USING CLOSED-LOOP DYNAMIC OPTIMIZATION TO IMPROVE BOILER EFFICIENCY AT CHEMOPETROL'S LITVINOV PLANT

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ABSTRACT

Due to ever increasing demands by shareholders, environmental and governmental agencies, and customers, power generation and co-generating companies are looking more and more into advanced technologies to help them gain an edge on their competitors. Intelligent empirical optimization is a promising family of technologies to "tune" boilers for maximum efficiency and/or minimum emissions.

A recent project teamed the Ultramax Corporation and Honeywell to install an on-line, closed-loop optimization solution on four new boilers at the Chemopetrol plant in Litvinov, Czech Republic. Honeywell has created an engineered solution called Individual Boiler Optimization (IBO) which utilizes the Ultramax Method and Dynamic Optimization, known as ULTRAMAX®, to optimize combustion of the boilers which are controlled by Honeywell's **TotalPlant** Solutions (TPS) System. IBO provides a real-time shell providing for automatic Ultramax operation in either open or closed-loop.

With this system, Chemopetrol will be able to improve their boiler efficiency and NO_x emissions on-line with little operator intervention. It can safely maintain best operating settings and compensate for changes that could potentially cause poor performance. The integrated dynamic solution enables greater emissions control, fuel savings, and the ability to respond rapidly and flexibly to changes in operating conditions, compliance regulations and plant demands.

BACKGROUND

Chemopetrol's coal gasification facility in Litvinov, Czech Republic, was originally commissioned in 1942 to support the German war machine and has gone through many owners in the last 50 years. Recently, it was privatized and the new owners have launched an aggressive program to reestablish itself and the Czech Republic at the forefront of the international petrochemical industry. To improve the manufacturing capacity and efficiency, they have bought and are installing eight (8) ABB corner-fired boilers to replace the original boilers that were 25 years old. These boilers supply steam to 5 steam turbine generators, the manufacturing process for heating and drives, and other utility functions (Figure 1). Not only does Chemopetrol expect these new boilers to save them a significant amount of money due to increased boiler efficiency, they expect them to burn the lignite fuel more cleanly, maintaining strict new national pollution limits. By being a better environmental neighbor, they will provide the people in the Litvinov area a more clean and healthy environment in which to live.

To control these new boilers, Chemopetrol has purchased Honeywell's state-of-the-art distributed control system, the **TotalPlant** Solution (TPS) System (Figure 2). This system provides all the measurements and controls for the utility area and integrates the various subsystems and applications around the utility area into one system with single-station viewing. TPS nodes have both process network and plant network integration capability, providing incredible potential for coordinated and intelligent applications.

To provide optimal operation of these new boilers, Chemopetrol has purchased three of Honeywell's state-of-the-art advanced application solutions which reside on the TPS nodes: Advanced Boiler Control utilizing Honeywell's Rate Optimal Control (ROC), Economic Load Allocation with Honeywell's Turbo-Economic Load Allocation, and Combustion Optimization with Honeywell's Individual Boiler Optimization (IBO) solution utilizing Ultramax Dynamic Optimization[1]. Advanced Boiler Control is layered on top of the regulatory control provided in the controllers of the TPS system; it improves the responsiveness and minimizes variances of the primary controlled variables for the boilers and steam production as a whole. Turbo-Economic Load Allocation adjusts relative boiler loading on a continuous basis to minimize overall cost of producing steam by exploiting the subtle differences in the boilers' efficiency curves. IBO interacts with the other two applications by inputting data from and outputting targets to Advanced Boiler Control, and by altering efficiency curve characterizations which affects Turbo-Economic Load Allocation's solution. IBO utilizes the Ultramax Method and Dynamic Optimization technology known as ULTRAMAX as its optimization engine. This suite of advanced control products will help Chemopetrol to further increase their boiler efficiency and reduce their emissions while maintaining plant responsiveness and stability. They also have the secondary benefit of aiding the quick identification of boiler equipment or control problems since they require everything to be functioning normally.

To affect the objective variables, adjustments were made to the O_2 setpoint, secondary air, and tertiary air, biasing the side-to-side and upper-lower splits. IBO compensated for mill orientation as well by maintaining and swapping in different model data sets which match the current orientation. Figure 3 shows a simplified boiler layout. In addition to the specific optimization objectives regarding boiler efficiency while maintaining NO_x, Chemopetrol required constraints be imposed on steam temperatures, CO, mill temperature and loading, and other operating parameters to ensure safe and productive operation. These constraints protected the turbine generators, avoided mill trips, and minimized a reducing atmosphere near the waterwalls. This ability to control strategic boiler parameters while maintaining operational constraints is an integral part of the Ultramax Method.

