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A Structure of Evidence Theory-Based Power Plant Diagnostic System for Stable Electricity Supply in Deregulated Environment

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Abstract

A reliable and easy maintainable system for power plant is essential to a stable electricity supply and this function cannot be possible without proper failure detection and diagnosis system. This paper presents a structural study on a synergistic diagnosis system for turbine-generator power plant. The evidence theory of the Dempster-Shafer uncertainty rule and its belief combination method is utilized to combine several different diagnostic methods.

I. INTRODUCTION

For the last decade, the power plant facilities have gown in its generation voltage and capacity to meet the increased load incurred by rapid industrialization and consumer demands. Efficiency of power plant facilities is improve by design, manufacture technology and electric materials improvement, however, unexpected breakdown occurrence still brings about either shut-down or decreased output power causing economical damage. To prevent an unexpected failure in power plant, diagnostic measures should be provided and there are a few methods available[1].

Diagnostic methods for power plant facilities are divided into three parts: electric, mechanical, and attached unit parts. Diagnosis for electric part is to diagnose about electric circuit and, generally, detect internal trouble of power plant facilities using insulation diagnosis. Diagnosis for mechanical part is to detect machinery failures in rotational machinery bearing or shaft using vibration analysis. Diagnosis for attached unit part includes diagnosis of refrigeration and circulation device units[2].

Power plant facilities are very complex in structure and have various failure factors and, currently, diagnostic methods of above three area are not complete and their failure detection is not precise: the diagnostic methods are exclusive and come to conclusion under confined and unique condition. Therefore, instead of using one diagnostic method, the combination of the methods, and thus utilizing the advantage of the methods may be a reasonable solution for better and precise detection of incipient failures in power plant[3].

To realize this synergistic diagnostic system, we need information on each diagnostic method's strength and weakness in various conditions and environments. However, this piece of information is not precise and, in most cases, uncertain. Therefore we need a reasoning and combining theory which can handle multiple uncertain beliefs (or confidences). Dempster-Shafer evidence theory is known to manage with several uncertain beliefs, and we utilized this evidence theory to produce synergistic diagnostic conclusion[4].

II. PLANT DIAGNOSTIC METHODS

As briefly stated above, there are three types of diagnosis method available for power plant facilities: diagnosis for electrical part such as generator winding and coil; diagnosis for mechanical parts such as unbalance, misalignment, oil whirl and looseness in bearings, shafts or rotating units; and diagnosis for attached parts of refrigeration and circulation device units.

There are several different diagnostic methods on each of the three areas. On the same element of the power plant, diagnostic methods use same or similar parameters as their inputs to determine the status of the element. Hence, it is extremely useful if we can find a way to combine the results of each individual diagnostic methods to produce a resultant conclusion on the status of an element in question. Actually, in the U.S., electric companies are moving toward the application of combination for useful and cumulative effect at predictive maintenance for power plant facilities[3].

A. Vibration Diagnosis

Failure data reveal that between 30% and 50% of all fossil-fuel power plant downtime is caused by failure of the rotating equipment; fans, pumps, drive turbines, and turbine-generators[5]. Generally, rotational machines have a failure phenomenon of misalignment, unbalance, rubbing, and oil whirl and it is possible to diagnoses about rotational machines by examining following parameters: main frequency range of failure signal, shape of rotational axle, main vibration frequency occurrence range and magnitude on abnormal operation[6].

B. Insulation Diagnosis

There are three methods in this area of diagnosis: megger method, high voltage method, and partial discharge method. Megger diagnostic method is, using a Megger device, to measure insulation resistance. This diagnostic method identifies insulation resistance necessary to operate rotational machines on normal operation. However, it is very difficult to decide a absolute standard about insulation in rotational machines.

