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Mirror *image*

Antoon Tuerlings, Yokogawa Europe, the Netherlands, describes a new 'Mirror Plant' concept that applies dynamic simulation to the online real-time process environment in order to improve plant operation.

In recent years, there has been an increasing focus on improving plant safety and strengthening competitiveness by making plants more efficient. The key objectives for plant operators can be summarised as:

◗ Achieving safe and stable operations, and preventing accidents.

◗ Rapid plant start-ups.

◗ Improving profitability.

◗ Optimising plant operations.

◗ Improving and propagating the skills of experienced staff.

◗ Conserving the environment.

Plant operators often need, in real time, to manage or adjust the state of process variables in order to optimise both plant productivity and product quality. However, many of the process variables are difficult to measure or cannot be measured directly. Based on actual process information, such as flow rate, temperature and pressure, simulation technology can make predictions on items that cannot be measured in real time, and can thus simulate the state of a plant. By means of high-speed calculations, a real-time dynamic simulator can make near-term predictions on the state of a plant. Operators can then anticipate events and take action earlier to ensure safe operation.

This article describes an online plant simulator that operates in synchronisation with the plant control system and constantly updates the process model. Based on real-time manufacturing process information, and using a proprietary function for adjusting model parameters, the simulator precisely simulates the state of a plant. By using plant models, it visualises the current state of the plant, as well as the state several hours in the future and at plant locations where it is not possible to measure parameters such as temperature or pressure. It then displays these results on screen and incorporates an alarm function that can alert operators to potential problems.

Dynamic simulation

A dynamic simulator is a software tool for building a virtual plant in a computer by modelling an existing plant or a plant to be built. With a dynamic simulator, the following can be achieved:

◗ Carrying out design and engineering programs for a plant at the design or construction stages as if it actually existed.

◗ Performing operations in a virtual plant that could not be tried in an actual plant.

◗ Visualising or estimating conditions in the plant, and predicting plant behaviour based on the current plant conditions.

Examples of the first category include the applications of a dynamic simulator to the verification of the logic in the plant design, control systems, and safety systems, and to the configuration and evaluation of operational procedures during the front-end engineering design

(FEED) and engineering procurement and construction (EPC) phases. One application example of the second category is the operator training simulator (OTS), which is currently one of the major applications for dynamic simulators. Another example is the use of a dynamic simulator for pre-verification of the advanced control logic before applying it to an actual plant.

Applying a dynamic simulator during the actual operational phase, as in the third category above, can be implemented by connecting the simulator to the actual control and safety systems online and by using real-time data. In this way, dynamic simulators can be used effectively during the respective phases of a plant lifecycle, from the upstream plant design and construction phase to operational improvements after having started actual operations.

Because a plant simulator builds a virtual plant on a computer, the simulator itself and the control and safety systems connected to it can be said to approximately replicate the actual plant, even though their accuracy depends on the strictness of the model. In practice, the simulator can serve as a unified platform for providing comprehensive solutions across a plant lifecycle by adding peripheral functions to them for resolving respective challenges.

Plant simulators play an important role in the engineers' work during the plant design and construction phases to help achieve a rapid and flawless start-up. They can be used for the validity verification of control systems during the commissioning and actual operation phases included in the plant operation phase shown in Figure 1.


Figure 1. Functions achieved by a real-time plant simulator during the operation phase of a plant.

Figure 2. Effective use of the Mirror Plant over a plant lifecycle.

However, simply adding online functions alone to the current dynamic simulators used for OTS applications is not sufficient for use in real-life control applications, as the following functions are required:

◗ A modelling function to build a more rigorous model.

◗ Seamless integration of dynamic simulation and steady-state simulation.

◗ Computation capability to solve the rigorous model at high speed.

◗ A data reconciliation function with dynamic compensation.

◗ Robustness as an online system.

The Mirror Plant system described in this article has been developed by Omega Simulation Co., Ltd. (OSC) jointly working with Yokogawa and Mitsui Chemicals Inc., and is based on OSC's Visual Modeler plant simulator equipped with the additional functions listed above. Its field tests have been conducted at an actual Mitsui plant, where satisfactory results have been obtained and its effectiveness proven.

