Advanced process control of boiler installation

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Abstract. In production processes, it is important find solutions to improve economic performance. This is especially topical for energy facilities, such as boiler plants. These problems are complex in nature and require solutions in the field of technology, apparatus designs, modes and algorithms of equipment operation. If it is required to improve the performance of an operating object without significant changes in the design of the apparatus, then often the solutions lie in the plane of the work algorithms. Thus, modernization of the object's automatic control system using a programmable logic controller and a control program will optimize processes without significant investments. In this regard, one of the rational and effective solutions for modernizing the automatic control system can be the use of predictive models. Predictive model control has excellent adaptability, although it uses a relatively simple control scheme. Such a system is a superstructure over an existing automatic control system. This paper proposes a method for implementing control with predictive models by using a virtual analyzer interfaced with a controller. This makes it possible to take into account and correct many disturbances in the control system of the boiler plant, which favourably affects the stability of the process and economic indicators.

1. Introduction
Advanced process control (APC) is an integrated approach and covers many possible automation solutions. In APC system employs model-based software. Such software is used for process control and is commonly referred to as multivariable predictive control or model-based predictive control. It is important that the model-based software algorithms accurately reflect the dynamics of the process. The need for the development of these software products is explained by the constant search for improved economic and production indicators of the technological process [1].

Model Predictive Control (MPC) - control with predictive models. This is one of the formalized approaches to the analysis of control systems based on mathematical optimization methods [2].

The scope of application MPC methods has expanded significantly, covering a variety of technological processes in the petrochemical industry.

The main advantage of MPC is the positive feedbacks on the practical application of such systems in industry. The peculiarities of the control system consist in a relatively simple basic scheme for generating feedback in the presence of high adaptive properties, in contrast to the known adaptive control systems [3-5]. The predictive model allows you to optimize processes in real time within the constraints on control and controlled variables, to take into account uncertainties in specifying objects and disturbances [6].
The purpose of creating advanced process control for a boiler plant is to stabilize the operating mode and improve the economic performance of the plant, subject to technological limitations and specifications [7]. The APC is created as a superstructure over the existing automation system of this installation and should cover the following processes:

- hot water circulation;
- combustion of fuel gas;
- combustion air and flue gas;
- fuel gas supply.

2. Development of a regulator using the MPC algorithm in Matlab

MPC is a multi-variable control algorithm that uses:

- internal dynamic model of the process;
- history of past control movements;
- objective function $J$ for optimization based on the predicted control error.

An example of a nonlinear objective function for optimization with a constrained control value:

$$ J = \sum_{i=1}^{N} x_i \left( r_i - x_i \right)^2 + \sum_{i=1}^{N} w_{ui} \Delta u_i^2 $$

where $x_i$ is the controlled variable;
$r_i$ is the required value;
$u_i$ is control variable;
$w_{xi}$ is a weighting factor reflecting the relative importance of $x_i$;
$w_{ui}$ is a weighting factor penalizing relatively large changes in $u_i$.

Construction of an MPC regulator based on the control of an object with one input and one output. This system shows how to manage a plant with two integrators in Simulink. A dual integrator is a complex subject to regulate. The PID regulator will not cope with it, requiring additional blocks that will correct the system [8].

The determination of the boiler plant model is carry out. The open loop linear dynamic model is a double integrator. Next, the MPC controller is being developed. Creation of a controller object with a sampling period $T_s = 0.1$, prediction $p = 10$, and control horizons $m = 3$. Numerical constraints for MV control actions are set.

```
plant=tf(1,[1 0 0]);
Ts=1;
p=10;
m=3;
mpcobj=mpc(plant, Ts, p, m);
mpcobj.MV=struc('Min',-1,'Max',1);
if~mpcchecktoolboxinstalled('simulink')
disp('Simulink(R) is required to run this example.')
Return
End
mdl='mpc_doubleint';
open_system(mdl);
sim(mdl);
bdclose(mdl).
```

The resulting model is shown in figure 1, where the MPC regulator block accepts the currently measured output signal (mo) and the reference signal (ref). The block calculates the optimal controlled
variables (mv) by solving a quadratic programming problem using a solver. Figure 1 shows the control action of the MPC block.

![Figure 1. MPC regulator with one input and one output.](image)

The operability check is carried out according to the transient response (figure 2). This system is workable.

The overshoot of the transient response (figure 3) is 10%.

Overshoot is the maximum deviation of the controlled value from the steady-state value. The stability margin is considered sufficient if the overshoot is within 10-30% of the steady-state value.

![Figure 2. Control action of the MPC regulator.](image)  ![Figure 3. The result of the algorithm.](image)

3. **Main algorithmic solutions**

   At the input of the developed model of the regulator on terms of quality indicators in Matlab Simulink, it is required to feed quality indicators from a virtual analyzer and combine it with the CENTUM CS3000 control system using the OPC mechanism.

   The virtual analyzer can be implemented as follows (figure 4). The virtual analyzer is designed to evaluate not directly measurable, but the necessary indicators of product quality by process parameters. The parameters can be attributed temperature, pressure and flow.
To connect the developed regulator model in Matlab Simulink with CENTUM CS3000, the OPC mechanism is used.

OPC (OLE for Process Control) is a set of accepted specifications that provide a universal mechanism for data exchange in a control and management system. This mechanism links and injects an object to control the process.

The technologies for implementing and linking objects for OPC systems are designed to provide a universal mechanism for data exchange between actuators, sensors, controllers, communication devices with an object and systems for presenting technological information, operational dispatch control, as well as database management systems.

To implement the MatLab data exchange with the CENTUM CS3000, the OPC Toolbox of Simulink package is used, which is shown in figure 5.

Figure 6 shows the OPC Configuration, OPC Read, and OPC Write blocks.

The OPC Configuration block is designed to configure communication with the OPC server. This block allows you to select one of the servers operating in the local network, as well as configure the data transfer parameters.

The OPC Read and OPC Write blocks are designed to receive and send data to the server.
4. Summary
The main economic effect from the introduction of the APC at the boiler plant will be from an increase in thermal performance by improving heat transfer inside the boiler. The introduction of such systems shows that the use of the APC in the processes of the boiler plant increases the efficiency and the heat output of the boiler.

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