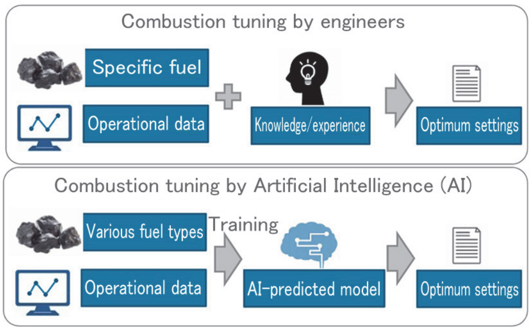
Boiler Digital Twin Applying Machine Learning



HIDETOSHI AIKI*1 KAZUHIKO SAITO*2
KAZUHIRO DOMOTO*3 HIROTOMO HIRAHARA*4
KAZUTAKA OBARA*5 SOICHIRO SAHARA*6

Artificial Intelligence (AI)-related technologies based on statistical processing have been attracting attention in recent years. While AI has a feature of learning data, in-service power plants generate operational data every second. If AI could learn these data and help achieve better operating conditions, it would be possible to build a more flexible control system, supplementing the conventional-style control process. This report will describe the installation procedure for Digital Twin, which can contribute to the enhancement of our clients' earning capacity by increasing the economic efficiency of power plants, and also presents an overview of Digital Twin's features, its system structure and an actual introduction example in Taiwan.

1. Introduction

Recently, due to the various changes in the market such as electricity deregulation and the introduction of renewable energy, flexible operational performance, O&M optimization and performance improvement are in greater demand. Under such circumstances, there has been active development in a wide range of services utilizing Information and Communication Technology (ICT) and data science (e.g., big data analysis and AI technology).

Digital Twin is an example of data science application, which collects information from actual devices and plant facilities and reproduces it in a digital space on a computer network in real time.

Mitsubishi Hitachi Power Systems (MHPS) began offering digital solution service "MHPS-TOMONI" in 2017, where cutting-edge technologies are applied to optimize the operation of thermal power plants to help boost the client's earning capacity by increasing the plant's economic efficiency.

The list of services of "MHPS-TOMONI" for coal-fired boilers includes remote monitoring, anomaly prediction/early detection, performance diagnosis and efficiency improvement. Among them is Digital Twin for boilers as an efficiency-booster service. Digital Twin for boilers collects the measurement data of thermal power boilers such as pressure, temperature and flow rate, utilizes AI technology including machine learning and MHPS's expertise as a boiler manufacturer, and reproduces a virtual boiler on a computer with the same behavioral patterns as the real unit, providing feedback to the control system of the real unit on the optimum settings. Digital Twin is illustrated in **Figure 1**. We believe that the development of this technology will lead to the establishment of automatic autonomous operation in the future.

This report will explain Digital Twin in terms of how it contributes to improved boiler efficiency and reduced auxiliary power.

*1 Senior Chief Engineer, Power & Energy Solution Business Headquarters, Mitsubishi Hitachi Power Systems,Ltd.
*2 Manager, Boiler Business Strategy Planning Department, Boiler Technology Integration Division, Mitsubishi Hitachi Power Systems,Ltd.
*3 Manager, Boiler Engineering Department, Boiler Technology Integration Division, Mitsubishi Hitachi Power Systems,Ltd.
*4 Boiler Business Strategy Planning Department, Boiler Technology Integration Division, Mitsubishi Hitachi Power Systems,Ltd.
*5 Nagasaki Power Systems Service Department, Power Systems Service Headquarters, Mitsubishi Hitachi Power Systems,Ltd.
*6 Control Systems Department, Project Management Division, Mitsubishi Hitachi Power Systems,Ltd.

