NIPPON STEEL TECHNICAL REPORT No. 89 JANUARY 2004

UDC 669 . 162 . 26 : 681 . 3

Operator's Training Simulator for Blast Furnace Plant

Takehiko IZUHA*[1] Takashi SATO*[2]
Hidenori GOMI*[3] Yasujiro SONO*[3]
Takashi HIDA*[3] Kazuaki WASHIZU*[3]

Abstract

We have developed an operator's training simulator for the blast furnace plant to improve operator's operation skill. The simulator consists of a workstation with a process model, human machine interface, and plant control system. We have achieved such an environment as the operator can operate through human machine interface as if the operator is operating an actual plant and system is controlling the same software that controls the actual plant.

1. Introduction

The recent wide application of distributed control systems (DCSs) has made centralized monitoring and advanced automation of plant operation practicable. On the other hand, however, plant operators have fewer chances of directly operating plant facilities and less first-hand experience of taking measures against plant troubles and as a result, it has become difficult for them to acquire operational skills. The authors developed a training simulator for blast furnace operators with the purpose of maintaining and improving their operational skills, and introducing them to a real blast furnace plant. This paper describes an outline of the training simulator that was developed.

2. Background and Object

The DCS technologies for monitoring plant operation have advanced remarkably over the last years and DCSs have been introduced to an increasing number of plants. In a DCS, a human-machine interface (HMI), through which an operator monitors the operation of a plant, and a control station, which controls the plant facilities and collects operating data, are organically linked through a control bus (see **Fig. 1**). Use of a DCS makes it possible to centrally monitor the operation of plant facilities through an HMI and realize high-level process automation through the control station. As a consequence, the required number of operators has decreased as well as the chance for operators to directly manipulate plant facilities. What is more, operation control systems have become black boxes and it has become difficult for operators to understand how the facilities are operated automatically. In addition, plant operation has been rendered stable as a result of enhanced reliability of DCSs and plant facilities and consequently, plant operators now have fewer chances of dealing with plant troubles.

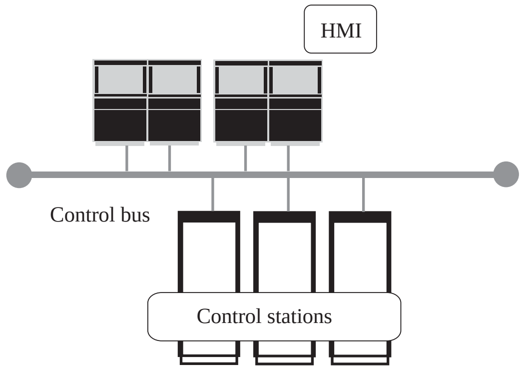

Fig. 1 System configuration of DCS

Under such circumstances, it is difficult for plant operators to maintain their skills at a level that would allow them to flexibly cope with a variety of plant troubles through their usual job experiences. Needless to say, this lowering of operator proficiency is now viewed as an imminent problem. However advanced the plant automation may be and however sophisticated the level of its control functions, the final stronghold of plant operation are the skills of its operators; therefore, fostering operators that capable of promptly coping with a wide variety of situations is always very important. It is known that training using a plant operation simulator that simulates a real plant is highly effective for acquiring and enhancing operation skill.

*1 Environment & Process Technology Center
*2 Nittetsu Elex Co., Ltd.
*3 Nagoya Works

Plant operation training simulators have been used at several oil refineries, petrochemical plants, boiler plants and the like. In view of these examples and in consideration of the fact that a blast furnace is a plant where the possibility of plant trouble or an operator's misjudgment can result in a serious accident is especially high among the plants of a steel works, the authors have developed an operation training simulator for a blast furnace with the purpose of maintaining and enhancing the skill of blast furnace operators. The developed simulator was put into use at No. 3 Blast Furnace of Nippon Steel's Nagoya Works in April, 2000 on the occasion of its blow-in after a relining.

3. Development Procedures

3.1 Basic policy

To effectively utilize an operation training simulator, it is essential to develop one that gives an operator a realistic feeling; one as if the operator were actually monitoring the operation of a real blast furnace through a DCS. In order to realize this, it is necessary that a training simulator include detailed process models that can reproduce the behaviors of a real plant with the same precision as that of the plant control DCS, and that the process models react against manipulations of the trainee in the exact same manner as the plant does. However, a system comprising the same number of devices of the same specifications as the control system of a real plant entails significant equipment costs, and the manpower required for developing detailed process models will also be significant. For this reason, the basic policy for the development of the operation training simulator was to utilize simulator systems available in the market that are capable of making the most of the resources of the DCS of the blast furnace and by doing so, construct a simulator that would give a minimum realistic feeling required for the training of an operator economically and in a short period of time.