Establishing the objective function or variable, controlled variables (boiler inputs), and constrained resultants variables (boiler outputs) is called the "Game Plan" of the Ultramax Method. The final game plan for Chemopetrol is shown as Figure 4.

The ULTRAMAX software utilized by IBO has been used to successfully optimize over 85 boilers world wide. Its unique combination of Bayesian statistics and weighted non-linear regression analysis has been applied to wall, tangential[2], cyclone[3], turbo, and cell types of boilers, fired with coal, gas[4], oil[5], and fuel blends[6]. It has often been applied stand-alone to problematic boilers to determine their true potential for NO_x reduction[7] and efficiency improvement. It has been effective in improving performance and reducing ammonia slip on an SNCR unit[8]. Ultramax Corporation, the inventors of the ULTRAMAX software, has installed fully integrated on-line Operator Advisory Systems for Illinois Power, GPU, Colorado Springs, and Allegheny Power in the United States.

WHY IBO AND DYNAMIC OPTIMIZATION

By implementing optimization technology on-line, Chemopetrol's goal is to continually minimize steam production costs and improve its profit margin. Through application of IBO and Dynamic Optimization, Chemopetrol expects to be able to improve boiler efficiency, thereby lowering fuel consumption costs and greenhouse gas emissions.

Implementing Dynamic Optimization as an integrated on-line solution assists the operator by automatically reacting when conditions change, and automatically handling data collection and updating of models. This continuous use of an integrated solution maximizes overall emissions control, fuel savings, and the ability to respond rapidly and flexibly to changes in operating conditions, compliance regulations, and the market environment.

DYNAMIC OPTIMIZATION AND BAYESIAN MODELS

ULTRAMAX Dynamic Optimization technology consists of a disciplined approach for solution analysis in addition to computer software. It builds on existing boiler system knowledge, models the process, and guides the operator through a sequence of control parameter adjustments to achieve improved levels of performance while staying within predetermined operations constraints. It is utilized during normal operations and can be applied to boiler systems of virtually any manufacture, type, and size, and burning any kind of fuel. In addition to integration with a DCS to provide an on-line operator advisory capability, it can also be implemented closed-loop and used stand-alone if existing controls do not accommodate integration. While the focus of this paper is on boiler optimization, ULTRAMAX can be applied to any process for which adjustments can be made to control settings and their resultant effects measured.

ULTRAMAX can be applied in three modes: on-line advisory, on-line closed-loop, and stand-alone. The stand-alone mode which is often used in the beginning stage of implementation, provides unique capabilities to quickly identify the most influential process parameters, achieve near optimal performance levels and confirm the validity of the models before integration with the control system.

Application of the technology begins with the Game Plan Formulation, in which the solution team sets the overall goal and particular objectives to be achieved. They define in specific terms the input and output variables, the measurement units, the beginning region over which adjustments will be made, and any constraints (as on steam temperatures, CO, or opacity levels) that must be met as limiting conditions of optimization. Constraints are used to impose limits having to do with safe operation, governmental regulations or improvement objectives. This information is used by the ULTRAMAX software as the structure for data entry, modeling, advice, and optimization. In addition, replicate runs are made of standard operating settings of input control parameters and their output results to establish the baseline operation of the boiler.

ULTRAMAX uses data acquired from the boiler unit at parameter settings under operator control. These settings, recommended by the software, take advantage of minor perturbations from standard settings in order to learn their effects on emissions and thermal performance. The software then immediately analyzes the data after each adjustment and measurement run to update nonlinear models and keep the boiler operating at optimal control combinations.

The critical element of the software is that it advises explicit control parameter settings for each run after detailed analysis of all data from previous runs. All selected control settings are purposefully and simultaneously adjusted; resultant performance effects are observed and models are updated reflecting the influence of all input parameters. New settings are advised for the next run, which is likely to obtain improved performance.

Because data analysis and model refinement occur after each run, settings that may lessen performance can be immediately identified and eliminated from consideration. This facilitates continuous improvement along a course toward optimum operations. This rapid optimization capability, unique to the ULTRAMAX software, is a result of the Bayesian statistics empirical modeling foundation on which the software is based. It makes ULTRAMAX suitable for ongoing use in on-line operating environments in closed-loop or advisory mode, unlike project-oriented testing procedures, such as parametric testing. The cause-and-effect relationships captured in the software's empirical models allow immediate, intelligent response to changes in uncontrolled variables, such as load, fuel quality, and seasonal temperature.

