

Order Optimization for Wavelet Shrinkage Methods-based Noise Elimination in Experimental CDVI Signal of the Series/Parallel-Cell Configured Battery Pack

Jonghoon Kim¹, Chang Yoon Chun², Woonki Na³

¹*Department of Electrical Engineering, Chosun University, Gwangju, gwzxas@hanmail.net*

²*Department of Electrical and Computer Engineering, Seoul National University, Seoul, wobniw77@snu.ac.kr*

³*Department of Electrical and Computer Engineering, California State University, Fresno, wkna@csufresno.edu*

Summary

Unexpected noise-containing experimental charging/discharging voltage information (CDVI) signal of the battery pack absolutely results in erroneous performance error in the equivalent-circuit model (ECM)-based adaptive state-of-charge (SOC) and state-of-health (SOH) estimators such as extended Kalman filter (EKF) and sliding-mode observer (SMO), etc. With increased necessity of an elaborate CDVI signal for improved SOC and SOH estimations performance of the series/parallel-cell configured battery pack, this work newly investigates an innovative topic that appropriately implements the noise elimination in experimental CDVI signal based on the wavelet shrinkage methods (hard- and soft-thresholding denoising techniques).

Keywords: wavelet shrinkage, multi-resolution analysis, series/parallel-cell configured battery pack

1 Introduction

These days, for electric-powered transportation of EV and HEV that requires high-voltage and high-energy specifications, the low voltage lithium-ion cells are vitally connected in series, parallel, and series/parallel to configure the lithium-ion battery pack. Specifically, in order to acquire more improved performance of the battery pack, the equivalent-circuit model (ECM)-based battery management system (BMS) has been absolutely recognized as a prerequisite condition, such as state-of-charge (SOC) and state-of-health (SOH). The most significant task in the ECM is to acquire elaborate experimental charging/discharging voltage information (CDVI) signal used in the SOC/SOH estimators such as extended Kalman filter (EKF), dual extended Kalman filter (DEKF) and sliding-mode observer (SMO). The performance on the aforementioned methods is absolutely dependent on voltage difference between experimental CDVI signal and an estimated voltage. It is important to obtain the little voltage difference for high-accuracy SOC/SOH estimations. However, because of unexpected and instantaneous sensing of noisy, the noise-containing CDVI signal can result in erroneous BMS performance such as long run-time calculation and an increased estimation error. In this overall perspective, a new research that gives insight to the implementation of the noise elimination of the CDVI signal should be required.

This research newly investigates an innovative issue for noise elimination in experimental CDVI signal of the battery pack. This research basically considers the wavelet shrinkage methods [1]-[3] (hard- and soft-thresholding denoising techniques) in order to eliminate the noise in the original CDVI signal. Particularly, this research develops prior investigation one step further by showing two comparative analyses (hard and soft) according to the different order of the mother wavelet (Daubechies db). With regard to the signal-to-noise ratio (SNR) value, two comparative analyses are evaluated. This research has been extensively validated by experimental results of the series/parallel-cell configured battery pack (2S3P) [4].

2 Basic concept of the wavelet shrinkage method for noise elimination

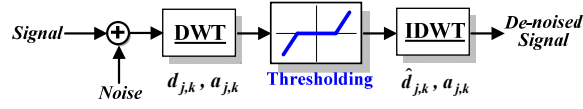


Figure 1: Three steps of wavelet shrinkage method-based noise elimination.

$$\hat{d}_{j,k}^{(hard)} = \begin{cases} d_{j,k} & |d_{j,k}| \geq \text{threshold value } \delta^T \\ 0 & |d_{j,k}| < \text{threshold value } \delta^T \end{cases} \quad \hat{d}_{j,k}^{(soft)} = \begin{cases} \text{sgn}(d_{j,k})(|d_{j,k}| - \delta^T) & |d_{j,k}| \geq \text{threshold value } \delta^T \\ 0 & |d_{j,k}| < \text{threshold value } \delta^T \end{cases} \quad (1)$$

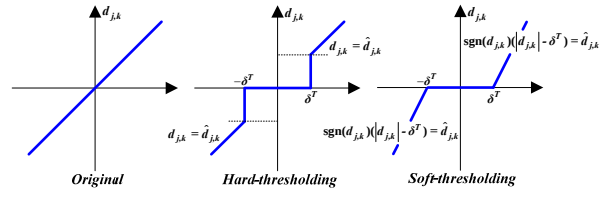


Figure 2: Original, hard-thresholding, and soft-thresholding functions for wavelet shrinkage methods-based noise elimination (denoising) technique.