Innovating plant operation

The Mirror Plant concept focuses especially on the plant's operations phase. It is built in a computer and so can follow temporal changes in the process and precisely simulate the behaviour of the real plant by identifying model parameters online. The Mirror Plant in virtual space enables plant safety operation based on future predictions, which would be impossible with conventional plant operations. It also achieves optimal operations even in processes with temporal changes, such as heat transfer changes of heat exchangers and deterioration of catalysts.

Challenges during the production phase

Generally, the life span of a plant is approximately 40 - 50 years. As shown in Figure 2, the production and operation phase is the longest in a plant lifecycle. During this period, technologies advance and the economic and social environments surrounding the plant can change greatly. To keep up with these changes, plants have to be run in different conditions from those assumed during the design stage. For example, economic conditions may force a plant to switch from full-load production during periods of high economic growth to variable production levels. Environmental concerns may force a plant to use LNG as fuel rather than heavy oil. In addition to changes in external conditions, the processes themselves can also change.

Unlike the operator training simulator, which covers operations from start-up to shut-down, the Mirror Plant focuses on the production phase. It uses a physical model based on principles and fundamental rules to simulate the process

Figure 3. Configuration of the Mirror Plant.
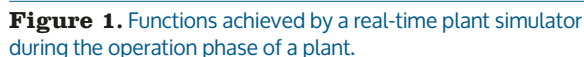
behaviour, identifies model parameters online, and provides an operational environment that can foresee plant behaviour by using visualisation and predictive functions.

At the same time, the product lifecycle is also involved in the production phase. It may involve changes in raw materials or fuels, and the production of new products requiring plant modifications. While it is true that engineering staff at the production site manage these changes, their investigations are usually static and mainly focused on equipment, and rarely include controllability.

The Mirror Plant enables a quicker release of new products by reflecting changed conditions into the model and concurrently designing more optimal operating conditions. For example, it can perform fine optimisation taking various factors into consideration, such as deterioration of catalytic activity, because it can track temporal changes in the parameters by using online model updating technology. Applications such as plant diagnosis and abnormality avoidance operations are also possible using predictive features of the simulator.

Factors that may disturb processes can be found by checking the data measured in the plant against the plant model and by investigating site factors that limit the assumptions that the model formula holds. For example, if the effect of pressure fluctuations on the reactor system cannot be quantified, the control target cannot be precisely determined.

After the process is stabilised, the operating point is shifted to the optimal point. The optimal operating point often exists in the vicinity of critical regions for processing: for example, near the explosive region or just inside the limit of the product specifications region. The Mirror Plant can verify and optimise safety during the transition to a new operating point and can also be used to stabilise the process around the (new) operating point.

Model configuration

Figure 3 is a schematic of the Mirror Plant that shows the following three components:

◗ The mirror model, which receives online data from the distributed control system (DCS) – a part of the actual plant – and performs real-time simulation to create a mirror image of the actual plant. It also estimates and visualises state quantities, which are not measured.

◗ The identification model, which periodically estimates performance parameters of the equipment to fit the models to the actually measured values.

◗ The analysis model, which achieves various operational assistance functions.

Operational assistance functions

These functions have been completed through the prototype development and field verification operations in an actual plant:

◗ Visualisation of the inside of a plant – state quantities at locations where sensors are not installed are estimated.

◗ Estimation and monitoring of performance parameters – performance parameters, such as catalytic activity and the heat-transfer coefficients of heat exchangers, are estimated, and the performance or status of equipment can be monitored.

◗ Steady state prediction – a steady-state balance can be predicted from the current plant status when operational conditions, such as production volumes, are changed.

One of the applications is to find and provide the optimal operational conditions.

◗ Transient state prediction – the future dynamic behaviour of a plant can be predicted from the current plant status, assuming that current operational conditions are maintained. Applications of this function include examining and providing operational procedures for avoiding critical operating conditions, and investigating ways of improving control performance.

Tracking and data reconciliation

Figure 4 shows the Mirror Plant operational sequence, especially the execution flow of the mirror model and the data reconciliation with dynamic compensation.

The mirror model performs dynamic simulation while executing processing for fitting the model to the actual plant at every calculation interval. This processing is called tracking.

This tracking aims for local conformity, and is achieved by the following means:

◗ Measurement values, such as temperature or pressure at the boundary of the model, are taken into the mirror model.

◗ The control parameters of the controllers in the DCS, including set values, PID parameters and alarm high/low limit values, are taken in as control parameters of the controllers in the mirror model.

