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Diagnosing Failure in Fuel Cell Pack: A Frequency-Based Approach

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Abstract

This research focuses on the development of a diagnostic method for identifying failures in fuel cell packs. The proposed approach involves the application of multiple alternating currents with different frequencies to the fuel cell pack. Measurements of distortion rate and impedance are obtained for each alternating current, and an optimal frequency is selected based on the distortion rate and impedance analysis. The selected optimal frequency is then used to calculate the distortion rate and impedance of the fuel cell pack. By analyzing the decline in distortion rate and the presence of water in the impedance calculation, the research aims to diagnose the reasons behind the decrease in cell voltage.

Keywords: Fuel cell pack, diagnostic method, alternating currents, distortion rate, impedance, cell voltage, failure diagnosis, water presence.

Introduction

Fuel cell technology has gained significant attention as a clean and efficient alternative for power generation in various applications. However, like any complex system, fuel cell packs are prone to failures that can hamper their performance and reliability. Diagnosing these failures accurately and timely is crucial for ensuring the efficient operation and longevity of fuel cell systems.

This research focuses on the development of a diagnostic method for detecting and diagnosing failures in fuel cell packs (Bae, Lee, and Shin 2019). The proposed approach employs multiple alternating currents with different frequencies to gather important measurements related to the distortion rate and impedance of the fuel cell pack. These measurements provide valuable insights into the condition of the cells and help identify potential issues. The key objective of this research is to establish a reliable and effective diagnostic method that can pinpoint the reasons behind the decline in cell voltage, which is often an indication of a failure. By analyzing the distortion rate and impedance at different frequencies, the research aims to identify an optimal frequency that correlates with the specific failure condition.

The proposed diagnostic method offers several advantages over traditional diagnostic approaches. By utilizing multiple alternating currents and analyzing their corresponding distortion rates and impedance values, it provides a more comprehensive assessment of the fuel cell pack's health. Furthermore, the ability to calculate the water presence in the impedance computation adds an additional diagnostic parameter, allowing for a more accurate diagnosis of the failure causes (Doh, Ha, and Eom 2019). The outcomes of this research have significant implications for the maintenance and optimization of fuel cell systems. By accurately diagnosing failures, appropriate corrective measures can be taken promptly, minimizing downtime and optimizing the system's overall performance. This research contributes to the ongoing efforts in advancing fuel cell technology by providing a reliable diagnostic tool for effective failure analysis and system health monitoring (Bae et al. 2019).

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In the following sections, the research methodology, experimental setup, and results will be presented in detail, showcasing the effectiveness and feasibility of the proposed diagnostic method for fuel cell pack failure diagnosis. Hydrogen-fueled vehicles create new opportunities in the hydrolyzer/electrolyzer market, where hydrogen is generated on-site at fueling stations instead of being transported over long distances like petrol. The key component in most hydrogen-producing electrolyzers or hydrogen-consuming fuel cells is a proton-exchange membrane (PEM), depicted in Figure 1.

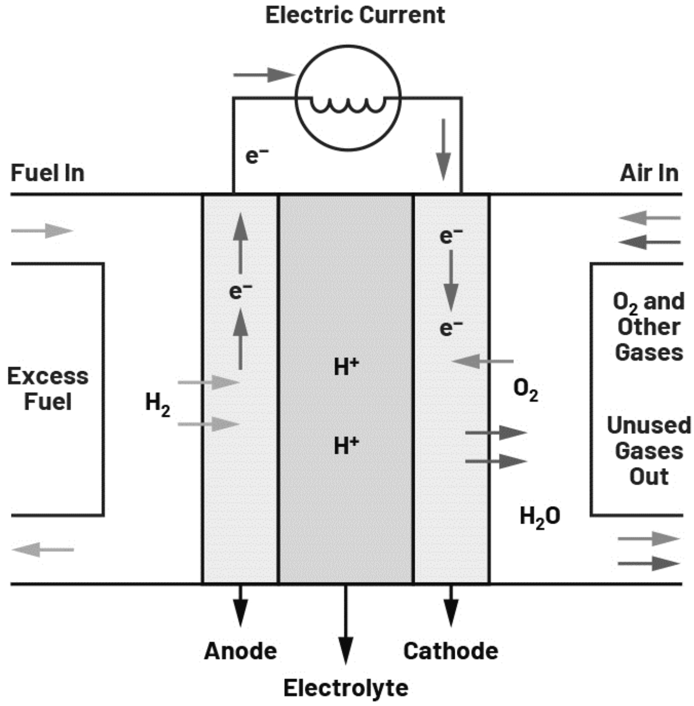

Figure 1. PEM fuel cell

Related Work

Fuel cells are devices that convert chemical energy directly into electrical energy through oxidation and reduction reactions. They can be considered as a type of battery that generates electric energy. Compared to traditional chemical cells, fuel cells operate by continuously supplying reactants from an external source and removing reaction products from the cell system. This characteristic makes fuel cells more suitable for continuous power generation. The commercialization of fuel cells has gained momentum due to their environmentally friendly nature, as the only byproduct of their reaction is pure water. This has sparked significant interest in utilizing fuel cells as an energy source for vehicles, particularly in the automotive industry (Li et al. 2019).

