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Implementation of discrete wavelet transform-based discrimination and state-of-health diagnosis for a polymer electrolyte membrane fuel cell

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ABSTRACT

This research investigates a new approach based on the discrete wavelet transform (DWT) that suitable for analyzing and evaluating output terminal voltage signal (OTVS) for discrimination analysis of a polymer electrolyte membrane fuel cell (PEMFC). Due to its ability for extracting information from the non-stationary and transient phenomena simultaneously in both time and frequency domain, the OTVS can be applied as source data in the DWT-based approach. By using the wavelet decomposition including the multi-resolution analysis (MRA) using the Daubechies wavelet (dB) as mother wavelet, the information on the electrochemical characteristics of a PEMFC can be extracted from the OTVS over a wide frequency range. Thus, the cells that have similar electrochemical characteristics can be eventually discriminated. In particular, this present research develops these investigations one step further by showing low-frequency components (approximation A_n) and high-frequency components (detail D_n) extracted from variable single cells with different electrochemical characteristics. Experimental results show that DWT-based approach is clearly appropriate for the reliable SOH diagnosis for a PEMFC.

Introduction

In general, fuel cell systems convert the 'chemical' energy contained in many hydrogenous fuels into electrical and thermal energies. Fuel cells have been widely considered as promising and environmentally friendly energy-conversion solutions for the future since they can offer high fuel economy, through high efficiency, and substantially low CO_2 emissions [1–5]. In contrast with different fuel cell types that can be encountered, polymer electrolyte membrane fuel cell (PEMFC) are considered to be the most promising energy technology with the advantages of low -operating temperature, high current density, high potential for low cost and volume, fast start-up ability, and suitability for discontinuous

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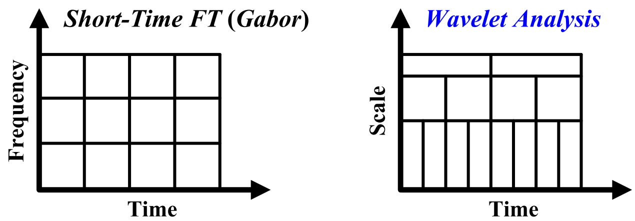

Fig. 1 – Window functions of two signal processing transform.

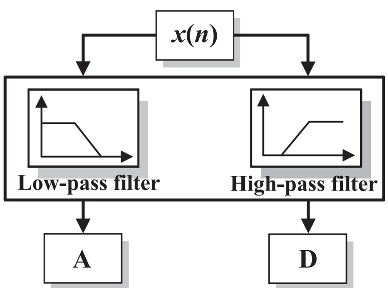

Fig. 2 – Basic level of the wavelet transform filtering process.

operation become the most promising and attractive candidate for electric vehicle power [6–14].

Nowadays, the PEMFC stack consists of multiple cells assembled together (in series) to satisfy the power demands of a variety of commercial applications, such as portable electronics and transportation [15–19]. A pertinent question regarding PEMFC stack is to determine how well stack performance can be predicted through the linear scaling of single cell behavior [15,16]. However, an accurate PEMFC stack configuration remains very challenging and problematic due to cell-to-cell variation caused by different electrochemical characteristics in the stack [20]. Besides, there is always possibility of cell-to-cell variation caused by degradation with use and manufacturing variability of real stack. Cell voltages non-uniformity have been detected in cells further from intrinsic or extrinsic to the cell properties [21,22]. The non-uniformity observed in cell voltages may limit the maximum power output of the stack and decrease stack's life. Therefore, discrimination that selects the cells with similar

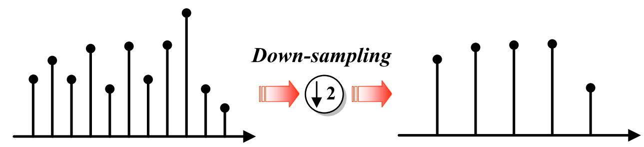

Fig. 4 – Down-sampling of the DWT.

electrochemical characteristics should be well extensively considered as a significant role to ensure stable and efficient operation, to protect the PEMFC stack from damaging operation condition, and to facilitate maximum stack lifetime. In terms of the reliability and durability of the PEMFC, the state-of-health (SOH) diagnostic methodology should be identified among the critical issues that need to be developed to increase system performance [23–27]. For this purpose, it is important to have precise SOH diagnosis in practical applications. Much research (model-based methods) has been devoted to developing improved methods for SOH diagnosis [28–33]. Unfortunately, there is more difficulty in implementing of the elaborate fuel cell model that accompanied the high complexity and long-time performance.

Consequently, a novel work as one of the key technologies of the increasing fuel cell system performance should be newly discussed. Therefore, this research deals with discrete wavelet transform (DWT)-based approach to discuss two issues such as similar cell's discrimination and SOH diagnosis. The DWT is becoming a powerful tool in the analysis of the signal with non-stationary and transient phenomena [34–51]. In generally, fuel cell output terminal voltage is highly dependent to the pulse current. According to pulse currents including different magnitude and time interval, various output voltages with non-stationary and transient phenomena can be obtained. Thus, in this work these voltages are properly used as an input signal applied to DWT, called as output terminal voltage signal (OTVS). One of its features is multi-resolution analysis (MRA) with a vigorous function of both time and frequency localization. Through DWT-based MRA requiring and down-sampling, the information on the electrochemical characteristic of a cell can be extracted from the OTVS from a wide frequency range [34–36]. During the research specifically developed for this methodology, wavelet decomposition based on the selection of the order 3 Daubechies wavelet (dB3) and scale 5 as the best wavelet function

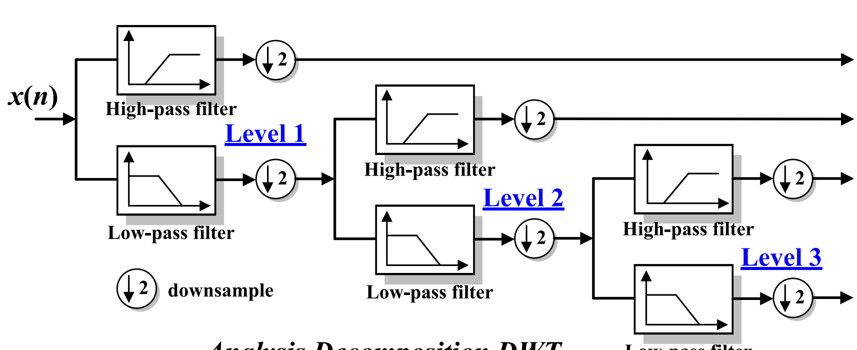

Fig. 3 – Discrete wavelet transform (DWT)-based multi-resolution analysis (MRA) with three levels for an original signal.