ADVANTAGES OF BAYESIAN MODELING

A common misperception about optimization is that by developing accurate models from historical data, the optimum will be contained within the range of that model. However, that is seldom true when dealing with complex processes. To discover improvements and move toward a region of optimal performance, a method must extrapolate to settings beyond the range of the historical data used to create the model. An effective solution must include both functions, optimization and modeling as represented in Figure 5.

ULTRAMAX Dynamic Optimization does not depend on historical data but instead directs the collection of data for model building that is packed with information. It begins to search for better control settings as well as begin model-building with the first set of data presented to it. Bayesian analysis and internal heuristics give its models the following special characteristics when compared with other empirical modeling methods such as neural networks:

1. They require no historical data to begin the optimization process. The models are built as optimization progresses eliminating a tedious "model training" period.
2. They provide guidance as to which direction to follow for improvements even with very sparse data. User supplied temporary boundaries limit software recommendations for early adjustments to low-risk operating ranges.
3. They extrapolate very well beginning with the first set of data and progressing to optimal adjustments. This is a unique capability of the Bayesian approach which enables "intelligent decisions" based on very little data.
4. The models are dynamic, not static. They adapt well to slow dynamic changes in process behavior due to unknown causes. They are refreshed and rebuilt automatically within minutes as new data are input to them, usually a daily operations procedure, so that the models always reflect the present condition of the boiler.
5. The models require no special expertise or retraining procedures to maintain and improve them.
6. They avoid fitting "noise" rather than the underlying process behavior. While excess noise, i.e., unexplained variation, is always a concern, the Bayesian models are much less sensitive to this weakness of neural network models.
7. Process models are built by the operators as a particular burner configuration or fuel change is encountered. No outside "experts" are needed and no special testing situations need to be established Plant staff are self-reliant in making changes to objectives and constraints that are immediately incorporated into the models.

Software menus allow models to be examined, parameter relationships displayed in two-dimensional and three-dimensional graphs, alternative approaches tested, and various analyses performed to enable engineers to learn the behavior and limits of their existing equipment. Optimization is a never-ending activity which combines equipment modifications and a deep understanding of how to extract the most from it.

INDIVIDUAL BOILER OPTIMIZATION OPERATION

IBO will provide for continuing optimization of all eight of the plant's boilers. Since the boilers being installed are similar in size and design, the configurable parameters in IBO and the operation are essentially the same, and we can therefore describe only one. However, this is not an IBO requirement. IBO software is always kept active and continually monitors key control system parameters which act as permissives to determine if a boiler is ready for optimization. IBO checks the configuration of the regulatory controls, its load, and whether or not it is at normal operation as defined by the customer. Figure 6 shows the main data display which presents the variables that are manipulated, their current value and the value that was advised by ULTRAMAX. IBO is configured to monitor steam flow, coal flow, number of mills in service, and an operator-set switch which indicates that advanced applications are allowed to operate. If any of these are at levels outside the limits, IBO will not allow on-line optimization control to be launched (it will allow a manual execution if required). Once IBO determines that minimum requirements have been met, it checks to see if an optimization run is demanded.

There are three primary triggers of an optimization run: maximum elapsed time since last run, significant change in key parameters since last run, and manual demand. Presently IBO will launch ULTRAMAX again if two (2) continuous hours (this is configurable) has elapsed since last run. It is trying to maintain the boiler at its peak efficiency and will "tune" it every two hours to ensure that the setpoints are at their best settings. This method is used to compensate for slow or undetected shifts and drifts in the boiler operation which is not sensed by the significant change parameters.

For the significant change trigger, IBO monitors the steam flow, boiler efficiency and primary air/fuel ratio. It looks at the difference between the current value and the value of the last advice cycle for each variable and compares it to a user-set limit. If there has been a significant change, IBO will launch the first of five (5) cycles back-to-back; this number is also configurable. As soon as the first cycle is completed, the second cycle will be started. IBO invokes ULTRAMAX to find the new optimum settings for the new boiler conditions as quickly as possible.

Once a demand has been detected, IBO checks to see if steady state exists on the boiler. Steady state is determined by monitoring the statistical variance of three key process variables: steam flow, fuel flow, and boiler stack O_2. Data samples are taken every minute and a running filtered variance is calculated. If the variance for any variable is greater than the user-set limit, then steady state is not achieved.

