



A M-EKF fault detection strategy of insulation system for marine current turbine



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ABSTRACT

Marine current power is a new renewable energy source, it is significant to keep the marine current turbine healthy. But harsh marine conditions, such as regular thermal cycling, high humidity and heavy salt mist, bring severe challenges to the marine current turbine, especially to the winding insulation system. Therefore, it is of great importance to perform fault detection on the insulation system. In this paper, a Modified Extended Kalman Filter (M-EKF) fault detection strategy based on the electrical parametric model derived from the RLC network modeling of Roebel bars is proposed. The proposed fault detection strategy mainly includes two parts. The first step is to establish reasonable state space equations for the model structure extracted to monitor the state of the insulation system. In the second step, the conventional continuous EKF is modified to follow more accurately the state of the marine current turbine. Simulation and experiment results show that the proposed method can realize timely monitoring of the winding insulation system of marine current turbine with good performance.

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1. Introduction

Marine renewable energy has become a very significant player in the society [1–3], but the harsh marine conditions, such as high humidity and heavy salt mist, bring severe challenges to the operation of marine current turbines. In particular, it may destruct the winding insulation systems of stators and rotors. Faults related to the insulation systems represent between 21% and 40% of the total failures in electrical machines depending on the type and size of the machine [4]. The harsh ocean environment makes the situation even worse. Due to the complex and variable ocean environment, the maintenance of marine current turbines [5–7] is more complex compared with other generators. What's more, the marine current turbines must be connected to the power grid with remote access. Therefore, the marine current turbines are critical machines that require high reliability and availability. Consequently, it is of great importance to perform fault detection [8–10], especially on the insulation system of marine current turbines. At present, a lot of researches have been done on the fault detection of insulation system and many approaches have been proposed.

Some methods are commonly used directly on the detected objects, such as partial discharge (PD) and motor current signature analysis (MCSA). PD [11–13] is a relatively mature method for the detection on the insulation system, and it is an efficient way to differentiate the fault types. But the detection result is greatly affected by the varying environmental

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conditions such as temperature, humidity and so on. Comparatively, MCSA [14–16] has no requirements on the environment. Besides, it is the most popular method and is effective to find faults in bars of rotors. But its accuracy is comparatively lower. In application, not every target object is easy to be detected directly, however, thus indirect detection strategy is necessary. Usually, the detected object is analyzed and then a proper model is proposed to describe the detected object. There are also some methods used on the model to indirectly get the detection result, such as recursive least squares, artificial intelligence (AI) based methods, discrete extended Kalman filter (EKF) and continuous EKF. Recursive least squares [17–20] is simple and easy to implement, so it gets higher efficiency. But it is sensitive to outlier dataset. The AI based methods [21–23] are able to manage the uncertainties, but they are usually more complex and difficult to apply. Moreover, they do not have high real-time performance. Discrete EKF [24–26] has been well applied in communications, navigation, guidance, control systems and other fields considering it is not so complicated to put into use. This solution often requires collecting the data firstly and then to process the data yet, greatly reducing the real-time capacity. Comparatively, the continuous EKF [27–30] method has higher real-time performance. But it considers only the first order information (due to the linearization of Jacobian matrix). Errors may be introduced reducing then the accuracy of the state monitoring.

For the problem of insulation system detecting difficulty due to complicated environment, proper model based on insulation system is necessary to complete detecting or monitoring. For example, the detecting of insulation system for marine current turbine is hard because it works in the sea, where detecting is not as easy as on land, so it is essential to build a model to represent the state of the insulation system of marine current turbine. Based on above analysis and to get higher accuracy, a new scheme called M-EKF fault detection strategy for monitoring the insulation system is proposed in this paper, which has a certain degree of real-time performance for dealing with the continuous system. This strategy includes mainly two parts. Firstly, the model structure, described by the state space method [31–33] is established through the insulation system identification. Roebel bars have advantage of decreasing circulating currents, many generators' insulation systems, such as marine current turbine, consist of Roebel bars, so the proper model is based on Roebel bars' features. It allows judging if the insulation system is in good health operation by monitoring the model's state. Secondly, the continuous M-EKF method is developed to realize timely monitoring of the insulation system of marine current turbines.

The rest of this paper is organized as follows. In section I, the model structure describing the behavior of the winding insulation system is established through system identification. Then, the proposed M-EKF method is described in section II. Finally, the proposed strategy is applied for monitoring the insulation system, and the results are analyzed and compared in section III.

2. System identification

The studied system consists of Roebel bars of rotating machine. Rebel bars are well known for its special winding style, which can decrease circulating currents. Roebel bars are usually used for generators, including marine current turbine, so it is employed in this paper to build the model. And marine current turbine works in the sea, so it is hard to put direct detection to use, thus proper model based on insulation system of Roebel bars is required. In the actual operation, the main difficulty is to find the best model to describe the behavior of the insulation system. In addition, the model should also have a good performance for detecting the fault. In [34], temperature study tests have been carried out. Fig. 1 shows the experimental bench of Roebel bars and Fig. 2 shows the scheme of the studied bars structure. It can be seen from Fig. 1 that a proper model is firstly built according to Roebel bars' features. Then the proposed M-EKF method is used in the model to indirectly detect if the insulation system is damaged.

Fig. 3 describes the basic principle of the output error based method [35]. For the system identification, the selected algorithm should be able to reflect the nature of the model structure, the dynamic of the involved variables or even parameters and structure noise. The system output $y_s(t)$ is supposed as the sum of the model output with exact parameter θ^* and the output noise $b(t)$ representing the measurement and modeling noise. We assume that θ is an estimate of θ^* . Then, a simulation of the system output $y_m(t, \theta)$ using only the measured input signal $u(t)$ can be obtained by the numerical integration of the continuous state-space model.

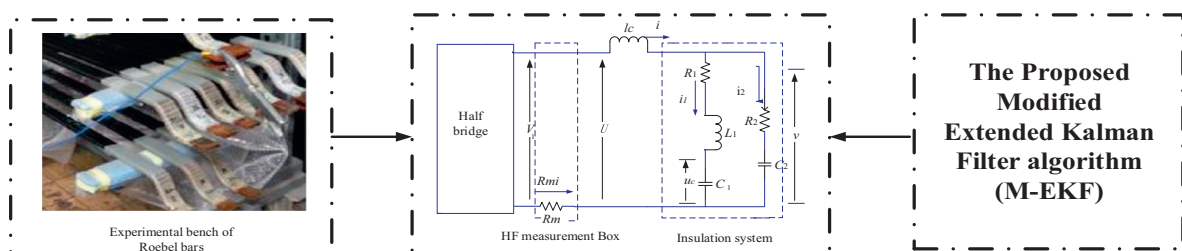


Fig. 1. The total structure of the proposed M-EKF fault detection strategy of insulation system.

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