The schematic in Figure 2 illustrates the integration process of the optimized parametric identification technique (red zone) into the EIS-based diagnostic framework. Within this framework, a frequency-domain parametric identification (blue zone) is linked to a diagnostic tool. The fault detection using EIS is executed through multiple steps. Initially, the duty cycle of the DC-DC converter is intentionally perturbed to generate a small-amplitude sinusoidal signal superimposed on the actual DC output current of the fuel cell (FC). The FC voltage (V) and current (I) are then sampled and processed using a Fast Fourier Transform (FFT), enabling the calculation of the FC impedance. This process is repeated at different input frequencies. The complete impedance spectrum facilitates the identification of an equivalent circuit model, leading to fault detection. The fault detection stage commences once the entire impedance spectrum is obtained and the equivalent circuit model is derived (Guarino, Petrone, and Zamboni 2019).

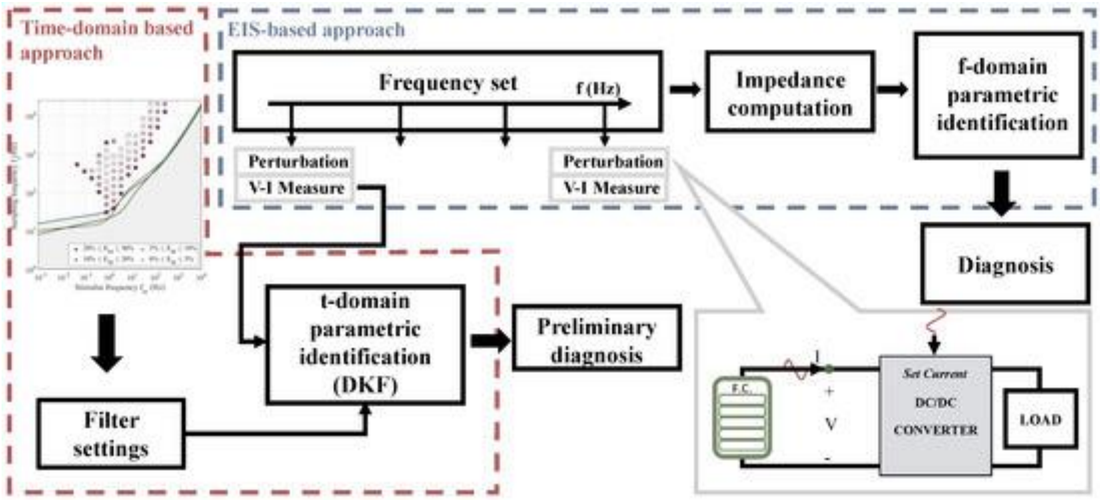

Figure 2. Electrochemical impedance spectroscopy (EIS)-based approach to fault detection and complementary time-domain scheme.

A typical fuel cell system consists of a stack assembly known as a fuel cell pack. The pack comprises multiple individual fuel cells stacked on top of each other and arranged in a continuous manner. Each individual fuel cell within the pack receives hydrogen as fuel and oxygen as the oxidant to produce electric energy (Atalay and Widanage 2019; Li et al. 2019). If any element cell within the pack experiences performance degradation or failure, it can significantly impact the overall performance of the fuel cell pack, potentially leading to unstable operation. In the existing technology, diagnosing the performance of fuel cells is typically done by measuring the voltage output of each individual cell within the fuel cell pack. One commonly used diagnostic method is the Total Harmonic Distortion Analysis (THDA) method, which involves analyzing the distortion rate of the stack voltage through frequency analysis to diagnose cell voltage decline. However, while THDA methods can easily detect voltage decline, determining the specific cause of the decline remains challenging (Huang, Zhou, and Yan 2015; Qin et al. 2016; Wang, Li, and Wang 2019).

Another method used for diagnosing fuel cell packs is the measurement of impedance using Electrochemical Impedance Spectroscopy (EIS) (Bae et al. 2019).This method applies a sinusoidal waveform as a current signal to the fuel cell pack and measures the resulting electric current and voltage. Based on these measurements, the impedance of the fuel cell pack is calculated. However, this method primarily diagnoses the presence of dampness within the battery pack rather than addressing voltage decline. Therefore, additional independent devices such as Space-Vector Modulators (SVM) or Capacitive Voltage Multipliers (CVM) are required for a more comprehensive diagnosis. The information provided in the preceding paragraphs aims to provide background understanding of the current state of the art in fuel cell diagnostics. It should be noted that this information may not encompass all the knowledge available to those skilled in the field and is provided solely for the purpose of enhancing the understanding of the context surrounding the present research (Pang et al. 2019).

