Evaluation and Prediction of Operation Status for Pitch System Based on SCADA Data

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Abstract— **Precise fault diagnosis of the pitch system in wind turbines is essential and is of practical significance for evaluating it by the usage of the SCADA (Supervisory Control And Data Acquisition) system. Firstly, the fault mechanism of the pitch system is investigated, including the source classification of the faults, and their direct connections with the SCADA data. Secondly, state feature extraction based on ReliefF algorithm is used to refine 11 state features, which are most closely related to the 3 different faults of the pitch system. Third, a support vector regression based on small-world particle swarm optimization (SWPSO-SVR) is proposed as the model of the status evaluation and prediction in which the SWPSO is used to enhance the searching ability and fitting efficiency of the SVR by optimizing the penalty factor *C* and nuclear parameter *δ*. Finally, the SWPSO-SVR is applied to the verification of the operation state prediction based on the 60 min ahead abnormal pitch running date.**

Keywords: Pitch system; SCADA system; Fault mechanism; Small-World Particle Swarm Optimization (SWPSO); Support Vector Regression (SVR)

I. Introduction

Wind energy, as a clean and pollution-free green energy, has become the driving force of renewable energy utilization. It is mainly reflected in the total installed capacity of wind turbines, which increases rapidly every year. However, the design life of a wind turbine is only 20-40 years [1]. For the earliest wind turbines that were put into use in China, their service life will reach the end, even numerous of them have exceeded the warranty period. In addition, with the adverse environment, lack of routine maintenance and overhaul, wind turbines' faults occur frequently. Especially the pitch system, which has a 25%~30% of total asset cost and 23.7% of occurrence of faults in a wind turbine, due to the randomness of the wind and the mutual coupling with other subsystems [2-3]. Therefore, it is of great theoretical and practical significance to study the operation state of wind turbine pitch system.

In wind farms, large amounts of real-time and historical data are detected by Supervisory Control And Data Acquisition (SCADA) system, which contains all the useful information about operation and device status of the wind turbines[4]. The impact of combining the SCADA data with the operating conditions of wind turbines is a subject that has attracted the interest of many experts and scholars for the recent years. Kusiak [5-6] used the Relief algorithm to select out the characteristic parameters from the historical data of SCADA system, aiming to analyze the blade pitch faults, blade angle asymmetry and blade angle implausibility. Also depending on the historical data of SCADA, S Gill [7] established the probabilistic model of wind power based on the Copula analysis function, and effectively monitored the early recognition of incipient faults such as blade degradation, yaw and pitch errors. For good measure, various intelligent algorithms for online data applications have been used in the area of health monitoring and prognosis due to their flexibility in generating suitable models. Zaher [8] developed an automatic anomaly monitoring system which can automatically detect the online SCADA data to achieve the early fault identification of the wind turbines. Garcia [9] built a gear temperature model based on the online SCADA data to evaluate the gears' health. Yang [10] proposed a SCADA data monitoring technique to evaluate the health state of a wind turbine with different conditions, which can detect the initial failures of blades and transmission systems and also track the further deterioration. Moreover, according to the relationship between tower vibration and other related variables recorded by SCADA system, Guo [11] constructed a regression model of tower vibration to diagnosis the pitch angle asymmetry fault by analyzing the residual error.

For these researches, the data utilized for this methodology is from the pre-existing SCADA system, no further sensors are required and no additional capital expenditure is incurred, which greatly mitigates the risks associated with proactive maintenance policies. In addition, Support Vector Regression (SVR) has been used to extract the multiple parameters of SCADA data for accurately locating the faults of pitch system [12-13], and a data-driven SCADA alarm system have been proposed for the overall operation of wind turbines [14]. Other studies have suggested that the Particle Swarm Optimization (PSO) can be selected to optimize the accuracy of SVR as an evolutionary algorithm, which has the fast convergence in solving practical problems [15]. However, PSO also has its limitation: the optimal solution only can be found within the feasible range and it is easy to fall into the local optimum when dealing with multi-objective optimization problem [16]. In order to solve the problems above, we propose to use the small world optimization algorithm [17] to global optimize the PSO for improving its accuracy and speed.

This paper is organized as follows: Section II surveys the fault mechanism of pitch system, which focuses on the faults' causes, classification and their connections with the SCADA data. In Section III, 11 state features that most closely related to the faults of the pitch system are selected by ReliefF algorithm. Section IV establishes a support vector regression model based on small-world particle swarm optimization (SWPSO-SVR) for evaluating and predicting of its operation status, and the results are compared for verifying its accuracy with the normal data. Furthermore in Section V, we also select the abnormal data before the fault occurs as the inputs to verify that SWPSO-SVR can realize the prediction of the running state and achieve early warning. Finally, our conclusions are in Section VI.