Once steady state is achieved, IBO begins collecting 1 minute snapshots of the designated input and output variables for ULTRAMAX. These input and output parameters are configurable. The number of data sets is also configurable, but for this application, 15 minutes seemed to work best. The actual time should be long enough so that the data collected represents the current boiler operating conditions. After the snapshots are collected, throughout which steady state must have been maintained, averages are calculated for each variable and ULTRAMAX is launched.

Using the current values of the uncontrolled inputs (load and primary air ratio) to determine where the boiler is operating, ULTRAMAX updates the model and returns a new set of setpoint adjustments and then sends Alerts to IBO. The Alerts are a series of checks done by the software to determine how well the boiler is being tuned. It will check if the data are in the expected range and if it violates constraints. It also will check to see if the models are robust and that progress is being made towards optimization.

IBO reads the new values of controlled variables and predicted results returned from ULTRAMAX and displays them to the operator on his console. It also interprets the Alerts and displays them on a different page for review and possible action. If the operator has set IBO for closed loop, the values of the controlled variables will be automatically implemented through control setpoints or appropriate parameters in order to achieve the target advice. If IBO is set for open-loop, the operator may have IBO implement the results on his command, or set some or all of the parameters manually, or decide to ignore this advice completely for operational or logistical reasons. Once the control setpoints have been adjusted, IBO again monitors permissives, demand triggers and steady state to schedule the next run.

CONCLUSION

Chemopetrol hopes to be able to realize further substantial efficiency gains through ongoing, integrated use of Dynamic Optimization. NO_x emissions and boiler efficiency may reach optimal levels as ULTRAMAX collects data and refines models of their boilers' operations. Chemopetrol’s personnel should be able to maintain control settings for least-cost operation under every scenario.

The successful utilization of IBO and Dynamic Optimization technology provided Chemopetrol with solid evidence that:

1. Dynamic Optimization is an effective approach to rapidly optimize a boiler operation to achieve multiple objectives of NO_x control and boiler efficiency.
2. Honeywell’s IBO is a robust, easily managed closed-loop application of Dynamic Optimization .
3. IBO and Dynamic Optimization can be effectively utilized by operations personnel as a support tool for continuous improvement and response to changing conditions.

DISCLAIMER

This project was performed for Chemopetrol and intended for its internal use only. Chemopetrol is providing this document concerning the project for informational purposes only. Chemopetrol does not represent nor warrant, express or implied, the accuracy or adequacy of this information. Any reliance on or use or this information by non-Chemopetrol personnel is done so at their own risk.

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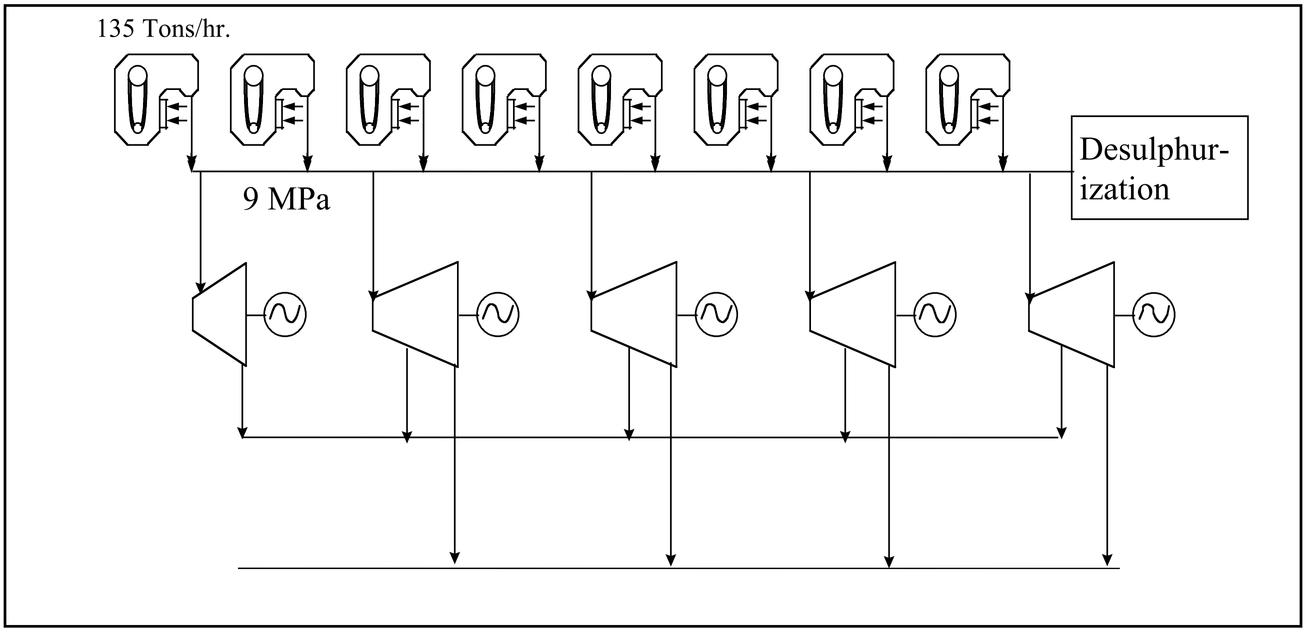


