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Data-based short-term prognostics for proton exchange membrane fuel cells☆

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ABSTRACT

Prognostics is an important tool in the life and cost management of the proton exchange membrane fuel cells (PEMFCs). In this paper, we propose a data-based short-term prognostics method based on the group method of data handling and the wavelet analysis. In particular, this method first decomposes the original voltage sequence of PEMFCs into multiple sub-waveforms. Then, prognostics are made for the sub-waveforms and are combined for the overall prognostics of PEMFCs. Moreover, the proposed method is validated by the experimental datasets from real aging tests. Simulation results demonstrate that, compared with the existing approaches, this proposed method not only can achieve accurate short-term prognostics for PEMFCs in different load conditions, but also can directly use the original experimental data with large disturbances.

Introduction

With the advantages of low operating temperature, high power conversion efficiency, and zero pollution, proton exchange membrane fuel cells (PEMFCs) are regarded as one of the most promising power technologies that can be widely applied in stationary, military, portable and transportation applications [1]. A PEMFC is a complex energy conversion system that consists of a proton exchange membrane, two electrodes (positive and negative), two bipolar plates, two gas diffusion layers, and sealing gaskets [2]. All these components degrade during operations, which could results in degraded performance and short lifetime of PEMFCs. One of the obstacles for the large-scale commercialization of PEMFCs, i.e., the excessive cost, is also partly due to the degradation process. However, degradation can be minimized or even mitigated with effective prognostics tools [3].

Accurate prognostics plays a significant role in the life and cost management of PEMFCs by predicting the future behavior and remaining useful life [4]. Prognostics have already been proved useful in many industrial applications [5]. The most popular definition is the estimation of time to failure and risk

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for one or more existing and future failure modes [6]. The aging process of PEMFCs is very complex in that different components have different degradation mechanisms, and the rate of the degradation is greatly influenced by various factors like temperature, humidity, and load currents [7]. Therefore, realizing the accurate prognostics of PEMFCs is challenging. Generally, there are three types of methods for the prognostics of PEMFCs [8,9]: model-based methods, data-based methods, and hybrid methods.

The model-based methods [10,11], use empirical or mechanism models to simulate the complex degradation phenomenon of PEMFCs. The main advantage of this method is that it does not require large amounts of data. Nevertheless, it is very difficult to develop an accurate degradation model since the degradation mechanism of PEMFCs is not fully understood yet. Another drawback of the model-based method is that it is computationally complex and could be difficult to be used in online applications. The data-based methods [12] can realize the accurate prognostics of PEMFCs by learning the degradation data with non-linearities. This method does not need to deeply understand the degradation mechanisms of PEMFCs, and thus is easy to implement with high computational efficiency. Therefore, it can be used in the online prognostics applications. However, the data-based method needs a large number of data in the training process while the degradation data of PEMFCs is very difficult to obtain. The hybrid methods [4] combines the advantages of the above two methods. It can reduce the model complexity and maintain an accurate prediction at the same time. However, this method still suffers from computational issues and needs further improvement. Considering the advantages and disadvantages of different prognostics methods, we propose a data-based prognostics method for PEMFCs.

In the existing literature, there has been a lot of research work on the data-based method for prognostics of PEMFCs. In Ref. [13], a prognostics method based on adaptive neuro-fuzzy inference systems is proposed to make long-term prognostics for PEMFCs by using the filtered data. The authors of [14,15], use a constraint based summation wavelet-extreme learning machine algorithm to develop an effective data-based long-term prognostics method for PEMFCs which use the filtered data. This method is also effective under dynamic load conditions [12,16]. In Ref. [17–21], the echo state network is proved to be an effective prognostics tool for PEMFCs. However, this method has too many parameters that difficult to adjust, and it is must uses the filtered data. A long-term prognostics method based on the relevance vector machine (RVM) is proposed in Ref. [22]. Later, an improved prognostics method based on a modified RVM algorithm is realized in Refs. [23,24]. Both of methods use the filtered data. A key performance indicator long-term prognostics approach for PEMFCs is developed in Ref. [25]. By combining the stacked contractive auto-encoders and support vector regression algorithms, a state of health estimation method for PEMFCs is realized in Ref. [26]. The effectiveness of the regime switching vector autoregressive based reasoning method for prognostics of PEMFCs is verified in Ref. [27]. A discrete wavelet transform based long-term prognostics method for PEMFCs is proposed in Ref. [28]. In Ref. [29], an effective long-term prognostics approach based on the model space learning is proposed to realize the remaining useful life estimation of PEMFCs under dynamic operating conditions. Based on the polarization curves and electrochemical impedance spectroscopy measurements [30–32], deal with a pattern recognition based long-term prognostics approach to estimate the remaining useful life of PEMFCs.

It is known that the regeneration phenomena, operating conditions, inherent differences in material properties and manufacturing assemblies, have significant effect on the accuracy of prognostics [33]. However, existing data-based methods seldom use the raw data series in prognostics, due to their failure in extracting a correct global degradation trend from raw experimental data series with complex local regeneration and fluctuations. Moreover, most of the data-based methods for PEMFCs are designed for long-time prognostics. The short-term prognostics is equally important for the life and cost management of electrochemical systems [15,34,35], but is seldom considered in the prognostics of PEMFCs. Considering all the drawbacks/gaps of the previously reviewed papers, we try to developed a data-based method which can use the raw experimental data series to realize the accurate shot-term prognostics of PEMFCs.

Since PEMFCs are complex multi-physics (electrochemistry, electric, thermal, fluidic and mechanical phenomena) and multi-scale (space and time) systems, the aging process of PEMFCs is very complicated and can be considered as a complex nonlinear system. Methods that have strong nonlinear mapping ability, e.g., neural networks, are able to deal with complex causal relationship problems. The group method of data handling (GMDH) network is a typical feed-forward neural network with self-organized learning ability. In this network, the input variables like the number of layers, the number of neurons in the hidden layers and the optimal network structure are all determined automatically. The GMDH network has been proved very effective in many time series forcasting problems [36]. Moreover, it is more accurate and less labor-intensive than traditional time-series analysis or regression-based methods.

In this paper, the previous voltage values are used to predict the short-term target voltage, which is equivalent to a time series problem. Therefore, we can use the GMDH network to implement the prognostics for PEMFCs. In addition, decomposing a time series waveform into multiple sub-waveforms and predicting them separately can greatly improve the accuracy of prognostics [37,38]. Wavelet decomposition is the most commonly used method of waveform decomposition, therefore, we use it in this paper. As the stack voltage is the simplest indicator of the degradation process [4], this paper proposes a data-based short-term prognostics method to predict the voltage decrease of PEMFCs under different load conditions. The proposed method is based on the GMDH and the wavelet analysis approaches. Moreover, we use two experimental datasets of PEMFCs from different aging tests to verify the effectiveness of the proposed data-based method.

The reminder of this paper is organized as follows. The principles of the wavelet analysis and the GMDH approaches are introduced in Section Wavelet analysis and group method of data handling. The data-based prognostics method is proposed in Section The framework of the proposed short-term