DC high voltage diagnosis method measures current level while applying DC high voltage to insulated material; current level is decreased with time if insulation level is low. Partial discharge happens at insulated material which has void of electrode. When there is a void, applied voltage is decreased by the partial discharge of the void. There are various and different size of void existent in real insulated material, so partial discharges alone cannot effectively check the status of insulation failure[2].

C. Acoustic Emission Method

Acoustic emission (AE) diagnostic method is to detect sudden energy release from cracks, variation and transformations of material. This method is used mainly to diagnose bearings damage caused metallic rubbing, touching, internal particle occurrence, and invasion of foreign material[2].

D. Problems of Current Diagnostic Methods

The vibration method is fairly good to detect failure, however, this diagnosis method, also reaches at a wrong conclusion about failure. Also, other method has some weak point in drawing conclusions. In some cases, therefore, we might have a scenario that a certain method confirms a failure in an element and another disconfirms the failure and, instead, confirms another failure as illustrated in Figure 1. Therefore, we have to have a systematic way to handle this perplexing situation.

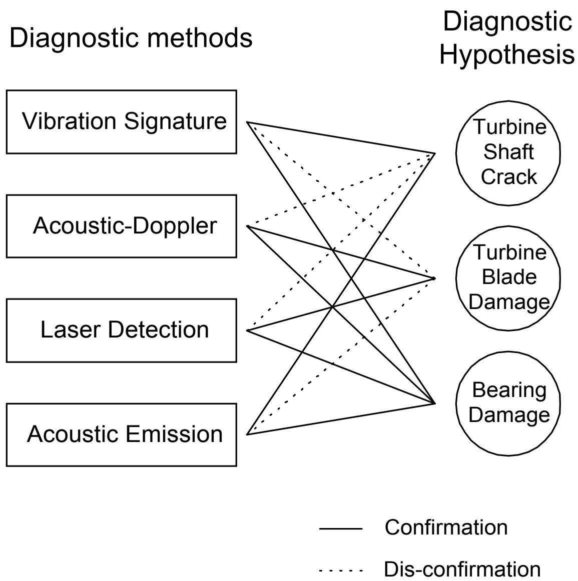

Figure 1. A hypothetical situation in plant diagnosis

III. UNCERTAINTY REASONING AND DEMPSTER-SHAFER THEORY

A. Incomplete Knowledge and Uncertainty Reasoning

The power plant facility failures are very complicated and mixed, therefore, it is extremely difficult to obtain complete knowledge and information about failure factors. Therefore, we should have a system which makes it possible to form an optimal and highly reliable diagnosis system by utilizing the incomplete knowledge and information.

To construct a system which can find out failure factors and thus diagnose, it is most important to be equipped with an ability to collect information on failure factors in plural number of failures. And the failure factor has a belief level or probabilistic value depending on a given signal and data. An uncertainty reasoning method, Dempster-Shafer evidence theory manages with plural number failure factors of uncertain information. In the next section, we review the Dempster-Shafer theory and suggest a diagnosis system structure for power plant.

B. Dempster-Shafer Evidence Theory

<u>Belief Function</u>

The Dempster-Shafer evidence theory like Bayesian theory, relies on degrees of belief to represent uncertainty[4]. Unlike Bayesian theory, however, it permits one to assign degrees of belief to subsets of hypotheses. In Bayesian theory, one constructs a probability distribution over all individual singleton hypotheses, but in the evidence theory, a distribution is constructed over all subsets of hypotheses. This is a great advantage.

The Dempster-Shafer theory uses a number in the range [0, 1] to indicate belief in a hypothesis given evidence. This number is the degree to which the evidence supports the hypothesis. The impact of each distinct piece of evidence on the subsets of frame of discernment, denoted Θ, which are all the case of cause or status, is represented by a function called a basic belief. A basic belief is a generalization of the traditional probability density function; the latter assigns a number in the range [0, 1] to every singleton of Θ such that the numbers sum to 1. The quantity *m*(A) is a measure of that portion of the total belief committed exactly to *A*, where *A* is an element of 2^{Θ} and the total belief is 1. This portion of belief cannot be further subdivided among the subsets of *A* and does not include portion of belief committed to subsets of *A*. It would be useful to define a function that computes a total amount of belief in A. This quantity would include not only belief committed exactly to *A* but belief committed to all subsets of *A*. Such a function is called a belief function.