3.2 Development steps

The concept of the development is shown in **Fig. 2**. Instead of developing models for all the plant facilities to be covered from the beginning, the development of models began with some selected component facilities of the blast furnace in consideration of the manpower and time required for the development. As the models for the selected facilities were developed, they were run for visual demonstrations to confirm whether they provide the trainee with a realistic feeling of the object facilities. The whole training simulator system covering all the object facilities was developed step by step in this manner.

Fig. 3 shows the development stages of the simulator. The total development period from the planning stage to the completion of the final tuning was as short as about 1 year. The activities at each of the development stages were as follows:

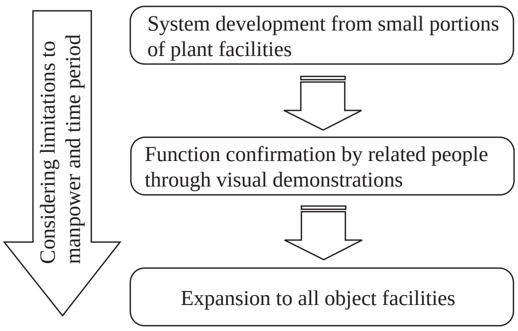

Fig. 2 Development concept

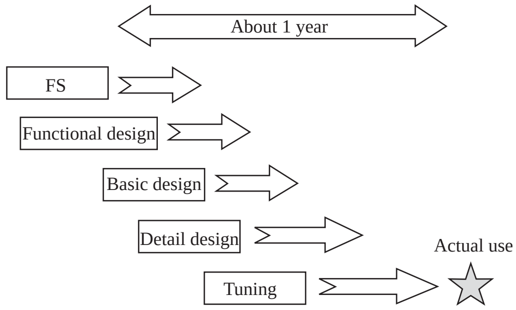

Fig. 3 Simulator development stages

(1) Planning stage
· Definition of the object of operation training and the scope of plant facilities to be covered
· Policy setting regarding required accuracy of models
(2) Functional design stage
· Selection of object plant facilities
· Prediction of the difference between the expected process behaviors simulated by models and real process behaviors
· Sorting out the causes of abnormal conditions and the furnace behaviors at the abnormal conditions
· Drafting of training scenarios
· Collection of process data
(3) Basic design stage
· Development of basic models
· Preparation of furnace operation guidelines
(4) Det ail design stage
· Development of detailed models
· Judgement on model behaviors
(5) Tuning stage
· Final tuning as a simulator system

4. Simulator Functions

4.1 Structure

Some conceivable configuration types[1)] of the training simulator are shown in **Fig. 4**. The stand-alone type is composed only of a computer. In this case, in order to make up for the application software of the HMI and control stations of a real DCS, which this type lacks, it is necessary to newly develop application software using a software generating function of the computer so that the system has the same functions as a real DCS. Since this type does not have the keyboard and the touch-screen functions of an HMI, it is impossible to provide the trainee with an operating environment similar to a real plant control system.

In the HMI + computer type, the problems of the stand-alone type related to the HMI are solved, and an operating environment similar to a real furnace control system is attained. However, it is necessary to develop new application software, as is the case with the stand-alone type. The direct DCS link type, which was finally selected, is composed of the same HMI and control station as used in a real process control system and for this reason, the application software of the real DCS can be used without newly developing or modifying an existing one.