The main characteristic of the wavelet transform [6][7] is to decompose a time domain signal into different frequency groups. By the multi-resolution analysis (MRA), an arbitrary non-stationary signal can be entirely decomposed with regard to approximation, provided by scaling function $\phi_{j,k}(t)$ and the details, provided by the wavelet function $\psi_{j,k}(t)$. Specifically, wavelet shrinkage method based on the wavelet transform has the possibility of the noise elimination in unexpected noise-containing signal. Figure 1 displays three steps of wavelet shrinkage method-based noise elimination: (i) decomposition of the noise-containing signal into a set of approximate $a_{j,k}$ and detailed coefficients $d_{j,k}$, (ii) thresholding the resulting detailed coefficients, (iii) reconstruction from the reduced set of detailed coefficient $\hat{d}_{j,k}$. As shown in Figure 2 and expressed in Eq. (1), the difference between wavelet shrinkage methods such as hard- and soft-thresholding is the magnitude of the detailed coefficients determined by threshold value δ^T [8].

3 Proposed approach

3.1 MRA-based decomposition of noise-containing CDVI with variable order

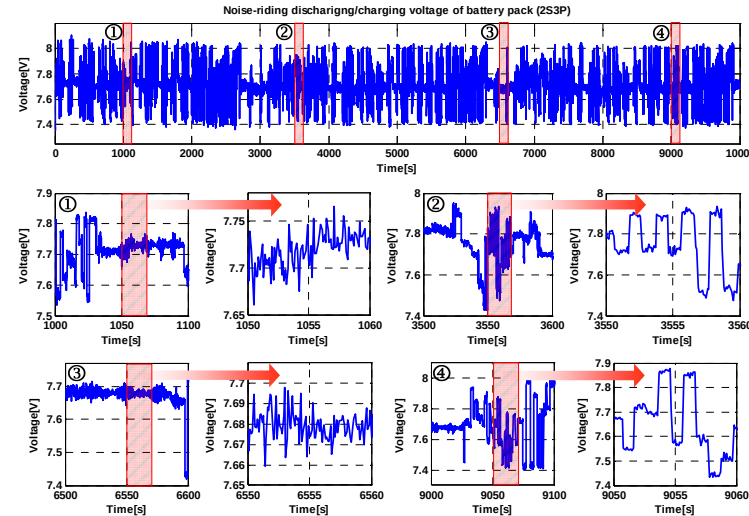
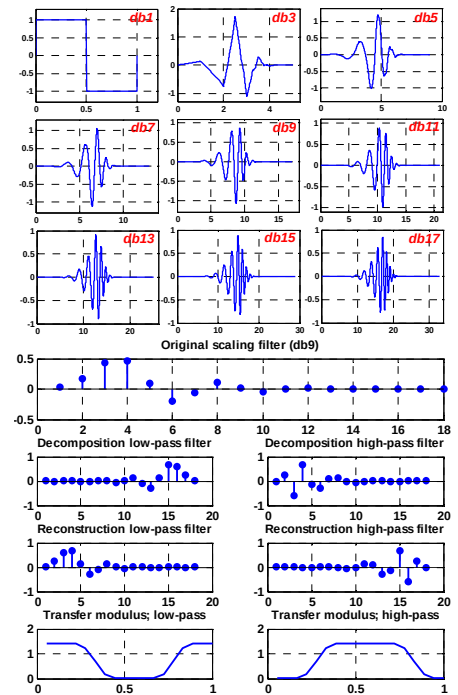


Figure 3: Four enlarged shapes of the noise-containing CDVI signal of the series/parallel-cell configured battery pack (2S3P).

Figure 4: Wavelet function shapes of Daubechies mother wavelet (db) with variable orders (right/top).

Figure 5: Original scaling filter, decomposition/reconstruction low- and high-pass filter coefficients and transfer modulus of Daubechies wavelet db9 (right/bottom).



The noise-containing CDVI signal can be easily obtained by non-filtering BMS part and a Gaussian noise inclusion. Figure 3 shows four enlarged shapes of the noise-containing CDVI signal of the series/parallel-cell configured battery pack (2S3P). For noise elimination from an original CDVI signal, the MRA-based decomposition process should be preceded. Then, it is required to determine the type of mother wavelet for MRA. This research basically adapted the Daubechies mother wavelet (db). Specifically, an interesting is that there are variable wavelet functions on Daubechies mother wavelet order dbN (Figure 4). For reference, Figure 5 shows original scaling filter, decomposition/reconstruction low- and high-pass filters coefficients and transfer modulus of db9. This research considered 20 Daubechies mother wavelet order (db1-db20) for MRA-based decomposition process. At level 5, the decomposition of the noise-containing CDVI signal is shown in Figure 6. There are one approximation component A_5 and five detail components D_1 - D_5 .