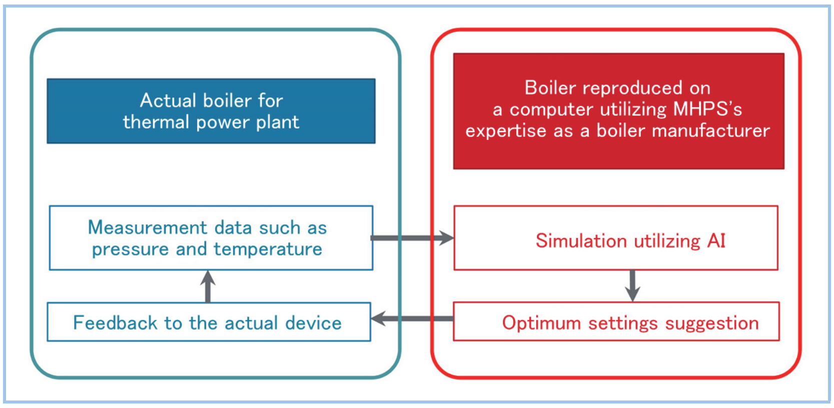


Figure 1 Digital Twin

2. Machine learning model

Generally speaking, basic technologies for artificial intelligence include rule-based control systems, deductive systems, machine learning and deep learning, whereas their applied technologies include question answering systems, search engines, image recognition, natural language processing and voice recognition. These are the technologies simulating (replicating with an engineering approach) one aspect of human intellectual activities.

The conventional control systems delivered to thermal power plants have an automatic operation feature which is mainly "based on strict rules and operable under certain conditions," an example of which is the start-stop function of power plants.

On the other hand, there is a possibility to develop a more flexible automatic operation feature by applying the above AI technologies. Machine learning is roughly classified into supervised learning, unsupervised learning and reinforcement learning. In this regard, Digital Twin for boilers adopts the kind of machine learning which would be classified as supervised learning to replicate measurement data such as pressure, temperature and flow rate.

3. Digital Twin installation work flow

The Digital Twin installation work flow consists of the following steps to solve clients' problems while achieving their understanding of the whole process. Each step will be described in **Figure 2**.

	Assessment	PoC	Installation	Additional learning
Outcomes	Reports	Reports	Reports, applications, pre-trained models	Pre-trained models
Contracts	Non-disclosure agreement, etc.	Installation validation agreement	Digital Twin installation agreement	Additional learning agreement

Figure 2 Digital Twin installation work flow

(1) Assessment

This is where any issues related to improved plant operation, (i.e., the reduction of fuel consumption, NOx amount, unburnt ash contents and auxiliary power) are discussed. A further discussion is held as to whether Digital Twin construction would be a good solution for the existing issues or whether there are any other ideas.

Meanwhile, to protect the operational data, a non-disclosure agreement is made with the client prior to receiving a certain amount of data for our review. Then, the amount and quality of the data is examined to determine whether a pre-trained model suitable for the purpose can be created.

(2) PoC (Proof of Concept)

This is where a pre-trained model is created and its accuracy is improved. Furthermore, a table-top optimization study is conducted utilizing the pre-trained model to help the client understand what kind of actual advantages can be gained by constructing Digital Twin.

Then, a pre-trained model with a high level of accuracy is constructed by making it learn MHPS's expertise as a boiler manufacturer (an enormous amount of knowledge/experience, as well as a deep understanding of physical phenomena) and the client's knowledge and expertise on operation and maintenance.

(3) Installation

Boiler Digital Twin is installed in the actual power plant. The connection with the control device is examined, communication is established with it and a combustion test and an optimization test are run on-site before evaluating the advantages quantitatively.

(4) Additional learning

This is conducted upon the client's request. Utilizing an additional dataset for learning, the pre-trained model obtained in (3) above is updated.

4. Overview of Boiler Digital Twin features

The major features of Digital Twin are described below.

(1) Monitoring feature

In terms of the main parameters of the boiler, operational data are indicated in the system diagram rather than in a table, for the purpose of achieving a more user-friendly interface. The data consist of the measurements of the water/steam system, air/gas system, instruments around the mill and burner. A monitoring screen is shown in **Figure 3**.