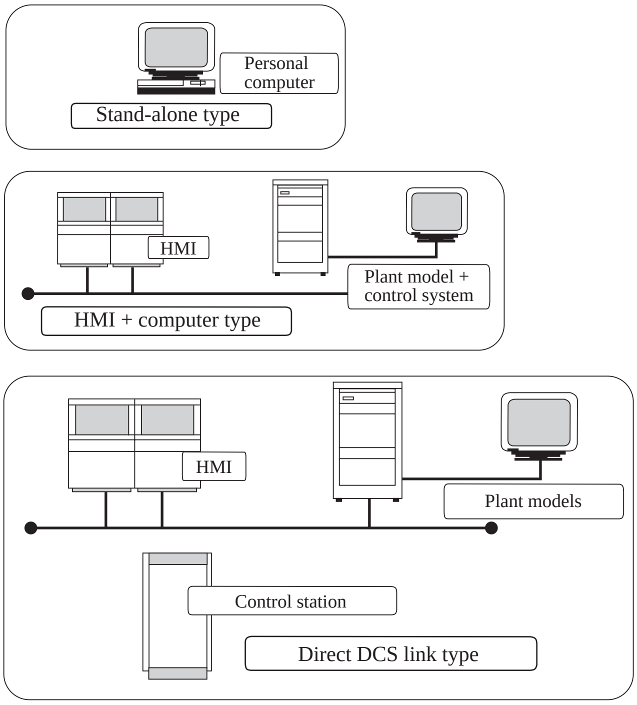

Fig. 4 Configuration types of training simulator

4.2 Concept of training simulator structure

A structural image of the training simulator[1)] is shown in **Fig. 5**. The real plant system is composed of a DCS, which consists of an HMI and control stations, and the blast furnace plant, and these component elements were reflected in the simulator as described below. The same type of HMI hardware as the real system was used for the simulator and the HMI software of the real system was ported over to the simulator. Instead of using the same type of control station as the real system, general-purpose EWSs were used in order to reduce costs, and the application software of the real system was emulated and used therein.

For developing process models of the blast furnace process, a commercially available dynamic simulator was used because of its excellent graphical user interface (GUI) function, with which process models could be easily developed by unitizing pumps, valves, piping, etc. and generating a process flow chart. The process models for the training simulator were thus developed on one of the EWSs using the dynamic simulator. Note that the simulator was structured to be independent from the plant control system so that an operator could use it off-line at any time for his training.

4.3 Hardware configuration

The hardware configuration of the simulator is shown specifically in **Fig. 6**. The simulator was composed of an HMI device, a control simulator (CS-EWS), a process simulator (MDL-EWS) and a gateway (AP-EWS). In order to give a trainee a realistic operation feeling of a keyboard and touch-screen functions similar to the real system, the same type of HMI device as that of the real DCS was used for the simulator system.

As a consequence, it was possible to port the HMI software of the real DCS such as plant monitoring and operating screens without modification. The CS-EWS simulates the control functions of the

