Implementation of predictive diagnosis algorithms for RCPs

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1. Introduction

Existing nuclear power plants operate separate systems for monitoring the status of Reactor Coolant Pumps (RCPs), such as the RCP Vibration Monitoring System and PI System (PMS). This makes it difficult to prevent similar failures and analyze root causes. To overcome this issue, we have developed an online predictive maintenance system specifically targeting standard-design nuclear reactors (OPR) with a focus on real-time remote monitoring and diagnosis of critical components like the RCPs. The RCP diagnostic engine is implemented to perform real-time predictive diagnosis of RCP status through data models, narrowband models, diagnostic rule models, ML (Machine Learning) models, and DL (Deep Learning) models. Each model diagnostic result and comprehensive diagnosis results are stored in big data and operational databases, and the machine learning diagnosis system management module is implemented to manage program setting information, execution environment, and each program status of the machine learning server. In the visualization server, when users update diagnostic model data or information through the diagnosis engine generation module, programs have been implemented to update the diagnostic engines on the machine learning server via the diagnosis engine transmission module and the engine updating module.

2. RCP Predictive Diagnostic System

The RCP predictive diagnostic system has established and networked to remotely perform real-time precision diagnosis of the integrity of operating pumps (four per unit) in target OPR nuclear power plants.

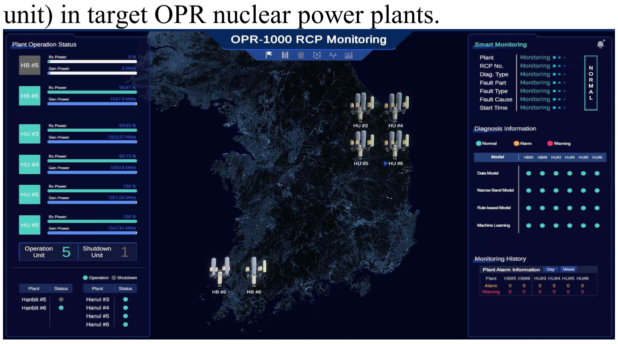

Fig. 1. Plant Level Monitoring of RCPs

2.1 Data-driven Diagnostic Algorithm

Data-driven diagnostic technology is an effective monitoring model-based diagnostic algorithm that early detects abnormal occurrences during normal operation. The RCP related system (including CCW, ESW, CVCS, and RCS) is an extremely useful identifier that helps determine whether a failure in the RCP occurred due to issues within the pump itself or external influences. The diagnostic model was developed for the main components of the RCP, including Motor, TBA, and Seal, to diagnose the exact cause of any abnormalities by considering driving variables related to systems affecting the operation of the RCP. Data-driven diagnostic technology diagnoses an abnormal state when there is a deviation of the model dynamic band between the learning model value and the actual sensor value. Data-driven diagnostic algorithms consist of two main components: model data generation and AAKR algorithm. If the residual value is out of the dynamic band, early detection (anomaly detection) of abnormal state occurs. Therefore, data-driven diagnostic algorithms require very important model-based driver grouping through correlation analysis and selection of model data, as well as configuration optimization for the AAKR algorithm.

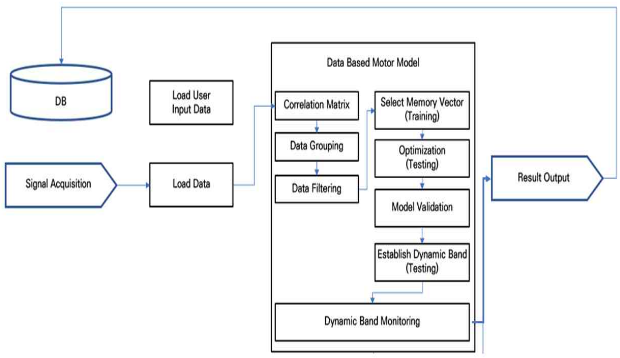

Fig. 2. Processing Schematic Diagram

The data model program stores prediction diagnosis result data in the operational database, and the visualization program allows for displaying the data model's prediction diagnosis results on real-time monitoring contents and diagnostic screens from the DB server.

2.2 Rule-based Diagnosis Algorithm

Rule-based diagnostic technology is a technique that builds on expert knowledge by converting various experience information of experts into knowledge and then uses machine learning for automatic diagnosis. This technology identifies pump failure based on changes in operating conditions of RCP related components and connected components such as CCW, ESW, CVCS, RCS etc. using rule sets to diagnose faults. Industrial rotating machinery in general can develop machine learning diagnostic technologies using multiple defect data that is available for use. However, in the case of RCP, there is insufficient failure data to utilize these techniques effectively. Therefore, developing rule-based diagnostic technology to compensate for this lack of information becomes very important. Rule-based diagnostic algorithms consist of two main components: rule set generation and database construction, as well as development of Bayesian inference engines.

2.3 Narrowband-based Diagnostic Algorithm

Narrowband-based diagnostic techniques rely on amplitude and phase information of frequency components in RCP vibration signals to diagnose defects, and they have been widely used in rotating machinery diagnostics. When rotating bodies fail, they have specific frequency and phase shift characteristics depending on their component structure and operation, which is why they are widely used in industry for diagnosing rotating machinery. The narrowband diagnostic algorithm consists of three main components: noise removal, narrowband parameter extraction, and rule-based diagnostic algorithms. Noise removal is to remove various noise components contained in vibration signals collected on site, and narrowband parameter extraction refers to detecting frequency and phase components included in the vibration signal through synchronous / asynchronous signal processing. The diagnostic algorithm identifies defects by inputting narrowband parameter components to the diagnostic algorithm. The details are as follows.

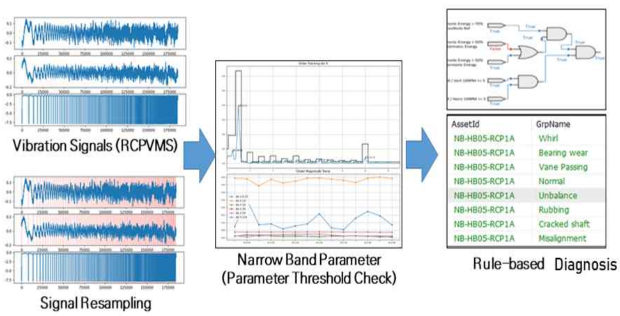

Fig. 3. Narrowband-based Diagnostic Process

2.4 Support Vector Machine (SVM) based diagnostic algorithm

The SVM-based diagnostic technique involves learning feature information extracted from vibration signals and then calculating features for real-time inputted vibration signals to identify which class they belong to in order to diagnose fault conditions. The Support Vector Machine (SVM) based diagnostic algorithm consists of two main parts: extracting and learning features, and identifying defect states using SVMs. Feature extraction involves performing operations on collected vibration signals in three domains - time domain, frequency domain and entropy domain to select features that have good identification capabilities for normal and fault conditions. The SVM fault identification process involves calculating feature vectors of real-time vibration signals measured by the learning model and then classifying them to determine which state they belong to in order to identify the fault condition. A classifier for fault diagnosis is an essential part of health monitoring and fault detection systems as it affects the overall classification performance.

3. Conclusions

The RCP Automatic Predictive Diagnosis System enables real-time monitoring and diagnosis of equipment status remotely to prevent unexpected failures in RCPs and improve operational efficiency. The RCP diagnostic engine has developed and applied data models, narrow-band models, diagnosis rule models, ML (Machine Learning) models, DL (Deep Learning) models for real-time predictive diagnostics. The surveillance and diagnostic AI algorithms applied to the system are currently undergoing validation and internalization at the same time.

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