Power Plant Fault Sign Monitoring Solution Based On System Invariant Analysis Technology (SIAT)

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Abstract

A power plant is required to operate safely, stably and efficiently so that the consumers may use electricity confidently. On the other hand, since the occurrence of faults is unavoidable, early detection and counteraction against faults are crucial. However the traditional method of monitoring threshold values of sensors have in some cases difficulty in the early detection of fault signs. The power plant fault sign monitoring system that has been developed by NEC in collaboration with power companies employs a proprietary big data technology called the system invariant analysis technology (SIAT) to detect signs of equipment faults early on and accurately by capturing any "unusual" behavior of the plant. In addition, NEC is also developing functions leading to the improvement of plant operations, with the aim of contributing to maintaining stable power supply by the power companies.

Keywords

System invariant analysis technology (SIAT), power plant, fault sign monitoring, big data, operation efficiency improvement

1. Introduction

A power plant is required to operate safely, stably and efficiently so that the consumers may use electricity confidently. On the other hand, since the occurrence of faults is unavoidable, early detection and counteraction against faults are crucial.

Plant monitoring is usually based on data obtained from sensors for temperature, pressure, flow, etc. Since monitoring of variations of a few hundreds to thousands of sensors is a very difficult task, the sensors have traditionally been monitored according to thresholds (alarm values) set based on the designs and achievements of past operations. This has led to the problem that the traditional monitoring system is not capable of detecting abnormal signs in the range below the threshold. Another problem is that the detection of abnormal signs below the threshold is hard to execute uniformly because it is critically dependent on human experience and knowledge.

As a means of resolving this issue, big data analysis technology is attracting attention because of its capability of acquiring useful information from a large amount of sensor value data by means of machine learning. NEC has developed a power plant fault sign monitoring solution using the system invariant analysis technology (SIAT). This is NEC's proprietary big data analysis technology, created jointly in collaboration with the power companies. SIAT detects "unusual" behavior at an early stage by learning the invariant relationships between sensors and by detecting any deterioration in these relationships. As a result of the effectiveness already verified regarding the past operational data of nuclear power plants, this procedure has already been introduced in nuclear power plants[1].

In this paper, SIAT and the fault sign monitoring solution are discussed.

2. System Invariant Analysis Technology (SIAT)

SIAT is a technology for detecting abnormalities by learning the invariant relationships between sensors from the sensor data in a system time series (**Fig. 1**).

For example, assuming a positive relationship in a power plant with which increasing the plant output while it is in stable operation status leads to an increased pump

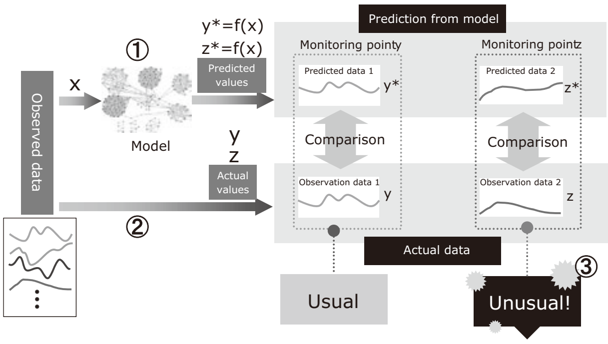

Fig. 1 Outline of system invariant analysis technology (SIAT).

pressure. Such a relationship can be expressed with a linear prediction formula such as "Pump pressure = Power output x α". SIAT compares the predictive values obtained from such formulae with the actual values and, when it detects deterioration of a relationship, it identifies it as an "unusual" behavior and outputs early detection of a faulty event.

Now let us assume a case in which the relationship described above exists. If a fault such as a crack is produced in a pump and the actual pump pressure does not vary even when the power output is increased, the pump pressure is predicted to increase. When the predicted value increases as time passes and the error between the predicted and actual values increases, deterioration of the relationship is detected and this finding is used as a pump pressure abnormality detection. In this example, threshold monitoring cannot detect the abnormality unless the pressure value rises above the threshold. Meanwhile, SIAT learns the relationships between sensors exhaustively so it does not require the labor of setting the threshold for each sensor. This means that it can be used with sensors for which the user does not have knowledge of the threshold.

