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Review

A review on non-model based diagnosis methodologies for PEM fuel cell stacks and systems

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ABSTRACT

A review of non-model based methodologies applied to diagnosis of Proton Exchange Membrane Fuel Cell (PEMFC) system is presented. Three types of non-model based methods including artificial intelligence, statistical method and signal processing method are discussed and compared. The artificial intelligence one, divided into Neural Network (NN), Fuzzy Logic (FL) and neural-fuzzy method, is applied as a fault classifier which is quite different from its role in model-based method. Linear feature reduction methods including Principle Component Analysis (PCA) and Fisher Discriminant Analysis (FDA), and nonlinear ones such as Kernel PCA (KPCA) and Kernel FDA (KFDA) are demonstrated as part of statistical methods. Additionally, a statistical theory based classifier- Bayesian Network (BN) is also introduced in this part. As for signal processing method, both Fast Fourier Transform (FFT) for stationary signals and short-time Fourier Transform (STFT), as well as Wavelet Transform (WT) for non-stationary signals are introduced. Since each method has its advantages and limitations, a comparison is made finally and hybrid approaches resulting from integration of different methods are believed to be promising.

1. Introduction

Proton Exchange Membrane Fuel Cell (PEMFC) is one of the most promising energy technologies nowadays. It has the advantage of low-operating temperature, high current density, fast start-up ability and also suitability for discontinuous operation [1,2]. All of these characteristics make it attract more and more attention. However, reliability and durability remain the most challenging problems for its commercialization. A PEMFC system is a complex integration of chemical, electrical, mechanical and thermal managements. In general, degradation or failure of the system may be induced by bad water

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management [3], Membrane Electrode Assembly (MEA) contamination, and reactant starvation [4]. Some common fault sources of a system such as sensors and actuators malfunction [5], improper operation and control, are also possible causes. In terms of occurring time, three degradation classes could be distinguished: long-term degradation, degradation due to transients and also incident-induced degradation [4]. Generally, monitoring of PEMFC system should be capable to deal with nonlinear, multi-fault source and different time-scale problems.

In recent years, various diagnosis methodologies have been developed and each has its advantages and limitations. According to whether a model is necessary, diagnosis methods can be classified into two general types: model-based one and non-model based one. For the former one, an analytical model based on a deeper understanding of the internal process of the fuel cell system or a black-box model should be built first. Since fault diagnosis in this case is usually based on the residuals generated between the experimental results and the model outputs, this kind of method is also called residual-based method [6]. Non-model based method could be either knowledge-based or signal-based. The objective of this kind of method is to obtain fault information based on heuristic knowledge or signal processing or a combination of both. Compared with model-based method, non-model based one is a relatively new trend in diagnosis of PEMFC system, but its application in other fields has already been widely and extensively studied.

Although there are some existing reviews about PEMFC system, few of them have focused on respective diagnosis methods. Yuan et al., 2007 [7] presented AC impedance technique applied in PEMFC field. Hissel et al., 2008 [8] summarized various modeling techniques used for PEMFCs and also the systems including the ancillaries. Different electrochemical diagnostic tools such as Electrochemical Impedance Spectroscopy (EIS) and Cyclic Voltammetry (CV) in PEM research were reviewed in [9]. Yousfi Steiner et al., 2008 [10] proposed a review focused on PEMFC voltage degradation associated with water management. Further, Yousfi Steiner et al., 2009 [4] published another review mainly dealing with PEM catalyst degradation and starvation issues. However, emphases of these two papers are mainly on causes and consequences of respective faults instead of fault diagnosis. Venkatasubramanian et al., 2003 [5,11,12] classified various diagnosis methods into qualitative, quantitative and process history based methods, based on which three reviews are achieved respectively. These three reviews are very comprehensive and detailed, but they don't address any special applications.

With the development of various methods dedicated to PEMFC system diagnosis, there seems to be necessary to summarize them and indicate a possible trend for PEMFC diagnosis. In this paper, fault diagnosis methods, mainly non-model based ones applied in PEMFCs field are emphasized on.

According to their principles of operation, non-model based methods in this paper are classified into artificial intelligence (AI) ones, statistical ones and signal processing ones. AI approach including Neural Network (NN), Fuzzy Logic (FL) and neural-fuzzy method plays an important role in fault diagnosis domain. Usually, they can be applied to constitute a pattern classifier for discriminating different types of faults. Statistical method including variable dimension-reduction methods – Principle Component Analysis (PCA) and Fisher Discriminant Analysis (FDA), and also a statistical classifier-Bayesian Network (BN) are addressed. Stationary signal processing methods like Fourier transform (FT) and non-stationary signal processing methods such as short-time Fourier Transform (STFT) and Wavelet Transform (WT) are efficient tools in extracting valuable features that can reflect the occurrence of certain types of faults. The various non-model based methods can be summarized in Fig. 1.

In the following sections, three kinds of non-model based approaches are introduced successively. Evolutions and improvements of the applied approaches are also suggested on the basis of the results obtained in other domains. It is worth noting that no single method can satisfy all the requirements of system monitoring. Hybrid methods integrating characteristics of different methods could be very interesting for overcoming the limitations of each one, and it could be also a new trend. Finally, comparison of each method is made and hybrid methods are discussed.

2. AI methods for PEM fault diagnosis

In the field of fault diagnosis, AI has attracted a lot of attention. It is very effective in recognition of fault patterns or its sources without system structure knowledge. The idea is to find relevant features that describe specific patterns in the feature hyperspace, depending on the state of the system (in normal or faulty operation). There is thus a need to classify the data points and determine at which class they belong to. This part focuses on applications of three kinds of AI methods: NN, FL and neural-fuzzy method. Due to its inherent pattern recognition capabilities and its ability to handle noisy data, NN is one of the most popular methods for fault diagnosis [13]. FL is mainly devoted to handle the impreciseness or uncertainty in the system in a way that mimics human reasoning [14]. A neural-fuzzy method combines the adaptive capability of NN and also the qualitative reasoning ability of FL. It has been proved to have superior recognition accuracy and better generalization capability compared with a single NN [15,16].

2.1. *Neural network (NN)*

Inspired by biological NNs, artificial neural network (ANN) was proven to be a powerful tool for learning and constructing a nonlinear mapping when a given set of input and output data is available. In recent years, numerous papers about PEMFC diagnosis using ANN have been published. However, most of them are model-based [17–21]. In this paper our focus is on its application in non-model based fault diagnosis as a fault classifier.

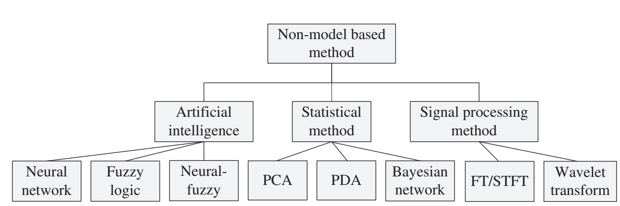

Fig. 1 – Classification of non-model based method.