Research Objective

The objective of this research is to develop a diagnostic method for effectively identifying failure causes in fuel cell packs. The research aims to utilize multiple alternating currents with different frequencies to measure distortion rate and impedance. By analyzing these measurements, the research seeks to select an optimal frequency and calculate the distortion rate and impedance of the fuel cell pack. The research further aims to diagnose the decline in cell voltage by analyzing the distortion rate and water presence in the impedance computation. Ultimately, the objective is to provide an accurate and efficient method for diagnosing fuel cell pack failures.

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This is a method used to identify problems in a fuel cell pack. It involves the following steps:

1. Multiple alternating currents with different frequencies are provided to the fuel cell pack from an alternating current generator.
2. A processor measures the distortion rate and impedance of the fuel cell pack for each alternating current. Based on these measurements, it selects the optimal frequency.
3. The alternating current with the selected optimal frequency is then supplied from the generator to the fuel cell pack.
4. The processor calculates the distortion rate of the fuel cell pack corresponding to the optimal frequency. By analyzing the decrease in distortion rate, it diagnoses any issues with the cell voltage.
5. The processor also calculates the impedance of the fuel cell pack corresponding to the optimal frequency. It uses this information to diagnose the reason for the decrease in cell voltage, specifically by examining the presence of water in the fuel cell pack.

The selection of the optimal frequency involves two steps:

- The processor determines the first optimal frequency by analyzing the distortion rate measured for each alternating current. It selects the frequency that corresponds to the highest distortion rate, which is used to diagnose any decline in cell voltage.
- The processor then determines the second optimal frequency by analyzing the impedance measured for each alternating current. It selects the frequency that corresponds to the highest impedance, which is used to diagnose the reason for the decrease in cell voltage.

In more detail, the selection of the optimal frequency in the diagnostic method involves two important steps. The processor, which is a part of the system, carries out these steps to identify the most suitable frequency for accurate diagnosis.

<u>In the first step,</u> the processor analyzes the distortion rate measured for each alternating current. Remember, the alternating currents are provided by the generator to the fuel cell pack. The distortion rate refers to how much the electrical signals deviate or change from their original shape. The processor examines the distortion rate for each frequency and selects the frequency that shows the highest distortion rate. This frequency is known as the first optimal frequency. It is chosen because it has the potential to reveal any issues or decline in the cell voltage of the fuel cell pack.

<u>Moving on to the second step,</u> the processor analyzes the impedance measured for each alternating current. Impedance is a measure of how much opposition or resistance the fuel cell pack offers to the alternating current flowing through it. By examining the impedance for each frequency, the processor identifies the frequency that corresponds to the highest impedance. This frequency is referred to as the second optimal frequency. It is selected because it can help diagnose the reason behind the decrease in cell voltage.

So, in simpler terms, the method uses different currents with varying frequencies to test the fuel cell pack. The processor measures the distortion rate and impedance for each frequency to determine the best frequency for diagnosis. The distortion rate analysis helps identify if there are any issues with the cell voltage, while the impedance analysis helps understand if water is affecting the cell voltage. By selecting the optimal frequencies, the method enables the identification and understanding of potential failures or problems in the fuel cell pack. This frequency-based diagnostic approach provides valuable insights into the performance and health of the fuel cell pack. It allows for targeted analysis and diagnosis, leading to effective maintenance and optimization of fuel cell systems.

Conclusion

In conclusion, the research introduces a novel diagnostic method that utilizes frequencies to detect failures in fuel cell packs. By employing multiple alternating currents with different frequencies, the method offers a comprehensive understanding of the fuel cell pack's behavior. The measurement of distortion rate and impedance provides valuable insights into the pack's performance.

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The selection of an optimal frequency is a crucial step in the diagnostic process. By analyzing the distortion rate for each alternating current, the method identifies the frequency that exhibits the highest distortion rate. This frequency becomes the first optimal frequency used to diagnose the decline in cell voltage. Additionally, by examining the impedance for each alternating current, the method identifies the frequency with the highest impedance. This frequency becomes the second optimal frequency and helps diagnose the reasons behind the voltage decrease, specifically by considering the presence of water in the fuel cell pack. By accurately measuring and analyzing the distortion rate and impedance, the proposed diagnostic method enhances the understanding of fuel cell pack failures. It provides valuable information for diagnosing the decline in cell voltage and identifying the underlying causes. This knowledge is essential for efficient maintenance and optimization of fuel cell systems. The frequency-based diagnostic method presented in this research contributes to the advancement of fuel cell technology. By effectively diagnosing failures in fuel cell packs, it enables timely maintenance interventions, reducing downtime and improving overall system performance. Furthermore, this diagnostic approach enhances the reliability and lifespan of fuel cell packs, leading to cost savings and increased sustainability.

Overall, the research findings highlight the significance of frequency-based diagnostics in fuel cell technology. The proposed method offers a valuable tool for researchers, engineers, and technicians working with fuel cell systems. It paves the way for further advancements in failure diagnosis and optimization strategies, ultimately supporting the widespread adoption of fuel cell technology across various industries.

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