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Development of a Plant Health Index Monitor

Gyunyoung Heo[a*], Sang Ha An[b], Ho Joon Seo[c], Cho Kim[d]
[a] *Kyung Hee University, Yongin-si, Gyeonggi-do, 446-701, Korea*
[b] *Korea Advanced Institute of Science and Technology, Yuseong-gu, Daejeon, 305-701, Korea*
[c] *BNF Technology Inc., Yuseong-gu, Daejeon, 305-500, Korea*
[d] *Korea South-East Power Co., Ltd., Gangnam-gu, Seoul, 135-791, Korea*
[*] *Corresponding author: gheo@khu.ac.kr*

1. Introduction

Since 2008, BNF Technology Inc. and Kyung Hee University have developed the ‘Plant Health Index (PHI)’ which is a software package to detect ‘unhealthy conditions’ of plant equipments in advance. While the difference between a setpoint and an operational condition is called ‘process margin’, the residual between an anticipated normal condition and an operational condition is called ‘process uncertainty’ or ‘healthiness’ in this study. It is obvious that the anomalies in process uncertainty can be observed earlier than those in process margin, which is the concept of ‘early-warning’ proposed in the recent condition-based maintenance (CBM) studies. One of the key factors for implementing the early warning capability should be how to expect the anticipated normal conditions using available information. The PHI was developed on the basis of empirical models, and we have published a few papers with regarding to the core technologies of the PHI [1]. However, the overall architecture and features of the PHI have not been introduced to academic area so far. This paper delineates the overview of the PHI, and focuses on the recently developed module, which is the health index generator.

2. Methods and Results

2.1 Benefits of PHI Monitoring

The PHI has the capability of (1) detecting the process uncertainty called as health index for individual signals as well as for an entire plant, (2) warning anomalies in health indices, and (3) customized user interfaces and historians. Since the PHI separately deals with safety-related as well as performance-related health indices, users are able to have appropriate decision-making in terms of their situation.

2.2 System Architecture

The PHI is based on client-server based architecture as shown in Figure 1. The server side is divided into the core modules necessary to build the PHI functionality and the PRISM, a real-time database developed by BNF Technology. The clients are divided into the standard client and the web-based client. The standard client has index display, tree display, counseling display, trend display, configuration manager, model display, and several utilities. Figure 2 shows the main display of the PHI client. All of these functions bridge the information of the server side with users.

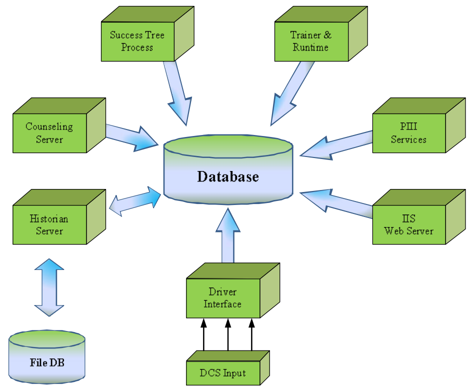

Figure 1. Server architecture of the PHI

2.3 Theory of Operation

Figure 3 shows the backbone algorithms of the PHI, which is based on empirical models. The detailed theory of operation has been published in several references [2, 3]. We are still improving advanced algorithms, for instance, (1) the grouping method based on statistical information and heuristic judgment, (2) the shrinking method based on data dispersion, and (3) digital data management. All of these algorithms have been tested using simulated and field data. We have also validated the performance of the PHI in the IAEA CRP.

Figure 2. Main display of the PHI

We have finished the development of all the modules using MATLAB for research purpose and the PHI has the executable files of the MATLAB source codes for commercial purposes.

2.4 Development of Health Index

The algorithm for generating the health index was appended recently even though the concept was established at the beginning of the study. The health index is characterized as a normalized number which can fuse the following three aspects: (1) safety-related and performance-related parameters, (2) process margin and process uncertainty, and (3) individual parameter-level and system-level, so that it improves the operator's awareness for overall plant conditions.

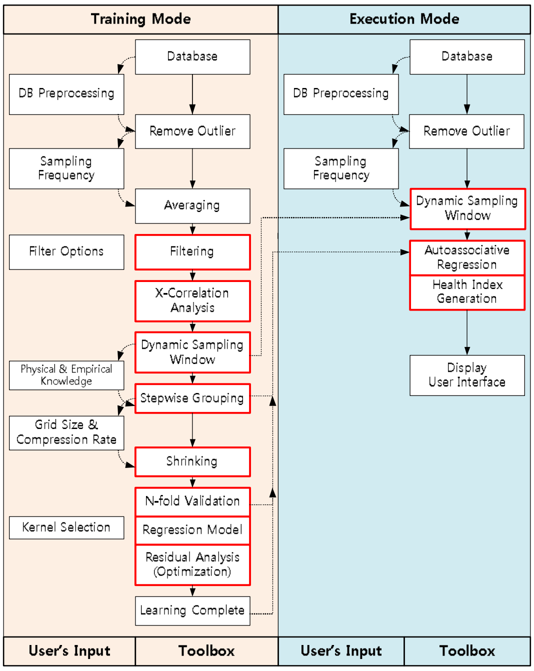

Figure 3. Algorithms of the PHI (Bold: Developed)

The nominal conditions (μ) are defined as the design conditions. In case of safety-related parameters, the setpoints (x_{set}) are defined as the trip- or alarm-setpoints depending on applications. Performance-related parameters have the setpoints as a certain limit which can be allowable in terms of cost. Focusing on the process margin, if a current operation condition (x) approaches to the nominal conditions, the health index should be 1.0. As opposed, if an operating condition approaches to the setpoints, the health index should be 0.0. The health index between two boundaries is dependent on how we characterize the health index distribution. The health index for this category (HI_{margin}) can be proposed as Equation (1):

$$HI_{margin} = 1 - \left(\frac{x - x_{set}}{x - \mu} \right)^2 \qquad (1)$$

In terms of the process uncertainty, the health index is characterized by the residual deviation. The health index is 1.0 if a current operating condition is same with the model estimate (x_{est}) (i.e. the residual is 0.0), and is 0.0 if the operating condition is far enough from the model estimate (i.e. the residual is infinity) as shown in Equation (2):

$$HI_{uncertain} = e^{-(x - x_{est})} \qquad (2)$$

The overall health index ($HI_{overall}$) of a parameter can be represented by the combination of two health index in Equation (3):

$$HI_{overall} = HI_{margin} \times HI_{uncertain} \qquad (3)$$

While $HI_{overall}$ represented the health index of an individual parameter, the health index at a system-level can be managed by the conditional combination of the individual parameters' health index. The system-level health index of safety-related parameters (HI_{safety}) is determined as the minimum health index to provide the conservative awareness as Equation (4):

$$HI_{safety} = \min_i (HI_{overall,i}) \qquad (4)$$

The system-level health index of performance-related parameters ($HI_{performance}$) is determined as the minimum health index to provide the realistic awareness as Equation (5):

$$HI_{performance} = 1 - \sum_i (1 - HI_{overall,i}) \qquad (5)$$

Since a stakeholder considers safety and performance, the PHI can deals with two kinds of health indices separately. However, it should be noticed that the health index distribution in Equation (1) and (2), the weighting factors of each term in Equation (3), and the combination of system-level health index can be changed depending on plant situation.

3. Conclusions

This solution was applied to a coal-fired unit and is operating now. Since the PHI is based on empirical models, the PHI is expected to work in nuclear stations. Considering the uncertainty of the empirical models, we particularly recommend to apply the PHI for the implementation of CBM for non-safety purpose, for instance, efficiency management.

ACKNOWLEDGEMENT

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