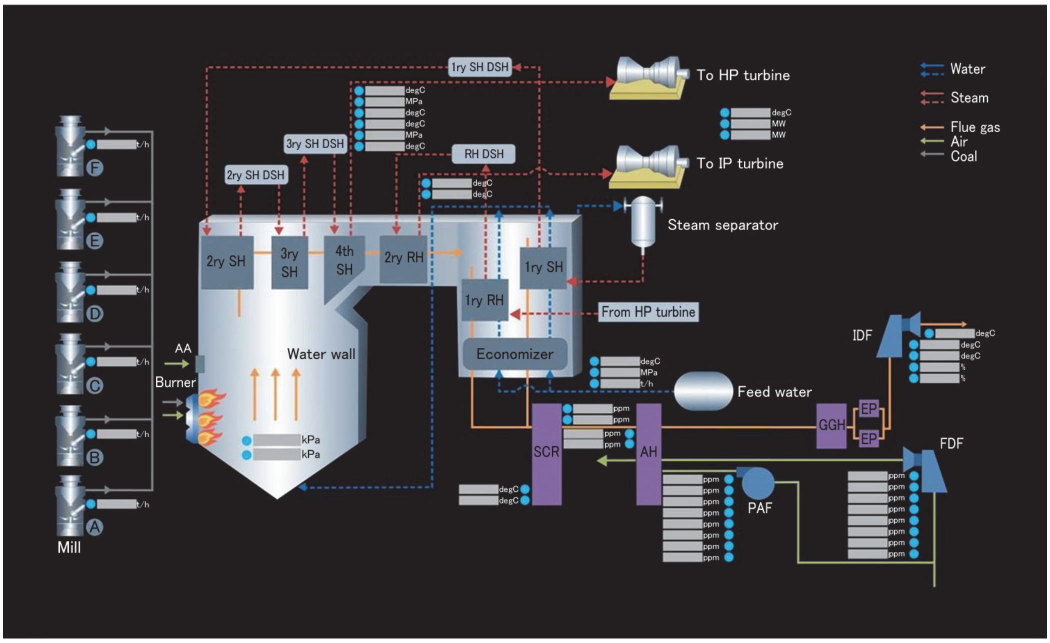


Figure 3 Monitoring screen

(2) Prediction feature

Real-time prediction of process values is available utilizing a pre-trained model. In terms of coal-fired boilers, some process values (boiler properties) fluctuate depending on the different kinds of coal used. However, MHPS has already experienced building a pre-trained model which is capable of predicting the properties of multiple types of coal, as well as biomass co-combustion, not just medium fuel-ratio coal which is the commonly used fuel.

(3) Optimization feature

Target values are set for major parameters which experienced engineers would consider in combustion tuning. Digital Twin suggests the optimum settings that are economically efficient (i.e., reducing fuel consumption, ammonium consumption and auxiliary power) and has no problem in terms of the setting parameters (i.e., satisfying the target values). Operators in power plants may choose to either reflect or not reflect the suggested optimum settings in the control device.

Settings for various operation terminals (e.g., damper opening settings) in power plants that are selected at the time of a test run are determined according to the design coal or test coal. Various types of coal are used in the clients' actual operation and boiler properties change depending on the coal used. Boiler properties vary due to age after being used for many years. The conventional control systems also allow the settings to be adjusted according to the change of coal types. However, the flexible adjustments in the settings whenever a change occurs, as explained above, would enable delicate optimum operation, cutting down on operational expenses.

(4) Change in target values

Target values may be adjusted according to the client's needs. For instance, it is possible to conduct reduced NOx operation in consideration of environmental performance, operation with reduced fuel consumption focusing on economic efficiency or having a good balance among environmental performance, economy and operational efficiency, as can be seen in **Figure 4**.

