Cementing profitability

Towards overall plant optimization in the minerals and cement industry

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Rising competition and increasing resource costs are eroding the profit margins of many process industries. For these industries to survive, optimization is essential, but the constant streamlining of such processes brings its own problems for operators. Automation control tools can mitigate these problems and, thanks to today's advanced algorithms and high-power computers, solutions are at hand. ABB has developed Expert Optimizer v5, a computer-based system for controlling, stabilizing and optimizing industrial processes. The system has proved extremely effective and is currently in use in more than 300 reference sites, keeping industrial processes on target.

In response to the increasing demands for efficiency in industrial processes, ABB has built on recent advances in mathematical algorithms and high-power computing to create a comprehensive engineering tool, able to combine the needs of optimal production scheduling with those of classical advanced process control. To ensure the success of this tool in the marketplace and to provide ABB with a competitive advantage, the following characteristics have been incorporated:

- Full compatibility with all state of the art optimization techniques

- Sufficient flexibility to handle applications in different industries with different goals
- Ease of operation, to allow use by non-specialists
- Modularity, reusability and scalability to speed up development

Expert Optimizer v5 with Hybrid Systems Toolbox

Expert Optimizer is a computer-based system for controlling, stabilizing and optimizing industrial processes. It achieves its aims using the most modern control technology, ensuring that the best possible actions are applied accurately, tirelessly and consistently at all times. It has a successful track record in the marketplace, with more than 300 reference sites worldwide.

ABB's vision, to incorporate in one product all the functionalities required to satisfy the range of business needs for optimization solutions, led to the development of Expert Optimizer. The ABB unit, Minerals, worked in collaboration with ABB Corporate Research in Switzerland. In 2004 they began development of new model-based functionality, with a close eye on the market and the technological requirements mentioned above.

Mathematical techniques

The model-based environment of the new Expert Optimizer, known as the Hybrid Systems Toolbox (HST) 1, adopts the Mixed Logical Dynamical (MLD) modeling class [1]. MLD systems were recently developed at the Automatic Control Laboratory at the Swiss Federal Institute of Technology (ETH), Zürich, with whom ABB launched a strategic collaboration in 2000 [2]. MLD systems generalize a wide set of models, including hybrid systems, in which both continuous and discrete processes interact. A simple MLD system in Expert optimizer is shown in 2.

A good example of a hybrid system is an electronic thermostat, where the temperature, a physical quantity, is modeled as a continuous variable and the state of the heater switch (on/off) is modeled as a discrete variable. The ability to model hybrid systems significantly increases Expert Optimizer's range of applicability (hybrid systems are very common in the process industry). Further, unlike standard industrial models, MLD systems are able to model constraints, such as logic relations of the type: "If unit one is ON, then unit two must be OFF", or production constraints such as: "either NO production, or production between MIN and MAX". Last, but not least, MLD systems can handle piecewise-linear mathematical models. This represents a good compromise between the high complexity of general nonlinear models and the ease of use of the linear theory.

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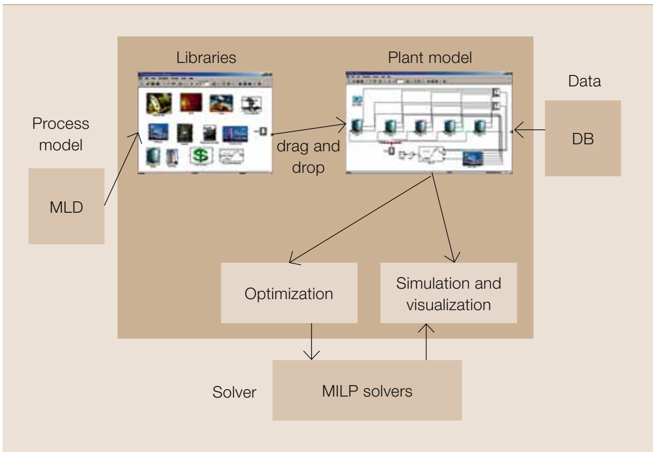
Among the advantages of the MLD framework is the existence of a standardized method to handle model predictive control (MPC), a well-known optimal control technique. The combination of MLD and MPC permits the solution of large-scale optimization problems where a cost-revenues index (known as cost function) is minimized over a given prediction horizon, while fulfilling the operating constraints. Depending on the requirements, the same framework can be applied either as an open loop, decision-making (scheduling) tool or as a closed loop, disturbance-rejection (re-scheduling) tool [3].

Modelling flexibility, acceptable computational times and optimal disturbance rejection are the key advantages of the approach.