Figure 1: Diagram showing simplified Chemopetrol Steam System.

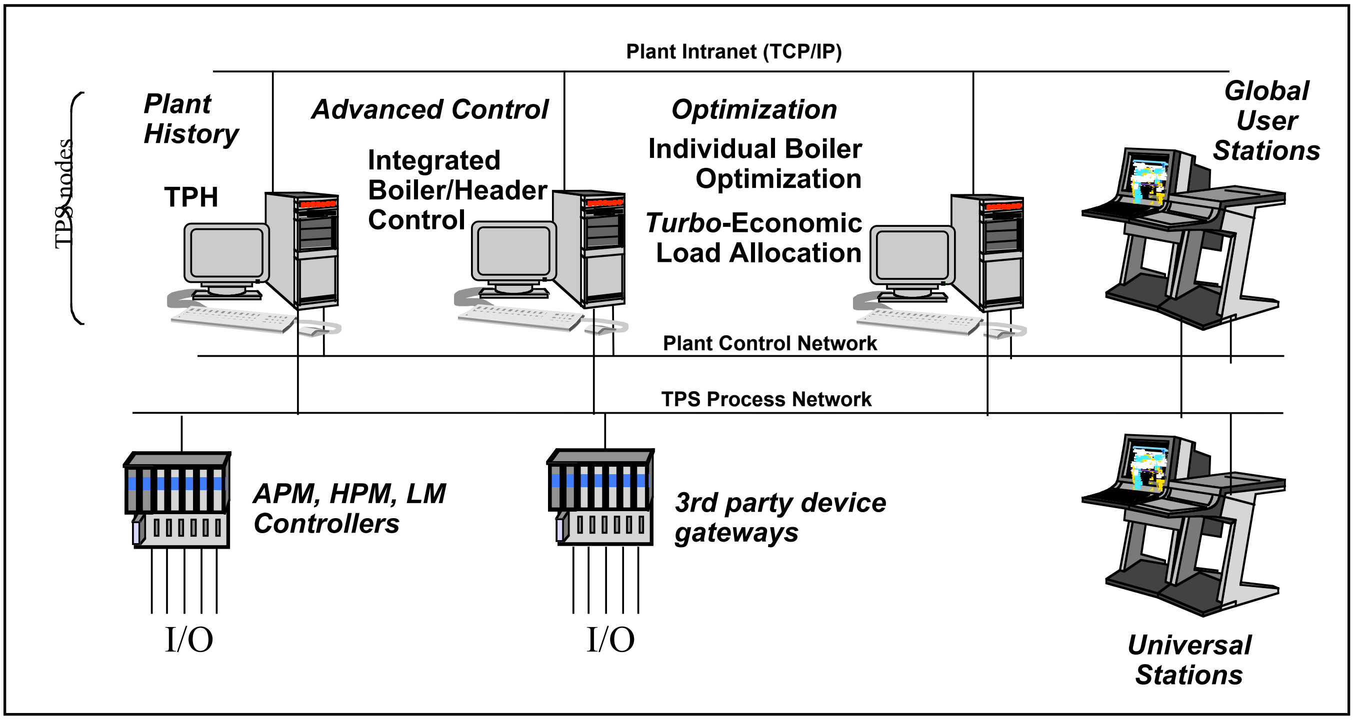


Figure 2: Honeywell TotalPlant Solution