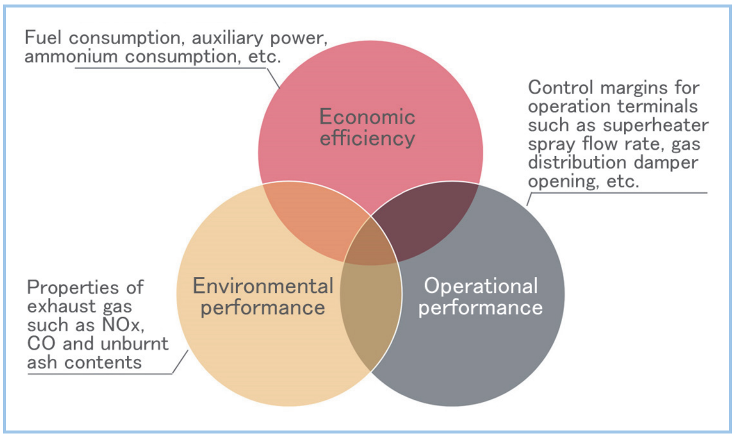


Figure 4 Optimum settings suggested by Digital Twin

5. System configuration

MHPS has 2 solid accomplishments (**Figure 5**) in system configuration as follows.

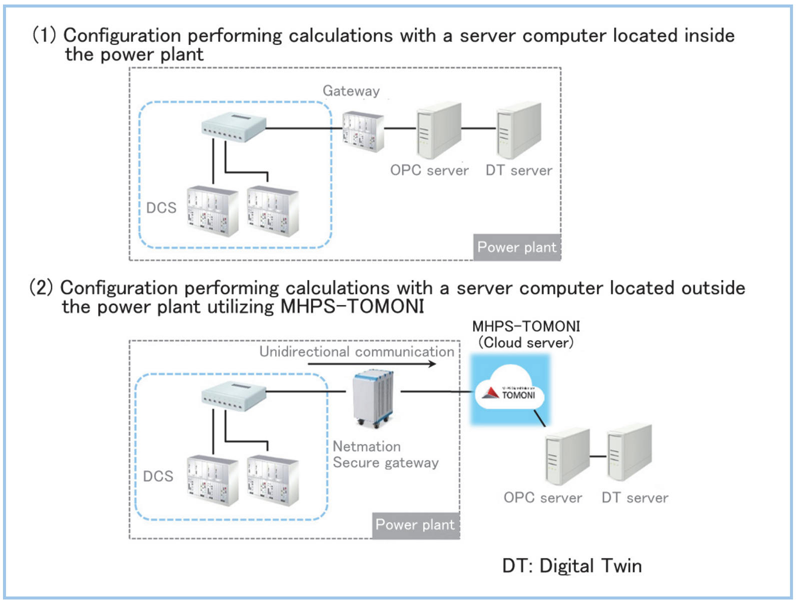


Figure 5 System configuration

(1) Configuration performing calculations with a server computer located inside the power plant:

This is one form of system configuration where the plant control device is connected to a Digital Twin server without any connection to external networks, which sends the optimum setting parameters calculated on the server back to the control device. The optimum settings can be obtained whenever the client needs them.

(2) Configuration performing calculations with a server computer located outside the power plant utilizing MHPS-TOMONI:

In this system configuration, operational data is transmitted to MHPS-TOMONI from power plants via Netmation Secure Gateway (NSGW), MHPS's data diode (unidirectional communication). This allows calculations of the optimum setting parameters on a Digital Twin server built in MHPS-TOMONI.

MHPS suggests the optimum setting parameters to the client based on the calculations carried out according to the client's needs such as changes in the types of fuel used. In this configuration, the optimum setting parameters calculated on the server should be updated manually, since they would not be fed back to the control device automatically.

In terms of security, utilizing MHPS's NSGW can block access from networks outside of the plant. Accordingly, a secure plant network can be achieved, fully protected from any external attacks.

In addition to those mentioned above, better configurations will continue to be discussed and proposed for our clients' best interests.

