal results. But operational stuff strives for stable operation and far away from process limits while these limits are close to emergency shutdown limits.

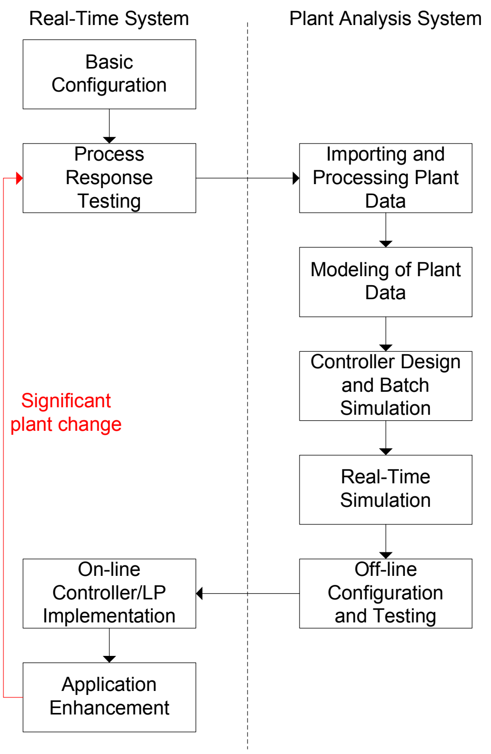

Fig. 3. Realization phase decomposition

Trying to test the plant close to its limits can lead to unveiling plant problems which didn't appear before. This influences the project time schedule or what can be worse the final operational area. Process response testing phase must be carefully prepared, carefully performed and carefully documented. Quality of process response testing impacts the quality of modeling phase and the quality of control depends on how precise is the model of the plant.

Modeling and control design are main engineering phases of the project. They are supported by the tool e. g. with the simulation environment to test the control before the implementation phase. To check if the reactions of controller on changing process values, constraints, cost factors are in concert with requirements.

During the implementation phase the MPC controller is put step by step into operation to test its function, to make adjustment of settings, logic rules behind and to test the whole function. This phase is also important to make operational staff be informed how to operate the advanced control system. If operators don't understand how it works and what its function is, the MPC will be turned off very often by them. After implementation the period of operation starts during which the benefits achieved should be monitored and confirmed.

The important fact is that benefits achievement analysis is usually end of project for supplier but it's the beginning of the MPC system life. To maintain achieving benefits the application enhancement analysis must be performed after each significant change in process. What is significant can vary from changing PID parameters of BPCS, thru control valve dimension change to adding new units within the plant. If plant changes have significant impact on quality of MPC operation, the whole or part of the realization phase should be performed again to reflect changes of process into changes of MPC.

If there is no life-cycle support it can happen that after some time and some changes in process the MPC is turned off by operators because of making problems instead of helping to solve them and forgotten.

4 TYPICAL PROJECT OBSTACLES

Some topics which can appear during the MPC project are listed below. They are not directly related to control theory but can have significant impact on the project success and has to be considered before the process response testing:

1. Condition of the plant.
   Mechanical condition of process equipment influences the whole life cycle of MPC system.
2. Condition of field devices.
   Measuring and actuation field devices have great impact on quality of control. Before process response testing phase all important field devices should be checked if they are in good condition.
3. Philosophy of existing control strategies.
   Existing control strategies diagrams of BPCS should be analyzed to decide how the plant is controlled, which control functions will remain and where will be the MPC system connected to.
4. Quality of control loops tuning.
   Loop quality of remaining control loops should be

checked and controllers should be tuned if needed.

5. Operational staff awareness of MPC and LP optimizer function.
Operators must be properly trained to understand the functions of MPC and optimizer and its integration to BPCS.
6. Local process engineer involvement in MPC project.
Process engineers from plant should be involved in whole life-cycle while their know-how can be used in developing phase as well as application enhancement phase later on.
7. Update of manually inserted data.
If the MPC system requires data which are going to be inserted manually e. g. prices of fuels, emissions limits, customer must guarantee that such critical data are really updated.

5 FUNDAMENTALS OF CONNOISSEUR

Our Boiler load optimization project is based on the Invensys Process Systems SimSci-Esscor's Connoisseur tool which is the member of the company's On-Line Performance Suite. Its principal hierarchy is depicted in Figure 4.

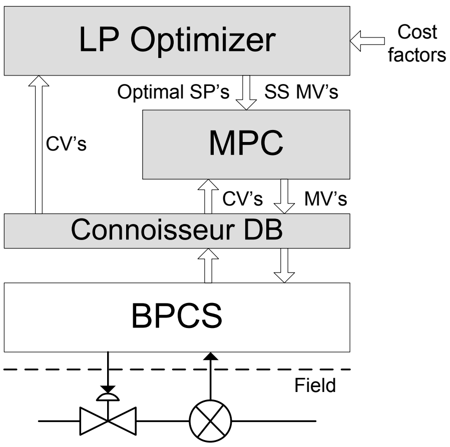

Fig. 4. Decomposition of Connoisseur structure

From the bottom the Connoisseur DB represents the interface between BPCS and Connoisseur. Process signals (measuring and actuation) are configured in database and provided to main functions of Connoisseur. Subset of measuring signals is configured as CV's – controlled variables which represents inputs to the MPC and MV's – manipulated variables representing outputs of MPC i. e. inputs to the BPCS control strategies. The BPCS in Boiler house is Foxboro I/A also from Invensys Process Systems.