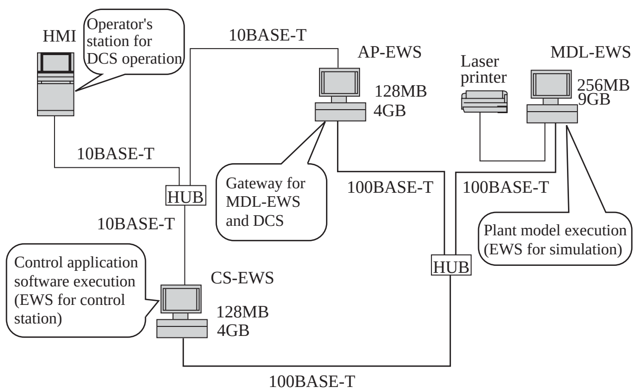

Fig. 6 Hardware configuration

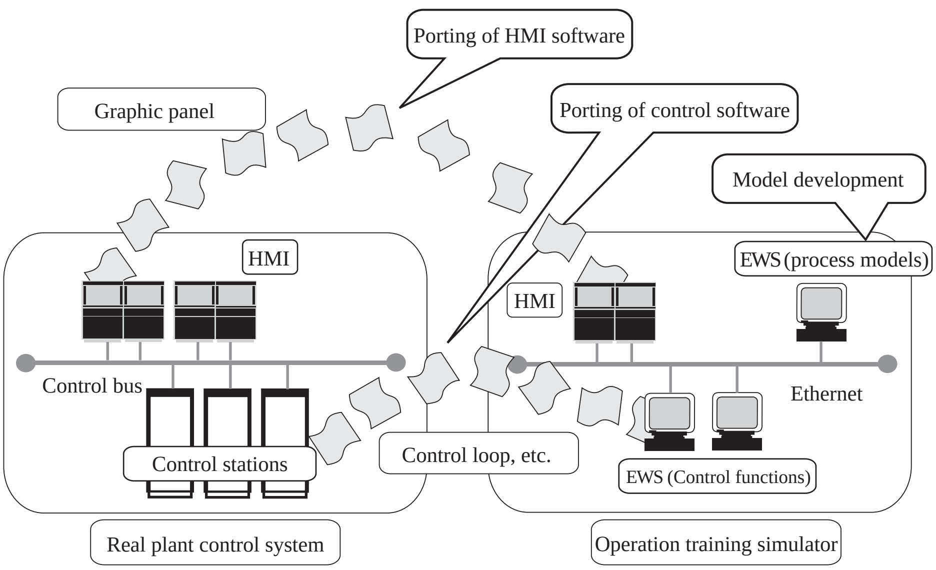

Fig. 5 Structural image of training simulator

real DCS, and the application software of the real DCS was emulated and used therein. As a result, the control functions of the real DCS and those simulated by the training simulator were made the same. The MDL-EWS is a simulator that reproduces process behaviors: it carries out process model calculations, training control and similar other essential functions. The AP-EWS mediates data exchanges between the HMI, CS-EWS and MDL-EWS. The application software of the real DCS was ported for use in the HMI and CS-EWS as it was; software development costs were thus reduced.

4.4 Software environment

The following three subsystems are installed in the MDL-EWS of the training simulator.

(1) Dynamic simulator

The dynamic simulator exchanges data with the HMI and CS-EWS and simulates plant models. It is necessary for the dynamic simulator to be capable of using detailed physical models that reproduce process behaviors realistically for a trainee, allowing a user to easily develop and modify the models and carry out complicated model calculations at high speed. The simulator that was actually used in the developed system is a modular type simulator; it expresses individual equipment (valves, pumps, piping, etc.) of the blast furnace plant in the form of modules called standard units, and an overall model is composed by combining the standard units. A module of a valve, for instance, includes flow characteristics, actuation speed and so on to express dynamic characteristics in detail; a module constitutes a detailed physical model composed of algebraic and differential equations that express material balance, heat balance and pressure balance.

A standard unit comprises process units each representing a pump, a valve, piping, a heat exchanger, etc. and instrumentation units each representing a flow meter, a thermometer, a pressure gauge, etc. As an example of standard units, **Fig. 7** shows a standard unit[1)] of a heat exchanger.

A plant model was developed by dividing it, first, into several process models; developing each of the process models independently from each other; and finally, putting the developed process models together. Each of the process models was formulated in a manner similar to preparing a process flow chart. Specifically, they link process units representing plant facilities with standard units representing piping, and instrumentation units with standard units representing signal lines.

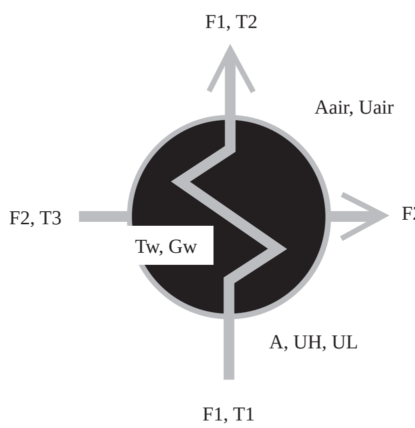

Fig. 7 Example of standard unit (heat exchanger)

(2) Training control function

The training control function simulates abnormal conditions, such as a malfunction of a valve and a failure of a pump, incorporated in plant models. It also preserves the situation at a given time during training exercises; thus it is possible to resume the exercise from the preserved situation after a pause. Abnormal conditions that require quick countermeasures are selected based on experiences of expert operators.

(3) Scenario function

The furnace operation training is automated and standardized by registering initial plant conditions for the beginning of a training exercise, the nature and timing of abnormal conditions, etc. as training scenarios.

4.5 Process models

A blast furnace plant is composed of a number of plant facilities such as the blast furnace itself, gas cleaning equipment, furnace top charging equipment, hot stoves and cast house equipment. These plant facilities are not independent from each other; rather the operating conditions of one system affects the others. In the development of the operation training simulator, hot stoves and gas cleaning equipment were selected as object facilities, because their control functions were more advanced and complicated than in the others.

The least required level of training is made viable when the models at least for the object facilities, namely hot stoves and gas cleaning equipment, are provided. In order to construct a simulating system that can give a trainee a realistic feeling as if he were actually monitoring the operation of a real blast furnace plant, however, it is necessary to take into consideration the operating conditions of the other related equipment. On the other hand, if models have to be developed for all the related equipment, a vast amount of manpower will be required. In consideration of the above, the facilities which were not the object facilities but the operating conditions of which exerted influences over the object facilities were taken into consideration as follows, depending on the case: for some of them, models were developed covering only some of their component facilities and processes; for others, models were not formulated but their affects on the object facilities were taken into consideration as disturbances.