System at Chemopetrol

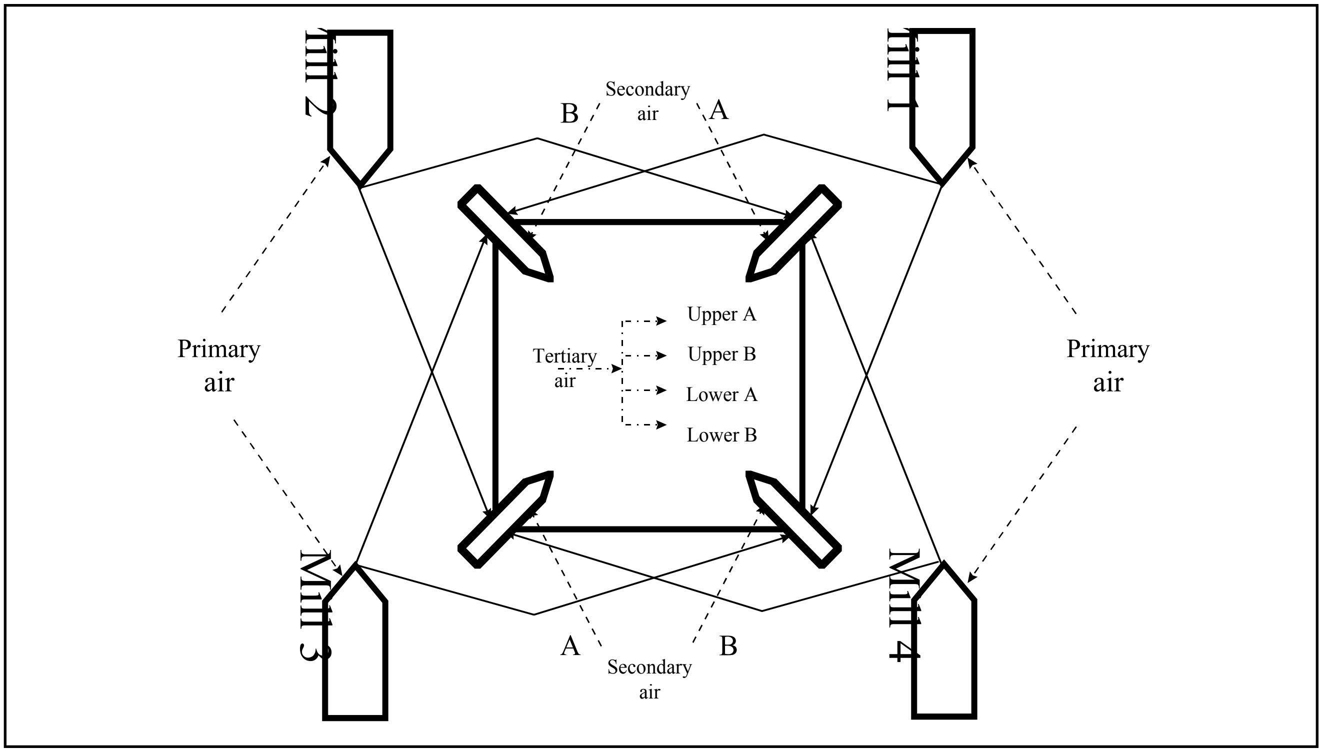


Figure 3: Simplified Boiler Configuration

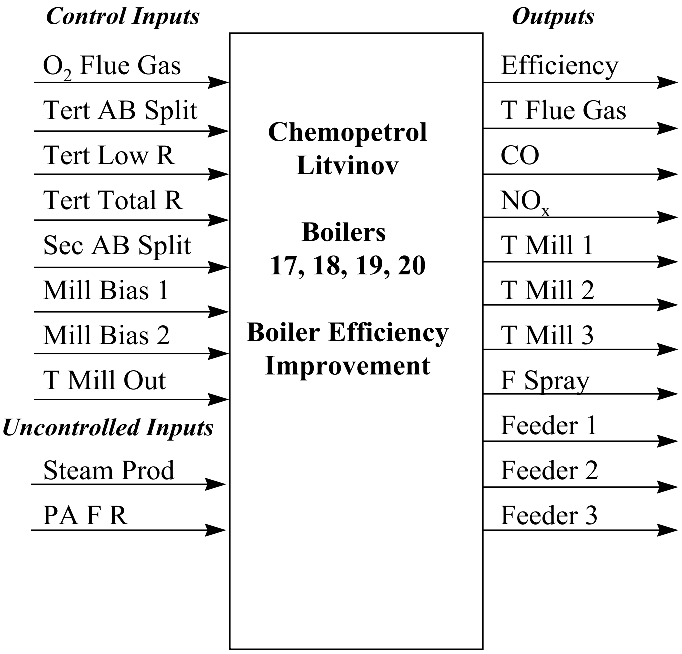