3. Power Plant Fault Sign Monitoring Solution

3.1 System Configuration

The power plant fault sign monitoring solution acquires data from existing operation monitoring devices and performs analysis based on such data. This means that the fault sign monitoring system can be introduced as an addition to an existing plant, and without newly installing dedicated sensors.

The system adopts a server-client configuration with multiple clients so that monitoring staffers in different posts such as operations and monitoring departments can check the status simultaneously (**Fig. 2**). There are two kinds of servers, the "analysis server" and "storage server", so that the acquired data is analyzed by the analysis server incorporating the SIAT engine and the result is stored in the storage server. The operations available for clients include the result check and monitoring method setting.

3.2 Learning Invariant Model

The first step for fault sign monitoring is to learn the invariant model in normal operation. The invariant model refers to the set of invariants existing in the system. With the SIAT, input of time-series data in normal operation initiates exhaustive learning of the relationships between sensors and a model is created automatically. This model makes it possible to "predict the behavior of sensors under normal operation (such as the prediction of pump pressure with respect to the power output)".

3.3 Fault sign monitoring

With regard to the fault sign monitoring, the errors between the predicted and actual values of all of the invariants in the invariant model are calculated and the degree of abnormality of the entire system is calculat-

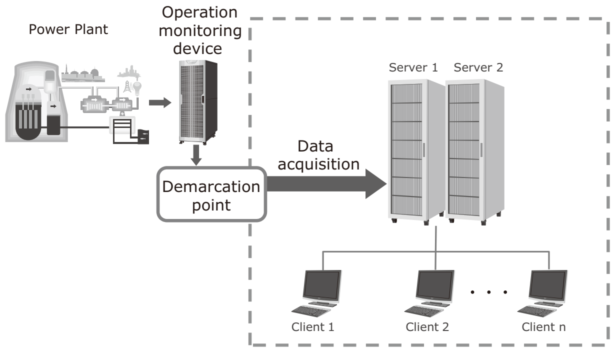

Fig. 2 System configuration.

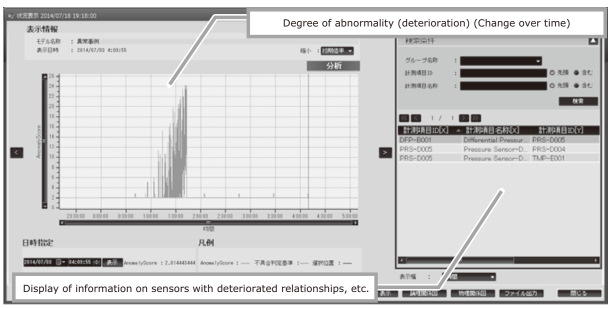

Fig. 3 Degree of abnormality display.

ed. Then, any sign of a fault is identified under certain conditions such as reaching or exceeding the degree of abnormality to or over a predefined value, or increasing in a certain degree over time (**Fig. 3**). This solution also displays the invariant model of each part of the system in order to indicate a part in which deteriorated relationships are concentrated. It assists the analysis of error positions and error causes by displaying the list of invariants with large errors and the ranking of sensors contributing to the abnormality.

4. The Effects of Introducing This Procedure in a Power Plant

There are two main effects that result from the introduction of the present procedure, which are the early detection of abnormalities and the easy identification of their causes. These effects make possible the application of quick countermeasures against abnormalities or signs of them. This enables applying countermeasures before a major fault occurs as a result of expansion of the range affected by the abnormality and thereby contributes to reducing the unplanned outage time.