In a power plant facilities, it could happen that there are three different system fault status to be identified for an example: "crack of turbine shaft" (shaft), "damage of blade" (blade), and "damage of bearing" (bearing). Then a belief function, denoted *Bel*, corresponding to a specific basic belief, *m*, assigns to A by m, could be represented as follows.

$$\begin{aligned} Bel\text{ (shaft, blade, bearing)} = {} & m\text{ (shaft, blade, bearing)} \\ & + m\text{ (shaft, blade)} \\ & + m\text{ (blade, bearing)} \\ & + m\text{ (shaft, bearing)} \\ & + m\text{ (shaft)} + m\text{ (blade)} + m\text{ (bearing)}. \end{aligned}$$

Thus, *Bel*(A) is a measure of the total amount of belief in A and not of the amount committed precisely to A by the evidence giving rise to *m*. *Bel*() is the sum of the values of *m* for every subset of Θ.

Combined Belief

Practically, a combined belief can be drawn by the following three steps:

Step 1: First, for each singleton hypothesis, combine all basic beliefs representing diagnoses confirming that hypothesis. If s_1, s_2, ... , s_k represent different degrees of support derived from *k* diagnoses confirming a given singleton, then the combined support is

$$s = 1- (1-s_1)\,(1-s_2)\ \dots\ (1-s_k)$$

Similarly, for each singleton, combine all basic beliefs representing diagnoses unconfirming that singleton.

$$s' = 1- (1-s'_1)\,(1-s'_2)\ \dots\ (1-s'_k)$$

Step 2: Combining the conforming and unconfirming basic belief for each system status; for example, case of blade:

$$E(\{\text{blade}\}) = s\cdot(1 - s') / (1-s\cdot s') = p$$

$$E(\{\text{blade}\}^c) = s'\cdot(1 - s) / (1-s\cdot s') = c$$

where, $1.0 - p - c = r$ (*r* is not include conforming or unconfirming)

$d = c + r$ (*d* is not conforming)

Step 3: The form of the required computation is shown below. Let [i] represent the *i*th of n singleton hypotheses in , that is, $i = 1$ for unbalance, $i = 2$ for foreign material, and i = 3 for normal. Then p_i indicates the *i*th confirming basic belief of n singleton hypotheses, c_i the *i*th unconfirming basic belief, and r_i the rest of the basic belief as shown below;

$Bel[i] = p_i$
$Bel[i] = c_i$
$Bel[i] = r_i$

Since $p_i + c_i + r_i = 1$, $r_i = 1 - p_i - c_i$, Let $d_i = c_i + r_i$. Then it can be shown that the function Bel resulting from combination of *Bel*[1], *Bel*[2], ... , *Bel*[n] is given by

$Bel([i])=K[p_i \Pi d_j + r_i \Pi c_j]$
where,

$$K^{-1}=[\Pi d_j][1+\Sigma(p_j / d_j)]- \Pi c_j$$

with $P_j=1$ for all j [6].

Structure for Evidence Calculation

The structure for this belief calculation and combination of the belief is illustrated in Figure 2. In the figure, diagnostic methods (V_s) are connected with hypothesis of failures (H) to calculate the combined evidence on each hypothesis.

