ON BOARD ENERGY MANAGMENT FOR A HYBRID VEHICLE: WAVELETS BASED APPROACH

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Abstarct : In this paper, a wavelet transform based strategy is proposed manage the power of a Hybrid Electric Vehicles (HEV) with multiple on-board energy sources and energy storage systems including several devices such that as ultracapacitor and battery.
To reach this aim, the driver power demand is modeled by a signal function. The proposed wavelet transform algorithm is capable of identifying the high frequency transient and real time power demand of the HEV, and allocating power components with different frequency contents to corresponding sources to achieve an optimal power management control algorithm. Then, a proper combination can be achieved with an ultra-capacitor dealing with the chaotic high-frequency components of the total power demand, while the battery deals with the low and medium frequency power demand.
Keywords : Hybrid Electric Vehicle, wavelet transform, wavelet decomposition, prediction, power management.

1 Introduction

In order to reduce pollutant emissions in the atmosphere, Hybrid Electrical Vehicle (HEV)may represents a potential solution with the ability to reduce fuel consumption, CO_2 emission and the rejects of other pollutants, and that thanks to the multiple energy sources (mechanical, electrical, ...)and energy storage systems..
A HEV combine two or more energy sources (at least one electrical), such

as Fuel Cell (FC), Ultracapacitor (UC), battery, ... and these systems have different characteristics and functions [pala07]. For example, the UC system allows fast dynamic which gives the ability to either supply or receive energy in a short period of time. FC system and battery allow and extended autonomy which gives the ability to supply energy for long periods of time.
For such systems, i.e. for systems containing multiple energy storage system, an appropriate power management algorithm is indispensable.
Fuzzy-logic-supervisory-based power management strategy and adaptive control method for power sharing in a HEV are resented in [Jaaf09]. These methods are efficient for some energy management problems, but they failed in several cases such that to address the lifetime of the FC system for example.
Wavelet-based power management strategy seems to be the most efficient method in this field, thank to its capacity in analysis and acquisition of high and low frequency transients during the drive cycle [Zha08].
But, all these methods and strategies are applied for off-line drive cycle, i.e. where the traject and all information about drive cycle are already known (power demand, stop and start of motion, ...).
In this paper, our goal is to find a strategy that could solve the main problematic that is : on-line energy management, i.e. without a priory information in the drive cycle.
During the drive cycle, the power demand is a function of time, and it can be modelled as a stochastic process, so it is a signal function (time series in the discrete domain, see part 4).
Because of its performance in the domain of signal processing [mal99, mis03], especially for the local analysis in both time-frequency domain, and its capacity in filtering high and low frequency components from a signal, we will choose the wavelet decomposition method to apply in our subject.

2 Energy management

HEVs have multiple energy sources to share energy supply. The presence of different power that have different characteristics in a hybrid power train introduces degrees of freedom on the realisation of the power required by the driver [rou08, Ker 09].
Therefore, it is necessary to find an effective way to share this power between the different sources, which are suitable with the nature and properties of each source and to minimize some criterions (e.g. fuel consumption, pollutant emissions , ...), or working to maintain the systems characteristics (lifetime,...).
The algorithms to solve optimization problems are called management law, or control strategies.
There are two groups of strategies for energy management :
The off-line strategy that requires previous knowledge of the driving cycle,

and the on-line strategy that uses current time information.

The off-line strategy is appropriated when the drive cycle is relatively easy to know in advance, like in rail-road application, or public transport application.
There are many methods to apply this strategy such as :
Daynmic programming : is a technique used to minimise fuel and emission in HEV [lin04, Pere06].
Start-Stop energy management strategy : in this method, the energy conversion sources work either in an optimum operating point or stopped under certain conditions [Cera08].
Predictive energy management strategy : which requires information about the future [Bubn10].
Other strategies are used too, such as Frequency-based energy management strategy [Jaaf09], and Global position system based energy management.

The on-line strategy for energy management requires only current time information such as speed or acceleration, power demand of the driver, state-of-charge, etc ... [Lin06, Murp09, Dosh10].
There are many techniques to apply this strategy, such as DC voltage regulation [Thou09], State-of-charge regulation [Pala07, Wou05], Acceleration based strategy [Allg10].
In this Paper, we are interested by applying the wavelet-based strategy, for on-line energy management, since the power demand for a driver is a function of time, so its can be modelled as a discrete signal function or series number [Zha08].