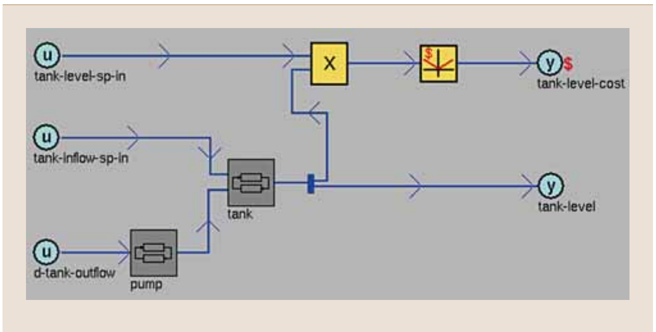
Implementation concept

The drawback of the MLD-MPC approach, as with other model-based techniques, is the relatively high complexity of the theory. This makes the modelling and maintenance of complex industrial systems difficult. The main driver for the development of the new Expert Optimizer was to make the MLD-MPC methodology accessible to non-specialist users, with the vision of making it a standard for model-based optimization projects within ABB and for its customers. Imagine that a certain process could be conceptually decomposed into smaller parts. For example, a hydroelectric power plant could be split into the reservoir, dam, turbine, generator, grid, etc. The idea is to model each part independently from the others in the MLD framework and to represent it graphically with a block. The block stores the model constraints and dynamics; its input and output ports match the inputs and

1 Hybrid Systems Toolbox (HST) outline



2 A simple mixed logic dynamical (MLD) system in Expert Optimizer



outputs of the MLD model. The complete process model is then obtained by graphically connecting the input/output ports of the various blocks. The next innovation is to represent the cost function that defines the optimal control problem as a second graphical MLD block. In the hydroelectric plant example, the goal could be to maximize the profits derived from the sale of electricity. The output of the generator block, representing the power produced, should then be linked to the cost function block, where the time varying tariffs of electricity could be stored. It is worth noting that each block, including the cost function, is a generic MLD system. The result is complete modelling flexibility.

Modularity simplifies the modelling phase and makes it easier to engineer, modify and maintain the models.

The modularity of the approach simplifies the modelling phase and makes it easier to engineer, modify and maintain the models. It also provides the opportunity to create libraries of standard blocks that can be reused in different processes, simply by dragging and dropping them from a library 3.

Once the user has created the plant model, the complex procedures of merging the MLD model blocks and formulating and solving the optimal control problem are automatically run in the background, unseen by the user. The user needs be concerned only with connecting library blocks or, in case of new applications, developing new basic blocks.

These features make the implementation of new robust applications faster than ever. What before might have taken months, can, with Expert Optimizer v5, now be achieved in a matter of a few weeks.

Continuous innovation

Scientists at the ABB Corporate Research Center in Switzerland have actively helped to develop and continue developing new functionalities related to advanced process control and scheduling in the MLD-MPC framework. The involvement of ABB Corporate Research and the contacts with the academic world guarantee that Expert Optimizer keeps pace with the latest innovations.

Typical new applications

Since the new model-based optimization capabilities became available, several Expert Optimizer projects have been installed and are running successfully in different domains. The most significant are in closed-loop process control: raw materials blending, mill and precalciner control; in production planning and scheduling: cement mill scheduling [4], titanium dioxide production scheduling and water distribution; in economic process optimization: alternative fuels management and thermal power plant optimization.

Raw Mix Proportioning

The Raw Mix Proportioning (RMP) module of Expert Optimizer uses new model-based capabilities to help cement manufacturers improve the quality of their raw mix and hence save money downstream. Blending raw mix components involves several non-trivial decisions that have a huge impact on later parts of the process. Deviations in raw mix quality are costly to correct later, with production losses and increased energy consumption being the immediate results.

The proportioning module applies MPC and MLD systems, which enable it to make predictions about the process and its chemistry. To achieve this, the model makes a prediction of the product quality after the mill and/or silos. Using information from the online and/or sampling analyzers, the model compares the prediction to the cost and quality optimization targets. A series of current and future optimal "moves" are then selected and the decision is implemented. Finally, the effects of process unpredictability and dynamics are absorbed and fed into the model to further improve predictions and decisions. See 4 for a screenshot from this model of Expert Optimizer.

The benefits of being able to make process decisions by looking forward instead of back are several:

- optimal trade-off between quality targets and material costs
- early smoothing of long- and medium-term disturbances
- meeting preconditions for maximized use of alternative fuels
- compensation for conveyor belt delays
- complete handling of process dynamics
- minimization of feeder moves

The RMP module is not a "black box" and the customer can change the priorities and weighting of various parameters without input or re-engineering from ABB.

Each block, including the cost function, is a generic MLD system. The result is complete modelling flexibility.

