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Selection of mother wavelet and decomposition level for energy management in electrical vehicles including a fuel cell

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ABSTRACT

The Wavelet Transform (WT) is a mathematical method used to represent a given signal in different scales. This method is also used to extract the different frequency bands (or different frequency components) from a signal.

In this paper, wavelet transform in the domain of energy management of Electrical Vehicles (EV) is considered. A method for choosing the mother wavelet and the decomposition level will be presented.

Taking into account the damages caused by the extreme variations of the power demand on the power sources, this paper shows how Wavelet Transform can help eliminating this negative impact.

Introduction

Electrical Vehicles (EV) have been considered environment friendly because they do not reject pollutants in the atmosphere. An EV can combine multiple energy sources such as Fuel Cell (FC), batteries and Ultra-Capacitors (UC). However, the lifetime of FC and batteries are dramatically affected by the high transients and rapid variations in the power demand [1,2]. Therefore, as the UC is the device that can handle with such high power demand transients, adding UC to the fuel cell and battery is recommended. For such EV, the presence of different power sources requires an energy management strategy, i.e. a strategy that allows a suitable dispatching of the power between the different power sources on board.

The WT decomposes a given signal in components with different positions and scales. With the WT, one can extract information both in time and frequency domains.

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WT has been widely and successfully employed in energetic systems and energy management domains.

It has been used in Ref. [3] to diagnosis a state of health in fuel cell, and in Ref. [4] to detect and analyze transient structures. In this work, authors present the basic concepts of WT and study how to detect transients in energetic systems by using a WT. In Ref. [5], the authors use WT to describe the construction methodology for a transient recognition system.

In Ref. [6] the authors propose an approach based on WT in order to detect and localize the perturbations in energetic systems. Such perturbations are related to the voltage variation, short fluctuations and harmonic deformation of voltage. In case of sharp variations, the authors use wavelets with small filter db4: (Daubechie's 4) and db6: (Daubechie's 6), and in case of slow variations, wavelets with long filters such as db8: (Daubechie's 8) and db10: (Daubechie's 10) are used.

In Ref. [7] the WT combined with the neural networks was used for fault detection diagnosis of PEM fuel cell systems and [8] a method for detecting the quality of perturbations in a given system, based on Artificial Neural Network (ANN) and WT has been applied on a signal. This method has the objective to eliminate the approximation signal (corresponding to the fundamental part of the signal) and to use the remaining part as the input of the network.

WT has been also used to denoise electrical signals in Refs. [9–11].

In Ref. [9], the continuous and Discrete Wavelet Transform (DWT) are used to reduce the noise in the carbon fiber reinforced polymer composites (CFRPs); the authors have found that if the noise was small, the discrete transform would be more suitable to reconstruct the original signal, whereas the continuous transform is more performing for larger noises. In Ref. [3] a discrimination between different faults in a PEM fuel cell is performed using a db3 wavelet to separate the frequency bands from the voltage signal.

The single object of investigation in Ref. [12] is the stack output voltage: by analyzing this voltage signal with Wavelet Packet Transform algorithm, discrimination between two SoHs of a PEM fuel cell (“flooding” and “non flooding”) was achieved.

The WT is used in Refs. [13,14] to compress data concerning the power quality disturbance signals. In Ref. [14], the db4 (orthogonal wavelet with compacted support) has been used with the theorem of minimax, in order to compress the power signal so a detection of perturbations and transients can be realized.

In Ref. [13] the authors use the wavelet decomposition, followed by thresholding the obtained coefficients, decimation of coefficients and reconstruction of the signal using the interpolation by spline.

In Ref. [15] the 2-D WT is used to compress data. With the bi-dimensional representation, this method allows exploiting the correlation between two given data separated in time, which is not the case with the 1-D formulation.

The WT has also been used for the energy management strategies in hybrid electrical vehicles [16,17]. Therefore, in Refs. [1,2,18] the WT has been applied on a power demand signal, in order to attribute the high frequency signal to the ultra-capacitors, and the low frequency signal to the batteries and fuel cell.

In Refs. [19,20] a combination between the WT and fuzzy logic has been realized, so that the fuzzy system can determine the value of the demanded power of the fuel cell and batteries.

In Ref. [21] the WT has been combined with the adaptive neural network. The neural network determines the required power of the fuel cell, by keeping this power under a fixed limit. In other work, the authors in Ref. [22] have performed a modeling and analysis of a hybrid vehicle containing a fuel cell and an ultracapacitor using the WT mixed with the fuzzy logic.

The drawback of these applications is that the frequencies of the power sources are not considered when choosing the mother wavelet and the decomposition level. Actually, in all the previous applications, the decomposition levels were chosen arbitrary. For example, three levels for a combination of a fuel cell, batteries and ultra-capacitors. This choice, even if it has been suitable for such applications, it remains still not related to the frequency limitations of the power sources, which may reduce the lifetime of the considered power source, it is not respecting to its frequency limitations, and thus it is not working in a healthy mode. Consequently, the decomposition level and the analyzing wavelet must be chosen with respect to the frequency intervals of the power source, which is the objective of this work.

In this work, a strategy for energy management of electrical vehicle is proposed. This strategy is based on the wavelet transform, and has as final objective to increase the lifetime of batteries and fuel cell (since the UCs can handle very high variations of the power demand, and their lifetime can extend up to several thousand cycles, they are not considered in this work when managing the energy, their function is just to respond to the high power solicitations, as can be seen in the Section 6 of this paper). This will be possible by assigning to each source, at each time instant, an amount of power that doesn't exceed the capacity of the power source, and with a frequency range that is included in the frequency interval of the considered power source. Therefore, a time-frequency filter, such as wavelet transform is necessary.

The problematic can be summarized as follows: Let P_{batt}, P_{FC}, P_{UC} be the powers delivered by batteries, fuel cell and UCs respectively. The total requested power by the vehicle is P, thus:

$$P(t) = P_{batt}(t) + P_{FC}(t) + P_{UC}(t) \quad (1)$$

The two signals P_{batt} and P_{FC} must have a frequency included in the interval frequency of the considered source (see Section 3). Therefore, by applying the WT on the signal P, a filtering in time and frequency is obtained, and the frequency of these power sources is considered in order to choose the mother wavelet and the decomposition level.

The paper is organized as follows: in Section 2, the electrical vehicle and the onboard power sources, with their characteristics are presented. In Section 3, the theory of the wavelet transform, with the necessary formulations are detailed, then the matrix formulation of the WT and the Haar filtering are presented.

In Sections 4 and 5, the choice of the mother wavelet and the decomposition level are detailed, and the results are shown and discussed in Section 6. Finally, Section 7 presents a general conclusion.

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