II. FAULT MECHANISM OF THE PITCH SYSTEM

As one of the core subsystem in a wind turbine, pitch system not only plays an important role for ensuring the efficiency of wind energy, but also acts as the support system when the wind turbine is in emergency. The blades in working will have irregular vibration which mostly caused by the great randomness of the wind speed and the different velocity in the sweep plane. Whilst, lacking of effective technical measures also makes a problem in the blade manufacturing process, which is that the distance between the blade's center calibrated position and the absolute pitch angle position has the large deviation. It causes that the three blades installed on the same hub are in an asymmetrical initial position, which is apt to raise the faults.

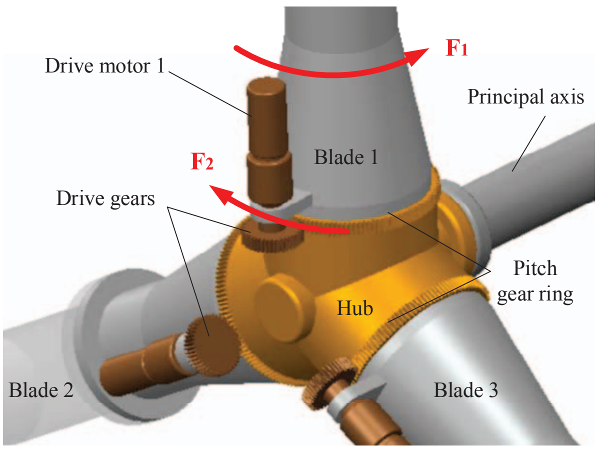

Fig. 1. Pitch control of pitch system.

During the pitch control as seen in Fig.1, the driving force F_2 and the wind force F_1 captured by blade 1 are a pair of reaction forces. F_2 is provided by drive motor 1, drive gears, pitch gear ring and other mechanical components. If the pitch control action changes frequently, as the same changes as F_1, the pitch system will have more mechanical faults. Such is the fact, the typical fault classification and their inducement are obtained in Table 1. Here we selected 3 frequent faults (blade angle fault, pitch torque fault and motor fault) as the research targets to study the association with specific features in SCADA data.

TABLE I. FAULT TYPES OF PITCH SYSTEM

Types		Incentives
Blade angle fault	Blade Angle anomaly	The angle recorded between pitch motor encoder and blade encoder beyond 2°.
	Blade angle asymmetry	The angle among the blades is larger than the normal operating threshold.
Pitch torque fault		Bolt looseness, reducer necrosis.
Motor fault		The temperature of the motor is high, the motor current is too large, and the motor vibration is larger.
Gear fault		Poor lubrication, damaged parts, improper installation of bearings
Bearing fault		Lubrication, looseness of bolts, and improper installation will lead to deformation, fatigue failure, or bearings of the wear.
Communication fault		The damage of engine compartment protector, slip ring, pin contact, slip ring contact, cable connection error and communication module damage.

The SCADA data is provided by a wind farm with 32 wind turbines from Shenyang Keywind Technology Co Ltd. in China, which included as high as 150 features. Obviously, it is a daunting task to use all the features for analysis. Besides each feature makes a different contribution for the system operating state. For example, some features not only can provide effective information, but also bring noise. Therefore, we extract 15 features based on the sensors' locations, which are directly mounted in the pitch system. According to a long-term statistics from the SCADA system, the connections between 3 faults and 15 features are shown in Fig 2.

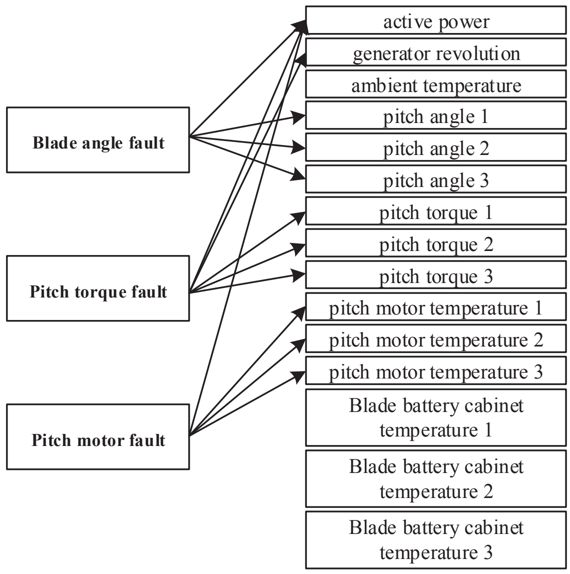

Fig. 2. Connections between 3 faults and 15 features.

As can be seen from Fig.2, there are 11 features that are closely related to the 3 faults, and the next section will give the accurately screening and verification by ReliefF algorithm.