Figure 4: ULTRAMAX Game Plan Decision Diagram

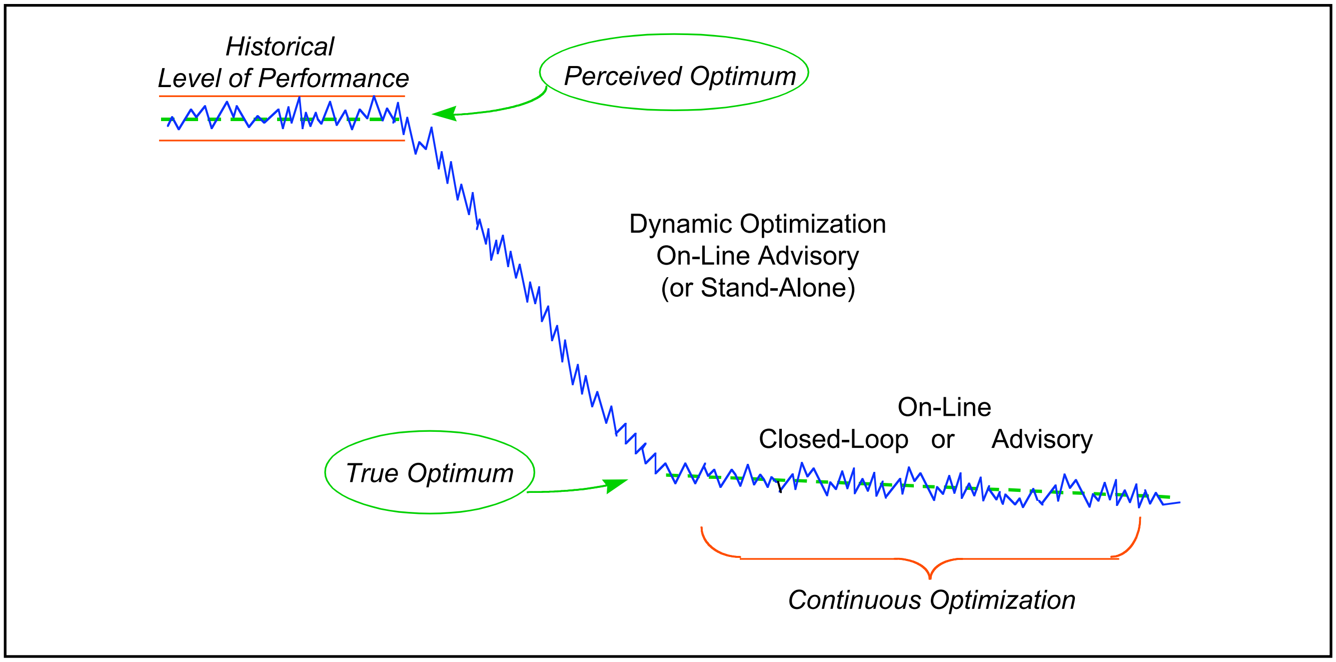
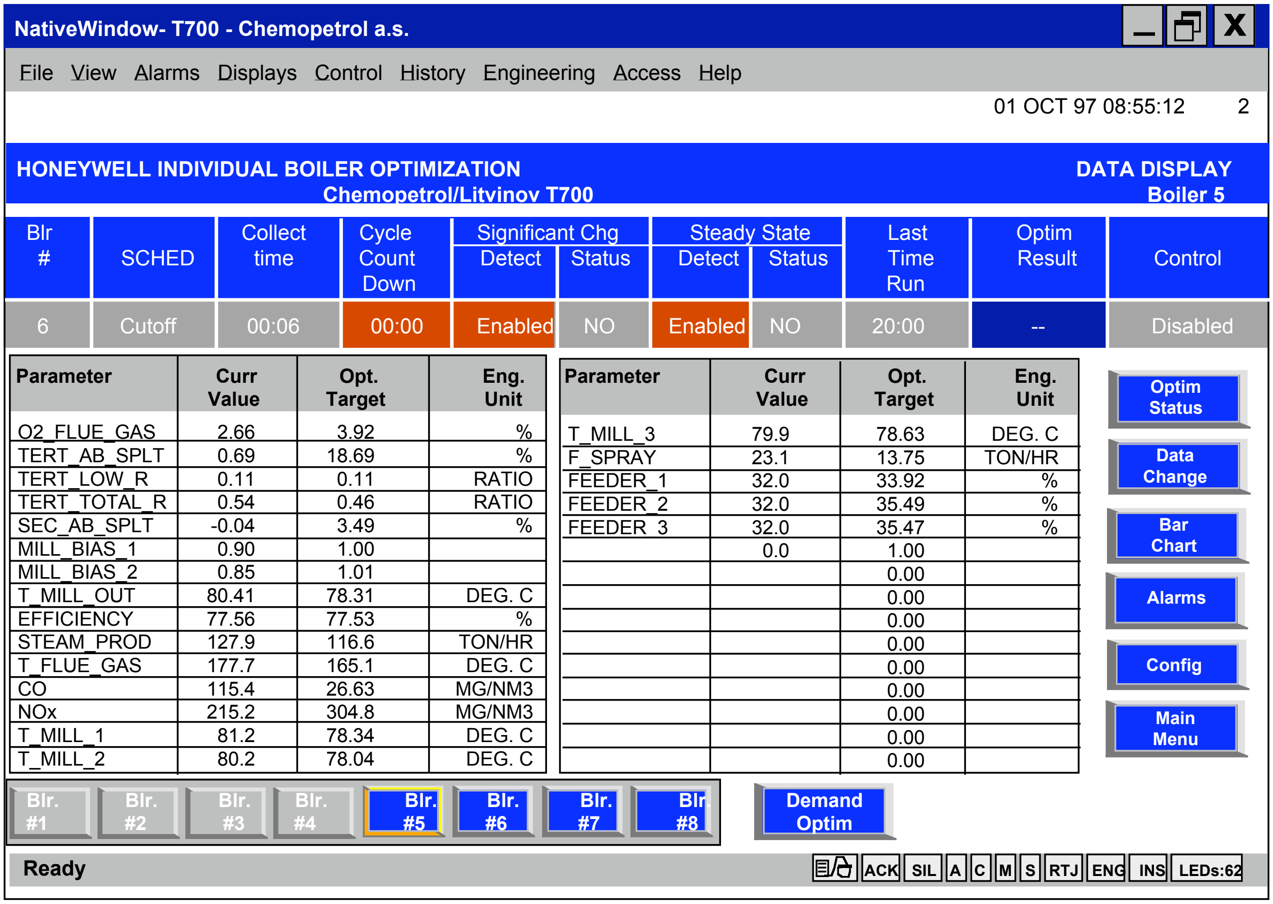