Requirements on MPC are represented by quadratic cost function J which has the form:

$$J = \sum_{i=1}^{M} \left[\underline{e}_{i+1}^T P \underline{e}_{i+1} + \Delta \underline{u}_i^T Q \Delta \underline{u}_i + \underline{f}_i^T R \underline{f}_i \right] \qquad (1)$$

Where:

M is a length of design horizon,

$\underline{e}_j$ is a vector containing all of CV errors from setpoints (SP) at stage j,

$\Delta\underline{u}_j$ is a vector containing all of MV incremental moves at stage j,

$\underline{f}_j$ is a vector containing all of MV deviations from steady-state (SS) targets at stage j,

P, Q, R are diagonal matrices containing weighting values for each CV and MV.

When constraints are not considered the minimization of quadratic cost function has fixed-gain control algorithm solution. For control under constrained conditions the Connoisseur offers three methods for the solution of a constrained control problem: Long Range (LR) method, Quadratic Programming (QP) method and combined LR + QP method.

While constraint controller has no means how to determine optimal values for CV setpoints and MV stead state targets, these must be set externally. The main part of our Boiler optimization project is therefore focused on LP optimizer as an external source of those values to maximize the profit while respecting process constraints. The general form of profit function is:

$$J = \sum_{i=1}^{M} \underline{y}_i a_i + \sum_{j=1}^{N} \underline{u}_j b_j \qquad (2)$$

Where:

$\underline{y}_i$ is a vector of process CV's

$\underline{u}_j$ is a vector of process MV's

a_i, b_j are costs assigned to each CV and MV

M, N are numbers CV's and MV's

Our profit function contains all important factors influencing monitored operational indicators important in our project i. e. which influence the cost of steam generation.

6 INTEGRATION WITH BPCS

Important part of MPC project is the integration of MPC system with the BPCS. There are different types of integration needed to provide:

1. Configuration data extraction from BPCS and import to MPC system.
Tag name, range and engineering unit of process signals which are later used for configuring MPC database.

2. Real-time process data communication between MPC system and BPCS and its synchronization.
   Synchronization is important to provide bumpless initialization and transfer after the restart of MPC system or reestablished communication.
3. Human-machine interface (HMI) to the MPC system for plant operators.

The real-time data communication and synchronization can be done in two ways:

1. Existing BPCS supports control blocks performing advanced control functions executed directly in control processors.
   In this case no special means of integration, synchronization and HMI is needed. Disadvantage is support of only basic functions of advanced control and the need of additional tool to configure those control blocks.
2. Advanced control system is delivered as an external application running on separate PC type application station networked with the BPCS.

In the second case which is also relevant to the Connoisseur tool, the whole application runs outside the BPCS and all integration, synchronization and HMI have to be done. According to supporting features of BPCS this can be more or less time consuming part of the project. On the other hand such solution can offer rich functions and tools supporting whole lifecycle of MPC system. This scenario is shown in Figure 5.

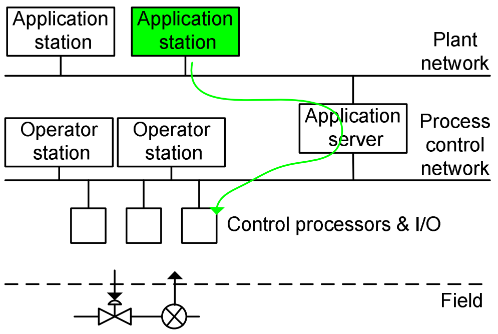

Fig. 5. Integration with BPCS on system level

The station with Connoisseur is on the Plant network level connected to the Process control network over Application server in role of gateway. This connection serves as communication channel to exchange data between Connoisseur and BPCS in real-time.

Thanks to the fact that MPC system and BPCS in our project are from the same supplier (both SimSci-Esscor and Foxboro belong to the Invensys Process Systems) above mentioned integration is easily done by semi-automatic process using Connoisseur Integration Tools.

Figure 6 shows the principles of MPC system and BPCS integration on the level of control blocks.

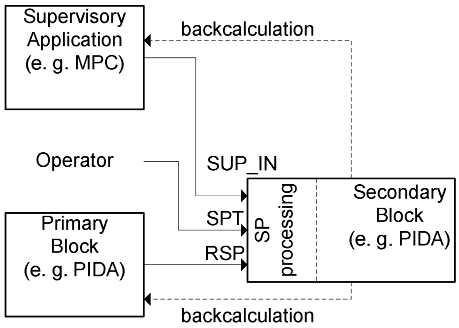

Fig. 6. Integration on control blocks level

The source of control block's (e. g. PID block) setpoint in I/A system can be the operator, upstream block in case of cascade control and the supervisory input in our case connected to MPC application. Synchronization of control blocks or control block and supervisory application is done by backcalculation functions of I/A control blocks. This is another crucial function for stable operation of the system.

8 CONCLUSION

Model Predictive Control is widely used member of the advanced control family in technical praxis. Beside the theoretical background also the practical aspects of implementing such technology are important. This article has presented only brief overview of issues which can substantially influence the timeline of the project and its result i.e. benefits to customer. Successful implementation of MPC project is therefore based on cooperation of different professions / experts on control systems, plant technology, field instrumentation and asset management.