Fault Diagnosis of Wind Turbine SCADA Data via Immunity Perception
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**Abstract.** Health monitoring of wind turbine (WT) has gained considerable attention, and the supervisory control and data acquisition (SCADA) data (such as power, temperature, and pressure, etc.) have been analyzed. However, many parameters in SCADA data are inertia parameters, which are easily affected by their inherent inertia. To solve this problem, a health pre-progress for SCADA data based on immunity perception (IP) is proposed in this paper. This progress uses the immunity perception to obtain the health information of a single parameter. Two numerical examples are given to validate the progress proposed in this paper.

**Introduction**

Wind energy is renewable and pollution-free, which is strongly supported by many governments. However, the high maintenance costs of wind turbine (WT) seriously restrict the development of wind energy industry [1]. The most commonly used progress for WT condition monitoring is critical signal analysis. Supervisory control and data acquisition (SCADA) systems, which have been widely installed in wind farms, can collect and record the health information from WTs and their critical parameters [2]. SCADA-based monitoring has been considered to be cost-effective due to the availability of a large amount of monitoring data and no additional cost. As a result, SCADA-based WT health monitoring has attracted wide attention in recent years [3], and different SCADA data analysis progresss have been proposed [4-6].

However, many parameters in SCADA data, such as temperature and pressure, are inertia variables, which are easily affected by their inherent inertia, and as a result, the original health information directly collected by the sensors cannot accurately reflect the condition of subsystems/parameters. When the fault is occurring or will occur, the data is still in a reasonable range, so early warning cannot be given; and when the external environment gives interference to WT, the fluctuation of data is easy to trigger the alarm by mistake.

To solve this problem, a health pre-progress for SCADA data based on immunity perception (IP) is proposed in this paper. This progress uses the immunity perception to obtain the health information of a single parameter. The health condition of the data is quantified by combining promoter and inhibitor. Two numerical examples are given to validate the progress proposed in this paper.

**Original Health Information**

The sensors in WT directly collect original real-time data. In order to analyze the health information, it is necessary to convert the multi-dimensional data into one unitary scale, since the dimensions of data are different. In this paper, the health information is set between [0, 1]. 0 represents the worst and 1 represents the best. According to the physical properties of parameters, they can be divided into three types: small, medium and large.

1) Small type parameters

For parameters like gearbox oil temperature and gearbox main bearing temperature, if the data value is small enough, it means the parameters are in healthy condition. The original health information of the small type is calculated as
where $\varepsilon$ is real-time value of parameter data, $\varepsilon_{\text{min}}$, $\varepsilon_{\text{max}}$ are the threshold values of parameter data.

2) Medium type parameters

For parameters like rotational speed and frequency, if the data value is not too large or small, it means the parameters are in healthy condition. The original health information of the medium type is calculated as

$$ H = \begin{cases} 
0 & \varepsilon < \varepsilon_{\text{min}} \\
\frac{\varepsilon - \varepsilon_{\text{min}}}{\varepsilon_{a} - \varepsilon_{\text{min}}} & \varepsilon_{\text{min}} < \varepsilon < \varepsilon_{a} \\
1 & \varepsilon_{a} < \varepsilon < \varepsilon_{b} \\
\frac{\varepsilon_{\text{max}} - \varepsilon}{\varepsilon_{b} - \varepsilon_{\text{max}}} & \varepsilon_{b} < \varepsilon < \varepsilon_{\text{max}} \\
0 & \varepsilon > \varepsilon_{\text{max}} 
\end{cases} \tag{2} $$

where $\varepsilon_{a}$ and $\varepsilon_{b}$ are the healthy condition boundary values of parameter data.

3) Large type parameters

For parameters like active electricity, if the data value is large enough, it means the parameters are in healthy condition. The original health information of the large type is calculated as

$$ H = \begin{cases} 
1 & \varepsilon > \varepsilon_{\text{max}} \\
\frac{\varepsilon - \varepsilon_{\text{min}}}{\varepsilon_{\text{max}} - \varepsilon_{\text{min}}} & \varepsilon_{\text{min}} < \varepsilon < \varepsilon_{\text{max}} \\
0 & \varepsilon < \varepsilon_{\text{min}} 
\end{cases} \tag{3} $$

Immunity Perception of Health Information

Considering the temperature and pressure are inertia parameters, which are easily affected by their inherent inertia, and as a result, the original health information can not accurately reflect the condition of subsystems/parameters. When the fault is occurring or will occur, the data is still in a reasonable range, so early warning cannot be given; and when the external environment gives interference to WT, the fluctuation of data is easy to trigger the alarm by mistake. To address this issue, immunity perception is used to obtain the health information of a single parameter.