◗ If a control action in the mirror model is slow and this affects other parameters, the process variable of the actual plant is taken in as a set value of the controller in the mirror model. Furthermore, its manipulation variable is provided in the model as a feed-forward signal to enhance responsiveness.

◗ If it is important for a state quantity in the model to coincide with that in the actual plant (even though it is not controlled in the actual plant), and if the relation between the state quantity and the equipment parameter is locally restricted,
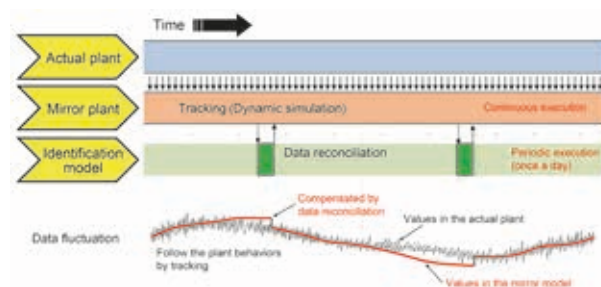

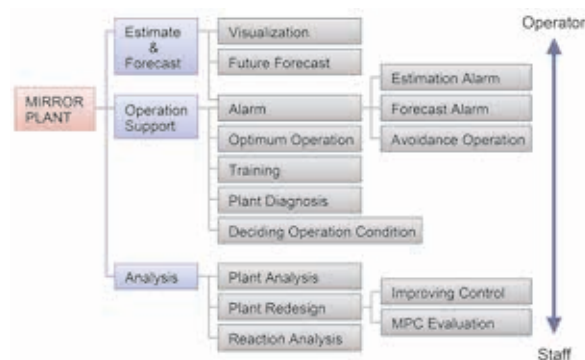**Figure 4.** Operation sequence of the Mirror Plant.

Figure 5. Application examples of the Mirror Plant.

an equipment parameter in the mirror model is adjusted so that the value calculated in the mirror model agrees with the measured value at the actual plant.

Following the four means described above, the data from a DCS of an actual plant are input into the mirror model through the OLE for process control (OPC) interface.

Forecasting plant behaviour

The simulator can also forecast future plant behaviour by running the virtual plant faster. Based on the information from the Mirror Plant, operators can understand possible conditions that may cause alarms, and run the actual plant much more safely by eliminating such potential alerts.

Applications

The Mirror Plant, which can precisely simulate dynamic plant behaviour, offers various applications. Figure 5 shows various application examples classified for the estimation and forecast functions, operation support functions, and plant analysis functions. The estimation and forecast functions visualise the values of temperature, pressure and flow rate, etc., for which sensors are not actually installed in the plant, and the values of composition and other elements, which are impossible to measure in real time (hereafter referred to as the estimated values). This function also visualises the future projections of internal conditions in the plant by executing the Mirror Plant faster than the actual time passage (the visualised projections' forecast values).

The operation support functions include the estimation alarm function, which can set alarm limits for the estimated values; the forecast alarm function, which works with the forecast function and creates alarms against possible abnormality if the current operation conditions continue; and

the supporting function to help avoid future danger from occurring with the activated forecast alarms. The operation support functions also include the plant diagnosis application, which detects abnormality in the plant before actual sensors do by calculating the steady-state balance of the plant. It then compares the results with the measured values.

Forecast plant operation

The estimated and forecast data of the Mirror Plant can be displayed on the screen of an existing DCS. This enables operators to operate a plant while monitoring near-future plant conditions. However, measured values, estimated values, forecast values of the measured values, and forecast values of estimated values are eventually displayed on the screen of the DCS at the same time. This increased amount of information may confuse operators and trigger misunderstandings or wrong operations. To resolve this potential problem, the following two basic requirements should be adhered to:

◗ Clearly distinguish between forecast data and current or past time data based on the time axis.

◗ Clearly distinguish between actual data from the DCS and estimated data from the Mirror Plant based on the information source.

The forecasting ability is the differentiation technology of the Mirror Plant. The human machine interface (HMI) uses the same display as that of the CENTUM VP, and allows plant operations using the information from the Mirror Plant. The HMI, which is capable of distinguishing between real/virtual and past/future, was designed on the basis of ergonomics. This HMI achieves the forecast plant operation by making use of the forecast trend, forecast alarm and other applications of the Mirror Plant. **LNG**