3 Wavelet transform

3.1 wavelet and wavelet transform

Wavelets are recent tools in signal processing. They permit the analysis of local properties in a non stationnary signal, and for different scales of time [Mis03,Mal99].
A wavelet ψ is a function localised and smooth, and has $m+1$ zero moment :

$$\int_{\mathbb{R}} t^k \psi(t) dt = 0 \qquad for \;\; k = 0, ..., m.$$

From this "mother wavelet" ψ, we construct delated-translated versions :

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi(\frac{t-b}{a}) \quad a \in \mathbb{R}^+, b \in \mathbb{R}$$

Where a is the dilatation parameter(factor), b is the translation parameter.
Let $f(t) \in L^2(\mathbb{R})$ be a signal, its direct and invers wavelet transforms are

respectively :

$$W_f(a,b) =< f, \psi_{a,b} >= |a|^{-\frac{1}{2}} \int_{\mathbb{R}} f(t)\psi^*_{a,b}(t)dt \tag{1}$$

et

$$\frac{1}{\sqrt{C_\psi}} \int\int \frac{1}{a^2} W_f(a,b)\psi_{a,b}(t)dadb \tag{2}$$

Where * denotes the complex conjugate, C_ψ is the admissibility condition [Mis03].
In practical application, it is conveniant that the parameters a and b corresponding to wavelets are sampled on a so-called "‘dyadic"’ grid in the space-scale plan (a,b) [Mis03,Mall99].
A common definition of such discrete wavelets is :

$$\psi_{j,k}(t) = 2^{-\frac{j}{2}}\psi(2^{-j}t - k), j,k \in \mathbb{Z} \tag{3}$$

And then, we have the discrete wavelet transform :

$$W_f(j,k) =< f, \psi_{j,k} >= \frac{1}{\sqrt{C_\psi}} \int f(t)\psi^*_{j,k}(t)dt \tag{4}$$

then the inverse form of (4) can be given in the following for :

$$f(t) = \frac{1}{\sqrt{C_\psi}} \sum_{j,k} W_f(j,k)\psi_{j,k}(t) \tag{5}$$

3.2 Multi-Resolution Analysis

In Multi-Resolution Analysis, for $f(t) \in L^2(\mathbb{R})$ (space of the square integrable function), there exist a nested chain of closed subspaces : [Mis03, Mall99]

$$0 \subset ... \subset V_{-1} \subset V_0 \subset V_1 \subset V_2 \subset ... \subset L^2(\mathbb{R})$$

such that

$$\cap_{j\in\mathbb{Z}} V_j = 0$$

$$close \cup_{j\in\mathbb{Z}} V_j = L^2(\mathbb{R})$$

Where V_j is the subspace spanned by the dilation and translation of a scaling function $\phi(t)$:

$$\phi_{j,k}(t) = 2^{-\frac{j}{2}}\phi(2^{-j}t - k), j,k \in \mathbb{Z} \tag{6}$$

An orthogonal complement space W_j is existed for each of V_j in V_{j-1} and we have :

$$V_{j-1} = V_j \oplus W_j, \quad ; V_j \perp W_j$$

so we have

$$L^2(\mathbb{R}) = \oplus_j W_j$$

There are two schemes for decomposing the function $f(t) \in L^2(\mathbb{R})$:

$$f(t) = \sum_{j,k} < f, \psi_{j,k} > \psi_{j,k}(t) \tag{7}$$

and

$$f(t) = \sum_{k} < f, \phi_{J,k} > \psi_{J,k}(t) + \sum_{j>J,k} < f, \psi_{j,k} > \psi_{j,k}(t) \tag{8}$$

Where J is the decomposition level, $k, j \in \mathbb{Z}$.
In fact, these two schemes are respectively the orthogonal projection over $\oplus_j W_j$ and $V_J \oplus \sum_{j=-\infty}^{J} W_j$ respectively, which give the details, and the approximations+details. That is, the space W_j is called the details space, and the decomposition of $f(t)$ over W_j gives the details of the signal $f(t)$ for the level j.
Same for V_j which called the approximation space, and the decomposition of $f(t)$ over V_j gives the approximation of the signal $f(t)$ for the level j. Every decomposition over W_j is the difference between two successive approximation levels j and $j-1$. In the next section, we will see how to obtain approximation and details by applying the wavelet method.