However, although MRA-based decomposition implements, it stands to reason that it is impossible to avoid the noise effect on the CDVI signal without noise elimination. From this reason, the next section 3.2 will show some experimental results of noise elimination based on wavelet shrinkage methods. For a clear judgement on noise elimination performance, this research considered the signal-to-noise ratio (SNR) value.

3.2 Wavelet shrinkage methods-based noise elimination and comparative analyses

Considered in noise-containing CDVI signal in Figure 3, this section performs the noise elimination based on the wavelet shrinkage methods-based noise elimination regard to the Daubechies mother wavelet order. With variable orders of db1 through db20, Figures 7 and 8 respectively show the noise elimination based on wavelet shrinkage methods such as hard- and soft-thresholding (*VisuShrink* threshold value δ^T). From obtained de-noised voltages in two figures, each SNR values are compared in Figure 9. These figures indicate that it can be defined as an optimized order db5 (hard-thresholding) and db20 (soft-thresholding) that have all maximum SNR values. These orders are finally selected for denoising.

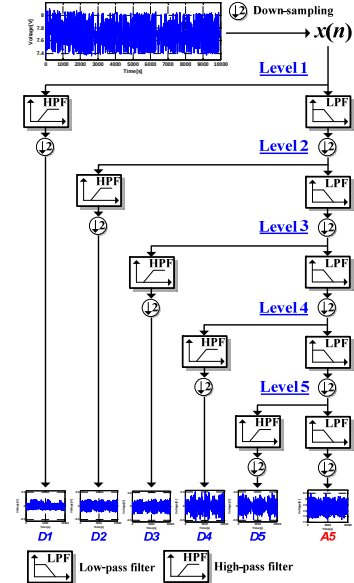


Figure 6: Five-level based MRA.

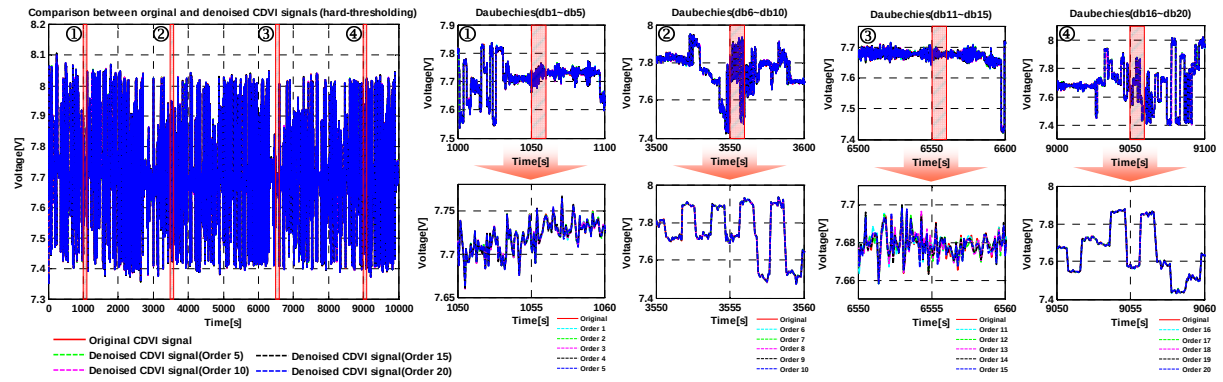


Figure 7: Comparison between noise-containing CDVI signal and de-noised voltages with respect to the mother wavelet order (hard).