For example, gas cleaning equipment is significantly affected by the condition of the blast furnace itself: if gas channeling occurs inside a blast furnace, the flow of blast furnace gas fluctuates as a result, and it affects gas cleaning equipment by changing the furnaces' top pressure. Another such example can be raised regarding furnace top charging equipment: before charging raw material from a hopper into a blast furnace through its top, the pressure inside the hopper has to be equalized to the furnace top pressure, and blast furnace gas is often used for equalizing the pressure. In this case, while the furnace gas is led to the hopper, the gas flow to the gas cleaning equipment decreases.

It is necessary to develop models of the blast furnace proper, top charging equipment and other related equipment in order to construct a training simulator in which the influences of the blast furnace proper are taken into account and which is capable of giving a realistic feeling and applicable to abnormal conditions such as a channeling. However, as stated earlier, a vast amount of manpower is required for developing detailed models of these facilities. To circumvent the problem, attention was focused on the change of the flow of blast furnace gas, and models were developed in which the blast furnace proper was viewed as a valve and the gas flow was changed by changing the opening of the valve. Similar models were developed regarding the top charging equipment, wherein the gas flow was changed by giving disturbances stepwise.

An outline of the thermal balance model of a hot stove is explained below as an example of process models. The equipment structure of a hot stove[1)] is shown in **Fig. 8**. The hot stoves of No. 3 Blast Furnace of Nagoya Works employ the inside combustion type. Therefore, a combustion chamber and a checker chamber are housed in one hot stove unit. Various valves are provided for hot blast control and combustion control. **Fig. 9** shows modeling of the checker chamber of a hot stove[1)]. In the modeling work, a checker chamber was divided into several blocks according to the physical properties of bricks laid in different portions of it, and the models for each of the blocks were simplified by assuming that the heat transfer between gas and brick is one-dimensional, and that the temperature of brick in the sectional direction is homogeneous. As a result of the simplification, a standard unit of the dynamic simulator called a "simplified general-purpose heat exchanger unit" was made applicable, and the manpower for model development was reduced.

As an example of the modeling, **Fig. 10** shows a part of a model program of a hot stove[1)]. The model is composed of process flow charts, and the process flow charts are composed of combinations of units such as the "simplified general-purpose heat exchanger units" and "valve units". The number of standard units used in models for all the hot stoves is approximately 600, and that in models for one unit of hot stove is approximately 100.