The two effects described above have already been verified in several demonstration experiments. For example, in a demonstration experiment using the actual data of a nuclear power plant, we have confirmed that the power plant fault sign monitoring system can detect a sign of a fault about seven hours (depending on conditions) before that achievable by human monitoring.

Although this paper is focused on real-time plant monitoring among the functions of the power plant fault sign monitoring solution, the system is also capable of detailed analysis using previously obtained data. For example, by checking the differences between invariant models obtained by learning data of several similar plants, it enables comparison of the operating status of the plants. In addition, another function can identify the successful completion of processes, such as plant start-up and periodical inspection processes, based on comparisons with past data.

5. Current Issues, Future Perspective

With SIAT, we have achieved early abnormality detection by capturing "unusual" behavior in the plant. Identification of "unusual" behavior requires learning and modeling of the "usual" status. Modeling is now possible by setting the period to be learnt from the past plant data.

As an example of modeling, we give the case of a nuclear power plant in which the power plant fault sign monitoring solution has been applied. Since the nuclear power plant is run as a base power source, it is generally required to run stably for a long period. This means that learning the period of stable operation enables modeling of the "usual" status. For example, learning the data of the past week enables abnormality detection.

On the other hand, with the power plants run as peak power sources such as the gas turbine power plants, each running period is relatively short and sometimes startup and stoppage are repeated every day. For such power plants, the operational status varies subtly every day or hour, so how to learn the "usual" status becomes problematic.

The power plant fault sign monitoring solution is required to provide functions other than fault sign monitoring. For example, the issue of operation efficiency improvement is more critical for thermal power plants than for nuclear power plants. For coal-fired thermal power plants, efficiency improvements are regarded as having a big potential for cost reduction because the overall efficiency varies significantly depending on coal type, plant condition, operation status and the equipment degradation situation.

Below, we discuss expansion of coverage of the system and the provision of new values by adding new functions.

5.1 Targeted Domains

In the case of a power plant where startup and stoppage are repeated every day, such as a gas turbine power plant, it is necessary to learn the "usual" status by taking the differences in operating situations on different days into consideration. In order to meet this requirement, we have developed the technique of entering the data of several operation periods to learn a model commonly applicable to each period. This function ensures early abnormality detection even if the operating situation varies slightly after every startup.

With a power plant using a renewable energy such as photovoltaic cells or wind turbine generation, the plant operating situation varies widely due to big fluctuations in the power output, depending on the weather for each day or season. Since it is difficult to lean the "usual" status from more than one operating situation, we have developed a technique that learns several operation status models by means of patterning, etc., and detects abnormalities by switching the models automatically one after another.

5.2 Provision of New Values by Addition of Functions

For the future, we are planning the enhancement of the abnormality cause identification functions and the development of functions that can contribute to improved operational efficiency.

The currently available abnormality cause identification functions include the ranking of sensors that may be causing the current abnormality. However, countermeasures to be adopted for each abnormality will still need human intervention for visually checking the changed sensor values. To eliminate this task, we are examining the development of a function that can propose countermeasures to deal with any newly occurring abnormalities.

With regard to functions for improving the operation efficiency, we are examining the development of a function that can compare the models obtained from two kinds of data acquired from two operations with different operational efficiencies such as the data from two plants with different combustion efficiencies or that of two different periods, therefore, it makes it possible to extract the sensors causing the difference in efficiency as well as the relationships between sensors. This function is expected to enable examination of efficient operations with low fuel consumption and to contribute both to improved economy and environmental load reduction.

6. Conclusion

In this paper, we have discussed the system invariant analysis technology (SIAT) and our fault sign monitoring solution. In the future, in addition to improving the accuracy and enhancing the abnormality cause identification function, we will develop solutions leading to operational efficiency improvement in order to contribute to stable power supply by the power companies.

Reference

1) G. Jiang, H. Chen and K. Yoshihira, "Discovering likely invariants of distributed transaction systems for autonomic system management", The 3rd International Conference on Autonomic Computing, Dublin, Ireland, June, 2006.

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