Figure 5: Diagram showing path to true optimization



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HONEYWELL INDIVIDUAL BOILER OPTIMIZATION
Chemopetrol/Litvinov T700

DATA DISPLAY
Boiler 5

Blr #	SCHED	Collect time	Cycle Count Down	Significant Chg Detect	Significant Chg Status	Steady State Detect	Steady State Status	Last Time Run	Optim Result	Control
6	Cutoff	00:06	00:00	Enabled	NO	Enabled	NO	20:00	--	Disabled

Parameter	Curr Value	Opt. Target	Eng. Unit
O2_FLUE_GAS	2.66	3.92	%
TERT_AB_SPLT	0.69	18.69	%
TERT_LOW_R	0.11	0.11	RATIO
TERT_TOTAL_R	0.54	0.46	RATIO
SEC_AB_SPLT	-0.04	3.49	%
MILL_BIAS_1	0.90	1.00	
MILL_BIAS_2	0.85	1.01	
T_MILL_OUT	80.41	78.31	DEG. C
EFFICIENCY	77.56	77.53	%
STEAM_PROD	127.9	116.6	TON/HR
T_FLUE_GAS	177.7	165.1	DEG. C
CO	115.4	26.63	MG/NM3
NOx	215.2	304.8	MG/NM3
T_MILL_1	81.2	78.34	DEG. C
T_MILL_2	80.2	78.04	DEG. C

Parameter	Curr Value	Opt. Target	Eng. Unit
T_MILL_3	79.9	78.63	DEG. C
F_SPRAY	23.1	13.75	TON/HR
FEEDER_1	32.0	33.92	%
FEEDER_2	32.0	35.49	%
FEEDER 3	32.0	35.47	%
	0.0	1.00	
		0.00	
		0.00	
		0.00	
		0.00	
		0.00	
		0.00	
		0.00	
		0.00	
		0.00	

Ready

Figure 6: Main Data Display