4 Application of the wavelet transform on a real power demand signal

In this section, we have real power demand profiles, modelled as signal functions, and we will show how wavelets proceed for separate low and high frequency components from the signal.
After application of the decomposition by wavelets, we shall have two signals, the approxiamtion signal (the low frequency signal), and the detailed signal (the high frequency signal). Signal obtained after decomposition will be attributed for devices the drive cycle, so that to agree with their caracteristics [Zha08, Zan11].

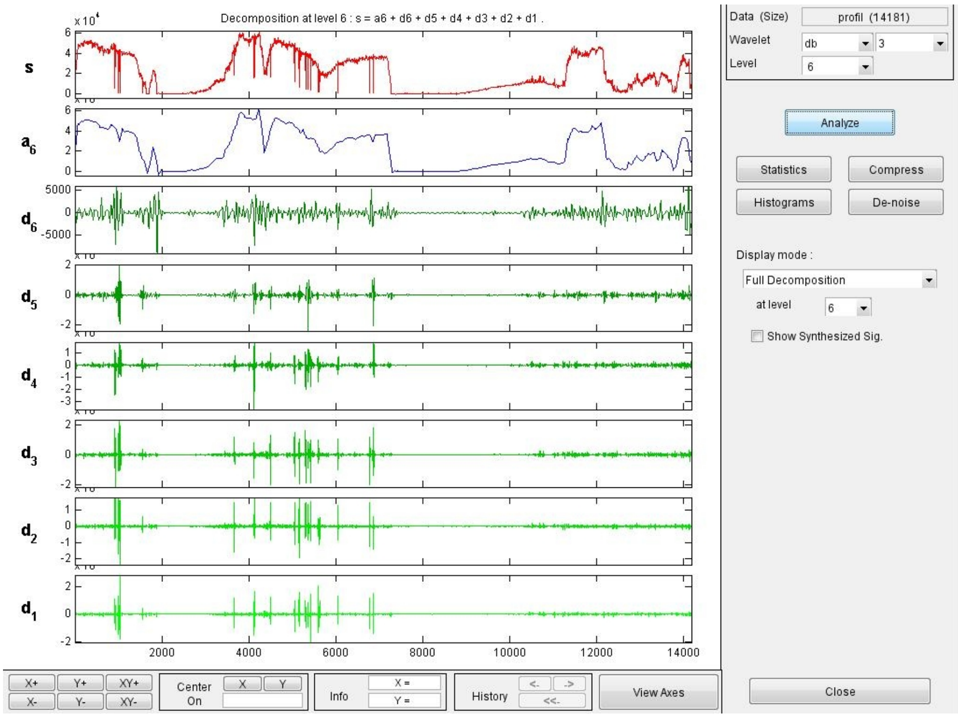

FIGURE 1 – wavelet analysis for an actual power demand signal using the Daubechie's wavelet

In figure 1, we have an actual power demand signal, which is the first signal on top (s), sampled. This is a numerical series [].
The figure (a6) just below the signal (s), is the approximation signal, or the low frequency signal, whch will be attributed to the battery and the FC during the drive cycle (see [Zha08] for the caracteristics of the battery, FC sytems, and UC systems).
The rest signals below (d1,d2, d3, d4, d5, d6) will form a single signal (d1+d2+d3+d4+d5+d6)which is the detailed signal, or the high frequency signal and will be attributed to the UC system [Zha08].
The choice of the mother wavelet (Daubechies 3 [Mis03]) and decomposition level are used in an adequate manner [Mis03].

5 Conclusion and Perspectives

By application of the wavelet decomposition method, we easily can see that the power demand signal consists on transients, sharp variations, noises, etc...
Using wavelet transform, and fixing some scale, we thus divide the power demand signal in multiple signals, which are parts of the power distribution.

After obtaining the signal components, we chose, for each instant t, the suitable device or source to ensure the demand at this time.
In the next work, we shall applicate prediction by wavelet method, in the real drive domain, for the power demand.

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