Grinding plant scheduling

The final grinding process of cement production, and the distribution of the various grades of cement to the different silos is dependent on careful scheduling of the mill. Using customer orders and energy-price forecasts, Expert Optimizer is able to help by executing periodic MPC iterations and its output is used as a reference schedule for operation of the mills 5. Here, the cost function represents costs associated with electricity consumption and the amount of low-grade cement produced (cement produced during the switch from one grade to another). Electricity cost reduction is achieved by committing the production to periods of low-tariff electricity, and by managing the mills so that the contracted thresholds of

3 Atomic Mixed Logic Dynamical (MLD) blocks library

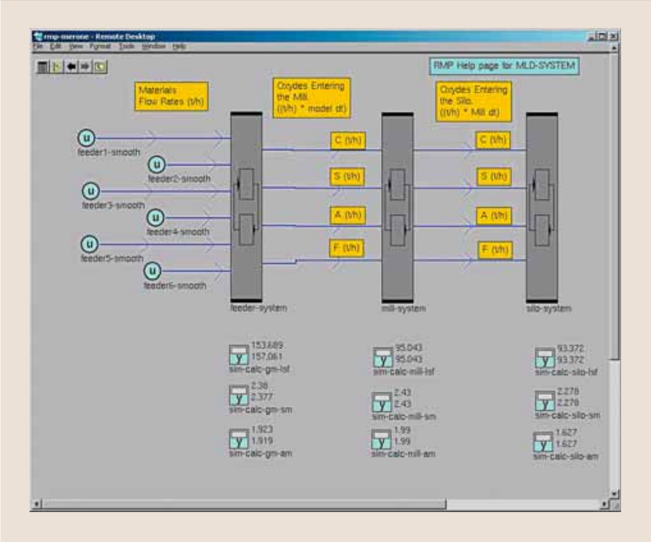
Sensing and controlling

maximum electrical power are not exceeded. The production of low-grade cement is minimized by reducing the number of production switches.

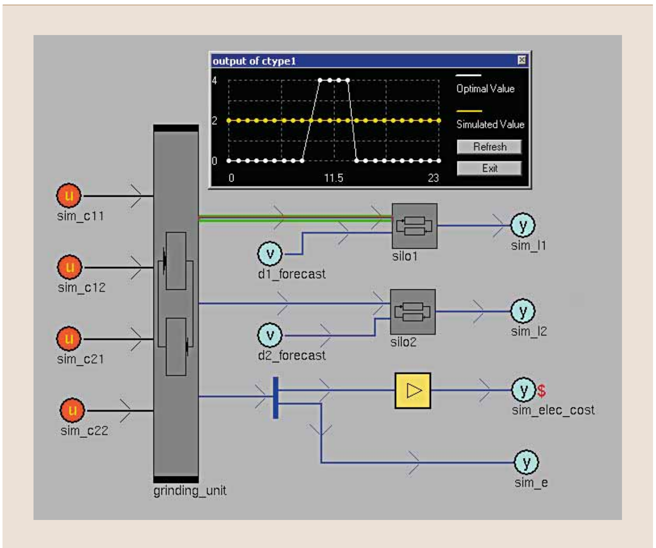
Note that this “control problem” is more closely related to economic process optimization than to regulatory control: it tries to exploit degrees of freedom to increase the plant’s financial performance.

The production of low-grade cement is minimized by reducing the number of production switches.

4 Raw mix proportioning strategy



5 Grinding plant scheduling



Conclusions

The results from this research and development work are excellent: twenty years of experience in the process industry with knowledge of established control techniques such as fuzzy logic, rule-based control and Neuro-Fuzzy are now combined with state of the art model-based optimization techniques. Complex real-world applications in the areas of closed-loop process control, open-loop decision support, as well as advanced production planning and scheduling, and economic optimization can now be tackled using a single product. Modeling, optimization and simulation capabilities are accessible within the Expert Optimizer graphic interface. The complexity is kept out of sight of the user, whose only task is process modeling. Flexibility is ensured by a modular structure and by providing libraries of reusable components.

Decisions about what tool functions are necessary to develop a solution are dependent on the amount of process knowledge and understanding available. By making use of the vast experience of its process engineers, ABB can be commissioned to develop the model and control strategy necessary to optimize the dynamic process, yet end users still have the option to capture their own process knowledge. The ease of use of Expert Optimizer v5, combined with comprehensive training and support from ABB, can help end users to develop and implement their own application more quickly.

The methodology developed will enable an owner to operate assets in an economically efficient and environmentally respectful way. With this tool, ABB has put the control engineer in a position to combine strategies of optimal control theory with econometric models of industrial assets.

The results described in this paper were obtained as part of the fruitful, long-term collaboration between the ABB Minerals and ABB Corporate Research in the program, Control & Optimization. This collaboration is an example of the benefits derived from close links between industry and research programs.

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