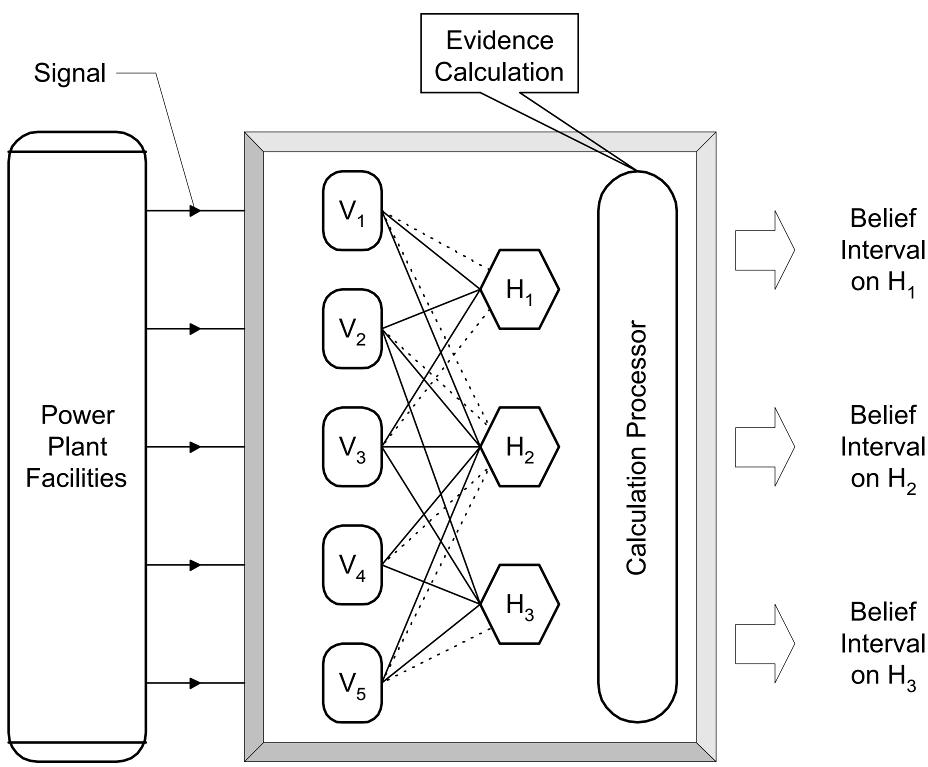

Figure 2. Belief Calculation and Combination

In Figure 3, we indicated a conceptual design for applying the belief calculation from the field data using a data acquisition system, then belief combination in a PC environment. This system can be implemented in a remote area connected via communication network including Internet or other communication protocols.

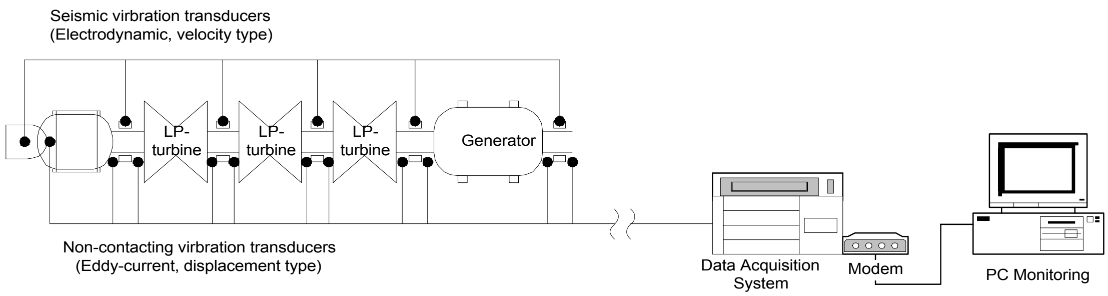

Figure 3. Conceptual design for evidence theory-based diagnostic system

IV. CONCLUSIONS

To provide reliable power, it is necessary to provide a predictive maintenance system for power plant facilities. Even though there are a few failure detection methods available, they are not precise and their information on the failure factor is not complete and uncertain. In this paper, to accomodate the uncertain information from multiple detection methods, evidence theory-based diagnosis system is proposed. This system is based on the Dempster-Shafer theory to manage the belief and combine the beliefs. A conceptual design for actual application is also suggested.

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