Immunity perception is a self-adaptive perception process that simulates the immunity response of organisms when facing the invasion of foreign antigens[7]. In this case, the original health information (such as active electricity or bearing temperature of a gearbox) can be considered as the antigen information injected into the immunity system. The health information $B$ is composed of promoter $T_H$ and inhibitor $T_S$. The promoter $T_H$ represents the real-time health information, the inhibitor $T_S$ represents the trend of health information. When the health information deviates from the healthy condition, the promoter $T_H$ can promote the amplitude of immune perception, which can quickly and directly reflect the condition of health information. When the interference health information fades, the inhibitor $T_S$ can inhibit the production of promoter, so that the immunity perception can avoid disorder. The process of immunity perception is shown in Figure 1.
At $k$ moment, the health information is $H(k)$, then the promoter is

$$T_h(k) = k_1 H(k)$$  \hspace{1cm} (4)

and the inhibitor is

$$T_s(k) = k_2 f\left(S(k-1), \Delta S(k-1)\right) H(k)$$  \hspace{1cm} (5)

where $k_1$ is the coefficient of promotion, $k_2$ is the coefficient of inhibition, and $f(\cdot)$ is a nonlinear function, representing the anti-interference ability of the inhibitor. Then the immunity perception is

$$S(k) = T_h(k) - T_s(k) = K\left[1 - \eta f\left(S(k-1), \Delta S(k-1)\right)\right] H(k)$$  \hspace{1cm} (6)

where $K = k_1$, $\eta = k_2/k_1$. Considering the immunity perception also requires unitary scale, it can be set as $K = 1$ and $0 \leq S(k) \leq 1$.

Since the non-linear function $f(\cdot)$ has a great influence on immune perception, a fuzzy model of two dimensional input and one dimensional output is adopted to approach $f(\cdot)$. The values of $S(\cdot)$, $\Delta S(\cdot)$ and $f(\cdot)$ are represented fuzzily by five sets, which are PB(positive big), PS(positive small), ZO(zero), NS(negative small) and NB(negative big). By using Lyapunov function, the fuzzy approximation rules are shown in Table 1.

| $f(\cdot)$   | $\Delta S(\cdot)$ |
|-------------|-----------------|
|             | PB  | PS  | ZO  | NS  | NB  |
| PB          | NB  | NB  | NS  | NS  | ZO  |
| PS          | NB  | NS  | NS  | ZO  | PS  |
| ZO          | NS  | NS  | ZO  | PS  | PS  |
| NS          | NS  | ZO  | PS  | PS  | PB  |
| NB          | ZO  | PS  | PS  | PB  | NB  |

Immunity perception $S(\cdot)$ is actually a non-linear function too, which can adjust its output adaptively according to the amplitude and trend of antigens to ensure the rapidity and accuracy of immunity perception.

**Numerical Examples Validation**

In order to verify the effectiveness of the MIP, SCADA data of a wind farm in Sichuan Province of China is analyzed. The WT in this wind farm is 1.5MW doubly fed induction generator. The recording frequency of SCADA is one minute. The SCADA data records 31 parameters, including active electricity, reactive electricity, generator speed, wind speed, etc, which are listed in Fig 2.
A Fault prediction: At 8:51 on Feb. 3rd, 2017, a WT in this wind farm triggered alarm because the gearbox bearing temperature exceeded the upper limit. To analyze this fault, the SCADA data of 7:00-8:50 on February 3rd, 2017 are collected. In order to validate the effectiveness of the immunity perception, the health information of gearbox oil temperature by immunity perception is compared with the original health information directly collected by the sensor. The results are shown in Fig. 5.

B Interference preclusion: The WTs are greatly affected by the environment, so there will be false alarm triggered by the interference. In order to verify the interference preclusion ability of immunity perception, the SCADA data from 21:00 to 22:00 on April 5th, 2017 is analyzed. During this period, the weather changed a lot. Although the WT did not fail, the SCADA data still presented a big fluctuation. Similarly, the health information of gearbox oil temperature by immunity perception is compared with the original health information directly collected by the sensor. The results are shown in Fig. 6.

As can be seen from Fig. 6, the health information of immunity perception is still consistent with the original health information. But the health information of immunity perception is more stable than
original health information. This is because the inhibitor plays a major role in the process of immunity perception during the interference. This proves that immunity perception can greatly limit the false alarm triggering.

**Summary**

Many parameters in SCADA, such as temperature and pressure, are inertia variables, which are easily affected by their inherent inertia, so the original health information directly collected by the sensors cannot accurately reflect the condition of subsystems/parameters. To solve the problem, a health condition monitoring progress for WT based on MIP is proposed in this paper. Numerical examples validate that the immunity perception can overcome the inertia and MIP can predict faults earlier than the original progress by constructing the immunity system. This could lay a foundation for the research of reliability analysis, fault warning, risk assessment, safety prediction and maintenance strategy formulation.

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