6. Installation of Taiwan Linkou Power Plant Unit 2

6.1 Combustion tuning optimization feature (Steps 1 and 2) and operational cost optimization feature (Step 3)

Below is the actual installation project of Digital Twin in Linkou Power Plant Unit 2 (800MW) of Taiwan Power Company (Taiwan Power).

Step 1 consists of system configuration and the construction of a machine learning model utilizing operational data from the actual device. In Step 2, optimization tests were carried out where Digital Twin, dedicated to the optimization feature for combustion tuning (mainly in environmental and operational aspects), was installed as application software. Consequently, the adjustments to various parameters (indices) achieved a proper combustion balance, allowing successful process optimization in terms of the environmental and operational performances.

In Step 3, a different feature, which predicts changes in process values in terms of economic efficiency such as boiler efficiency and auxiliary power, was added to the features mentioned in Steps 1 and 2, equipping the parameters suggested by Digital Twin with improved economic effects (the operational cost optimization feature). Furthermore, the machine learning model has become capable of handling multiple types of coal by learning data of various coal types. **Figure 6** illustrates the installation process of the Digital Twin adopted in Linkou Power Plant.

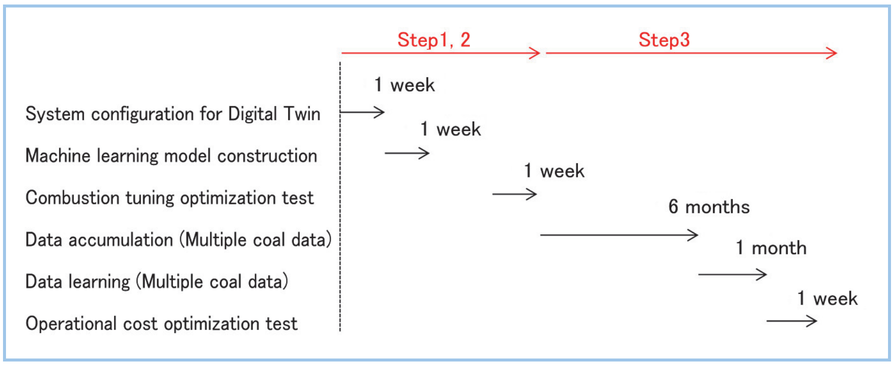


Figure 6 Digital Twin installation process

6.2 Installation results and effects

In Step 1, it was confirmed that creating a highly-accurate model is possible through a test where a machine learning model would learn the trend of fluctuations in the installation process by applying different values to multiple parameters. In Step 2, the process was optimized utilizing the pre-trained model. The optimization test includes "Overall optimization test with a good balance of exhaust gas characteristics, steam temperature, etc." and "Optimization test focusing on certain process values (e.g., NOx)" while applying different target values. **Figure 7** presents the combustion tuning results from Steps 1 and 2. For example, when the limit value for NOx was

100%, experienced engineers would make some adjustments to keep it down to around 70%, whereas Digital Twin's adjustments also achieved 69%, which confirmed Digital Twin was capable of adjusting the settings as good as the human engineers. Moreover, Digital Twin's estimate then was 65%, which was quite accurate in light of the actual value. This tendency has been confirmed in terms of the spray valve opening, which needs to be within the control range, as well as the metallic temperature distributed on every panel.

