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Investigation of PEMFC fault diagnosis with consideration of sensor reliability

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ABSTRACT

Despite the wide range of applications for the polymer electrolyte membrane fuel cell (PEMFC), its reliability and durability are still major barriers for further commercialization. As a possible solution, PEMFC fault diagnosis has received much more attention in the last few decades. Due to the difficulty of developing an accurate PEMFC model incorporating various failure mode effects, data-driven approaches are widely used for diagnosis purposes. These methods depend largely on the quality of sensor measurements from the PEMFC. Therefore, it is necessary to investigate sensor reliability when performing PEMFC fault diagnosis.

In this study, sensor reliability is investigated by proposing an identification technique to detect abnormal sensors during PEMFC operation. The identified abnormal sensors will be removed from the analysis in order to guarantee reliable diagnostic performance. Moreover, the effectiveness of the proposed technique is investigated using test data from a PEMFC system, where fuel cell flooding is observed. During the test, due to accumulation of liquid water inside the PEMFC, the humidity sensors will give misleading readings, and flooding cannot be identified correctly with inclusion of these humidity sensors in the analysis. With the proposed technique, the abnormal humidity measurements can be detected at an early stage. Results demonstrate that by removing the abnormal sensors, flooding can be identified with the remaining sensors, thus reliable health monitoring can be guaranteed during the PEMFC operation.

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Introduction

As an environmentally friendly alternative for electrical power generation, polymer electrolyte membrane fuel cells (PEMFCs) have potential for widespread application, including stationary power station, automotive, and consumer devices. However, PEMFC reliability and durability are still two major barriers for further commercialization.

In order to address the above issue, many studies have been devoted in the last few decades to evaluate PEMFC state during operation using fault diagnostic techniques. From the results, PEMFC faults can be detected and the sources for occurrence of faults can also be determined, which can be used for the design of mitigation strategies to recover and extend PEMFC performance. From these studies, the diagnostic techniques can be loosely divided into two groups,

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data-driven approaches [1–16,27–33] and model-based methods [17–26].

With model-based techniques, a model should be developed to represent the PEMFC behaviour, by calculating the residuals between model outputs and actual measurements, PEMFC faults can be detected and isolated [26]. From previous studies, different models are developed for fault diagnosis purposes, including white-box models using space differential formulas to express the mass and momentum equilibriums of the PEMFC system [17,25], black-box models deriving PEMFC inputs and outputs relationships by training algorithms [20,24], and grey-box models combining both features from physical white-box models and empirical black-box models [18,19],[21–23]. However, it is noted that due to the complexity of PEMFC systems and its electrochemical properties, it is usually extremely difficult to develop reliable models incorporating all the possible failure mode effects [8,26]. On this basis, data-driven fault diagnostic approaches are more widely applied for PEMFC fault diagnosis.

In data-driven approaches, features are extracted from the PEMFC measurements using signal processing techniques, and the PEMFC state can be determined by applying pattern recognition methods to these features [8,11]. From previous studies, several different methodologies can be applied to extract features from the PEMFC sensor measurements, including principal component analysis (PCA) [16,27], kernel PCA (KPCA) [28], Fisher discriminant analysis (FDA) [29], kernel FDA (KFDA) [30], and signal processing techniques [7,31–33] like fast Fourier transform (FFT), short-time Fourier transform (STFT), wavelet transform (WT). Moreover, several pattern recognition algorithms have been applied to the extracted features to evaluate the PEMFC condition [34–36], such as Gaussian mixture model (GMM), support vector machines (SVM), k-nearest neighbour (KNN), self-organizing map, etc.

However, it should be mentioned that as the data-based diagnostic approaches depend largely on the measurements from PEMFC, the quality and quantity of the measurements can greatly affect the diagnostic performance. Moreover, as a set of sensors are usually installed in the PEMFC to collect enough information from the system, the effect of sensor reliability on PEMFC fault diagnosis should be better understood for reliable diagnosis. Although sensor selection algorithms have been applied in PEMFC to determine the optimal sensors for health monitoring [37], which can reduce the complexity of reliability of multiple sensors, only very limited studies have been devoted to the sensor reliability, especially in the field of PEMFC fault diagnosis. Therefore, it is necessary to investigate the effect of sensor reliability in the diagnostic procedure, and propose corresponding mitigation in order to provide reliable diagnostic performance during the system operation.

In this study, the effect of sensor reliability on fault diagnosis is investigated using test data from a PEMFC system, and results demonstrate that the unreliable sensors can affect the PEMFC diagnostic performance significantly. On this basis, an approach is proposed to identify the abnormal sensors during the PEMFC operation, by monitoring features extracted from each sensor. The identified abnormal sensor is then removed from the analysis, and the diagnostic performance using the remaining sensors will be studied. In order to keep the consistency, the same data-driven approaches are applied to the datasets with and without abnormal sensors. Results demonstrate that with abnormal sensors being identified and removed from the analysis, reliable diagnostic performance can be guaranteed and PEMFC state can be determined with good quality.

Data-based approaches and its performance in PEMFC fault diagnosis

Description of data-based diagnostic approaches

In this study, several data-based approaches are used in PEMFC diagnostic analysis, including Kernel principal component analysis (KPCA), wavelet packet transform, and singular value decomposition (SVD) technique. It should be noted that these techniques will only be described briefly herein, and more details can be found in Refs. [8,11].

As mentioned in section Introduction, as multiple sensors are commonly used to monitor PEMFC performance, this can lead to a high-dimension dataset. In order to reduce the computational time and complexity, KPCA is utilized to reduce the dimension of the original dataset while keeping the useful information in the original dataset. Wavelet packet transform is then applied to extract features from the reduced dimensional dataset. Compared to wavelet transform, wavelet packet transform can provide more coefficients as both detail and approximation are filtered, which can better represent the original dataset [11]. As a set of features can be extracted using wavelet packet transform, SVD is applied to select the features containing the most information, which can be used to determine the PEMFC state. Fig. 1 illustrates the flowchart of data-driven approaches in PEMFC fault diagnosis.

Description of PEMFC test

The test rig with capability of 80 W is used to provide the PEMFC test data in this study, which contains a fuel cell stack,

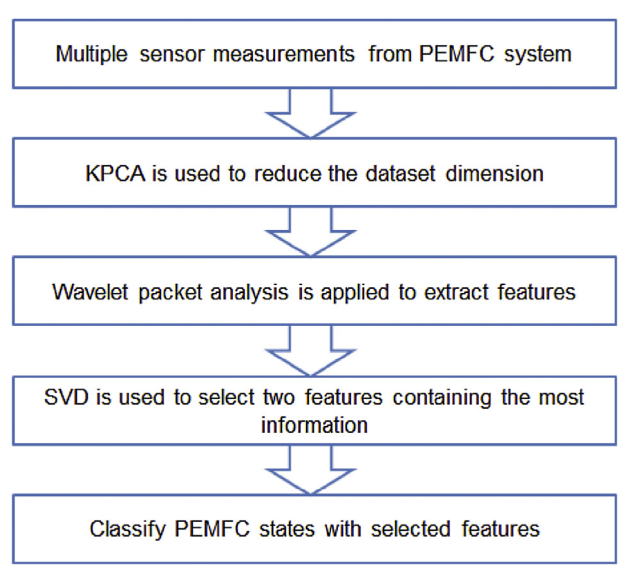

Fig. 1 – Flowchart of data-driven approaches in PEMFC fault diagnosis.

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