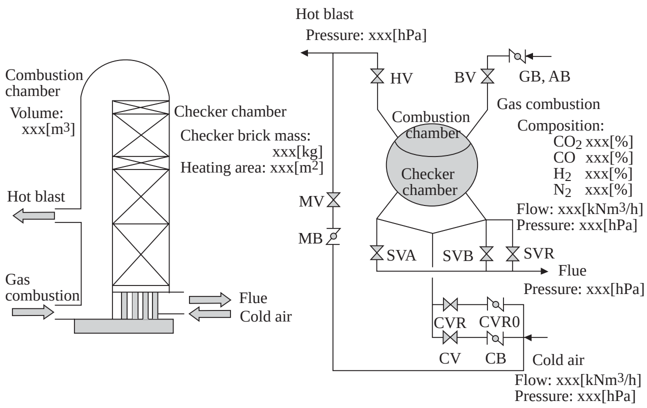

Fig. 8 Hot stove equipment

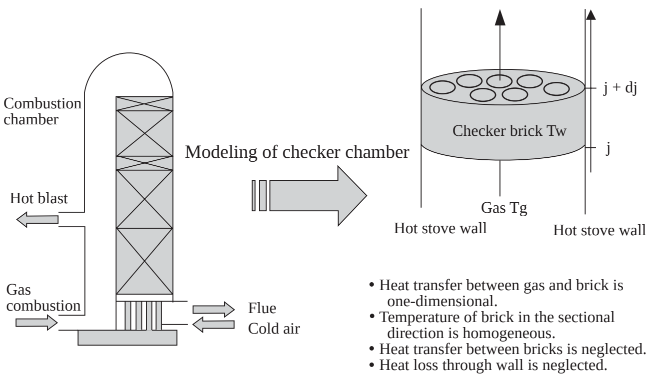

Fig. 9 Checker chamber model

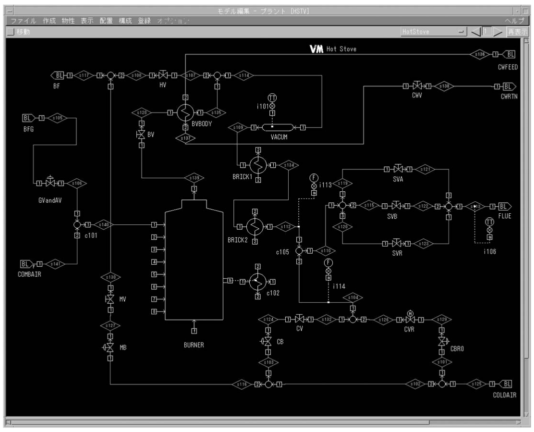

Fig. 10 Example program of hot stove model

Other models were developed, likewise, so as to create the least minimum realistic feeling of operating a real plant. The standard units of the dynamic simulator such as the "piping units", "heating furnace units" and "valve units" were utilized in them to the maximum possible extent.

4.6 Operation training functions

The developed training simulator has the following four operation training functions that cover not only the training of new operators but also are engaged to refresh and enhance the skills of experienced operators in relation to the kinds of operation that are required comparatively rarely.

(1) Manual operation function

Plant facilities such as valves and pumps are operated manually, so to speak, through the HMI. This function also serves to familiarize operators with the operation of the DCS.

(2) Process monitoring function

Process conditions such as the flow, temperature, pressure at each plant facility are monitored.

(3) Non-steady state operation training function

Operations of the shut down at a blow-off and the start up at a blow-in are simulated.

(4) Abnormal state operation function

The following typical abnormal states are simulated for the training of operational measures.

(i) Change of hot stove switching schedule

Operational measures against valve troubles

(ii) Change of hot stove operation modes

The change from one hot stove operation mode to another (parallel mode, single mode, etc.)

(iii) Blast furnace gas receiving operations (gas cleaning)

The gas receiving operations at low to high pressure

(iv) Measures against abnormal states of the blast furnace (gas cleaning)

The operational measures against abnormal states of the blast furnace such as fluctuations of furnace top pressure and gas generation amount and channeling

(v) Manual operation at tripping of the TRT (gas cleaning)

Measures against tripping of the top pressure recovering turbine (TRT)

5. Advantages of Developed Training Simulator

The following advantages were realized as a result of using the developed training simulator during the relining work and the blow-in of Nagoya No. 3 Blast Furnace:

(1) Contribution to quick and smooth start-up operation

The development of the simulator was completed before the blow-off, and it was used as a tool for familiarizing all the operators of the furnace with the furnace operation before the blow-in. While the operator training had been limited to familiarization with DCS operations in the past cases of relining, operation training similar to real operation was made possible this time. Thanks to the simulator, all the operators were fully acquainted with newly introduced operation methods and guidelines before the blow-in. As a result, the blast furnace started up very smoothly.

(2) Efficient tests of DCS software

The software of the DCS was tested in combination with the process models of the training simulator; this enabled effective debugging of the DCS software in close relation with process and equipment behaviors, and high-quality software was developed as a result. The test runs of the developed DCS software using the real hardware could be completed in a short period, thanks to improved software quality.

(3) Smaller production loss at gas channeling in the furnace

Thanks to the training of measures against abnormal conditions of the process and equipment, it became possible to take quick and adequate operational measures in abnormal situations. As a result, furnace interior pressure has come to be quickly rectified by prompt countermeasures on occasions of furnace problems such as channeling, and the time period of reduced blast volume operation has been made shorter.

In addition to the above, the developed training simulator is expected to be useful as a tool for studying revisions of furnace operation and control guidelines by improving the accuracy of the process models of the simulator as well as for supporting software development, especially for the debugging of DCS software newly added or modified on the occasions of temporary shutdowns.

6. Closing

A plant operation training simulator for a blast furnace that offers trainees a realistic feeling of monitoring the operation of a real blast furnace was developed at a low cost and in a short period of time by utilizing the application software of a real plant control DCS and employing the same type of HMI as that of the real system.

The simulator, which has been introduced to No. 3 Blast Furnace of Nagoya Works, is a compact system composed of an HMI and EWSs. It is installed near the operators' room for easy access, not only for scheduled training exercises but also for personal learning efforts of individual operators. It can be accessed by any operator, at any time. Thus, the simulator has proved effective for keeping and improving the skill of operators.

Reference

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