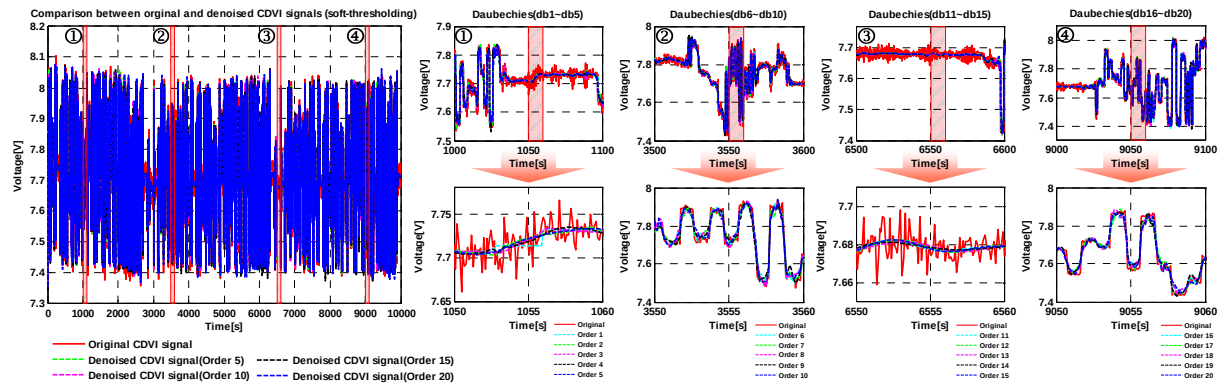


Figure 8: Comparison between noise-containing CDVI signal and de-noised voltages with respect to the mother wavelet order (soft).

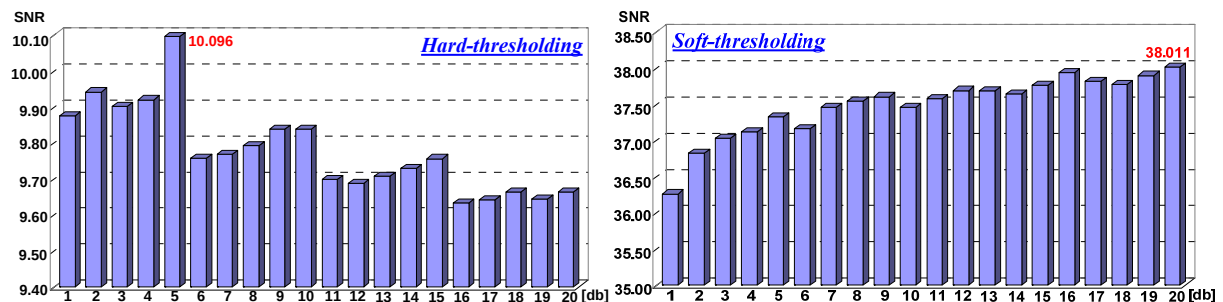


Figure 9: Each SNR values of de-noised voltages with respect to the mother wavelet order (hard- and soft-thresholding).

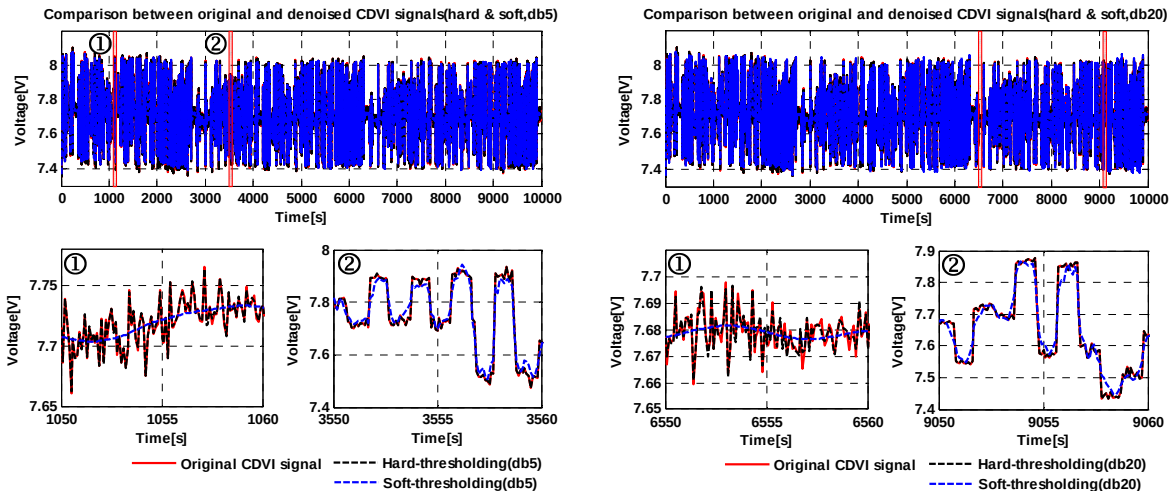


Figure 10: Comparison between noise-containing CDVI signal and de-noised voltages with hard- and soft-thresholding (db5, db20)

Figure 10 compared between noise-containing CDVI signal and de-noised voltage (db5 and db20). Also, each SNR values of noise-containing CDVI signal and de-noised voltages related to the mother wavelet order are entirely shown in Figure 11. From these results, irrespective of mother wavelet order, it can be shown that the performance on noise elimination of soft-thresholding is more superior to that of hard-thresholding. Finally, by wavelet shrinkage methods-based noise elimination, these de-noised voltages can sufficiently guarantee an improved SOC/SOH estimation.