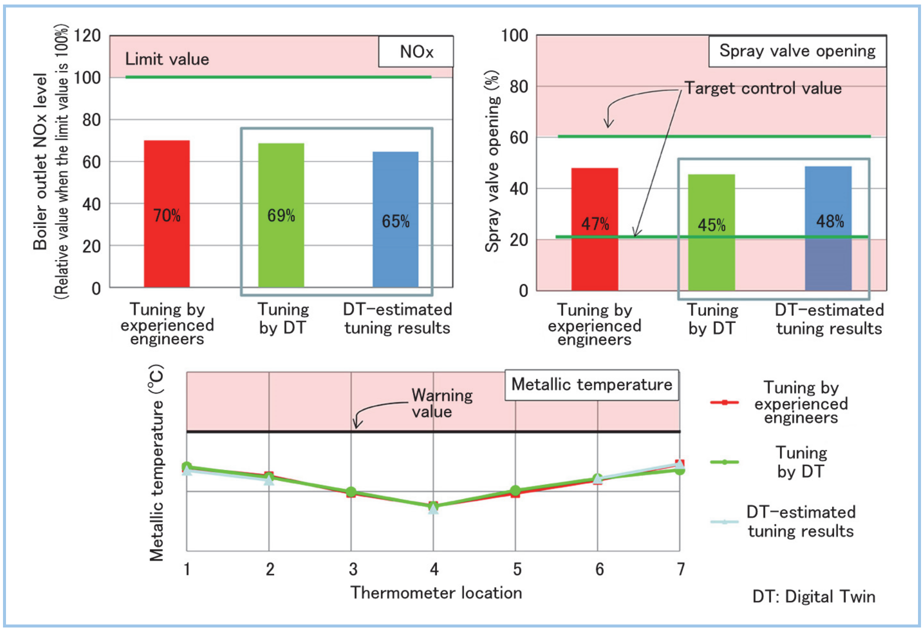


Figure 7 Results of Digital Twin combustion tuning

In Step 3, a test focusing on operational cost optimization was performed while maintaining a certain amount of control margin for load change etc. **Figure 8** gives the results of the cost reduction effect achieved by the operational cost optimization feature in Step 3. The condition before Boiler Digital Twin was installed is referred to as "the benchmark cost," by contrast with which we evaluate the cost reduction realized as a result of the Boiler Digital Twin's control. The cost reduction effect varies depending on the types of coal or operational conditions. However, in the test, the cost reduction effect was confirmed to be about 100 million yen a year.

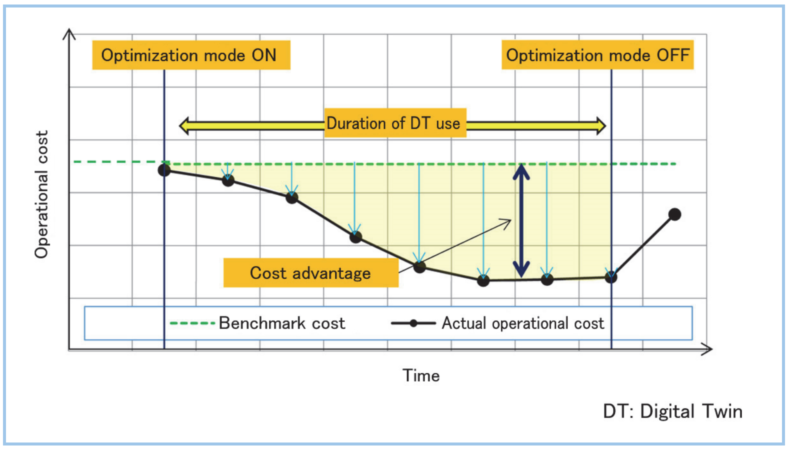


Figure 8 Results of optimum operational cost adjustment by Digital Twin

7. Conclusion

Our clients can enjoy various benefits from Boiler Digital Twin to suit their needs. Taiwan Power Linkou Power Plant Unit 2 (800MW) demonstrated an operational cost reduction effect worth 100 million yen annually thanks to the introduction of Boiler Digital Twin.

In our work flow, the PoC phase is introduced prior to installation where we help our clients understand the details and let them decide whether Digital Twin can be installed.

Among various AI technologies attracting global attention, some are being developed and put into practical use that are more advanced than the machine learning described in this paper. MHPS will continue to develop new features which would contribute to solving our clients' problems by combining new technologies and the expertise we possess as a boiler manufacturer.

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