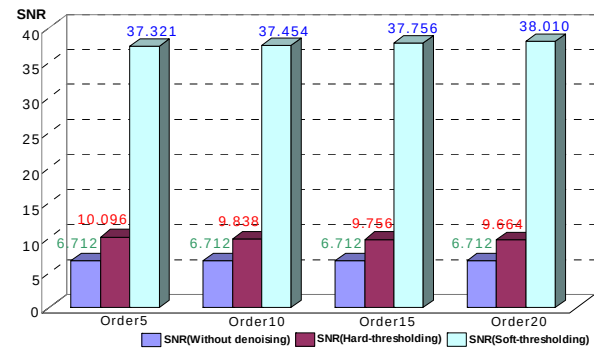


Figure 11: Each SNR values of noise-containing CDVI signal and de-noised voltages with respect to the mother wavelet order

4 Conclusion

This work newly investigates an innovative topic that appropriately implements the noise elimination in experimental CDVI signal based on the wavelet shrinkage methods (hard- and soft-thresholding denoising techniques).

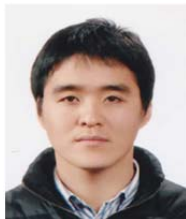
References

- [1] M. A. Farahani, M. T. V. Wylie, E. Castillo-Guerra, and B. G. Clopitts, "Reduction in the Number of Averages Required in BODTA Sensors Using Wavelet Denoising Technique," *J. Lightwave Technol.*, vol. 30, no. 8, pp. 1134–1142, Apr. 2012.
- [2] C.-C. Liu, T.-Y. Sun, S.-J. Tsai, Y.-H. Yu, and S.-T. Hsieh, "Heuristic wavelet shrinkage for denoising," *Appl. Soft Comput.*, vol. 11, pp. 256–264, Jan. 2011.
- [3] D. Giaouris, J. W. Finch, O. C. Ferreira, R. M. Kennel, and G. M. El-Murr, "Wavelet Denoising for Electric Drives," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 543–550, Feb. 2008.
- [4] <http://www.lgchem.com/global/main>

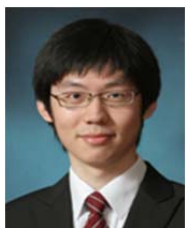
Acknowledgement

This work was supported by the Human Resource Training Program for Regional Innovation and Creativity through the Ministry of Education and National Research Foundation of Korea (NRF-2014H1C1A1066713).

Authors



He received the B.S. degree in Electrical Engineering from Chungnam National University, Daejeon, Republic of Korea and Ph.D degrees in Electrical Engineering and Computer Science from Seoul National University, Republic of Korea, in 2005 and 2012, respectively. From 2012 to 2013, he was a Senior Research Engineer in Energy Storage System (ESS) Development Group, Energy Solution (ES) Division, Samsung SDI, Cheonnan, Republic of Korea. He is currently an assistant professor with the Department of Electrical Engineering, Chosun University, Gwangju, Republic of Korea. His main research interests include battery management system (BMS; modelling, screening, equalization, SOC/SOH estimation), Lithium-air, and fuel cell system (ripple current analysis, fault diagnosis, SOH prediction, and modelling). He is a member of IEEE and the Korean Institute of Power Electronics (KIPE).



He respectively received his B.S, M.S. and Ph.D. degrees in 2009, 2011 and 2016 from Seoul National University (SNU), Seoul, Republic of Korea. Dr. Chun is currently working as a Senior Research Engineering in Samsung SDI. His research interests are in the areas of resonant converters and battery management system.



He received the B.S. and M.S. degrees in electrical engineering from Kwangwoon University, Seoul, South Korea, in 1995 and 1997, respectively, and earned the Ph.D. degree in electrical engineering from the University of Texas at Arlington in May, 2008. From 2008 to 2009, he was with Caterpillar Inc., Peoria, IL and participated in several hybrid electric drives programs as Senior Engineer. He was Assistant Professor with the Department of Electrical and Computer Engineering, Bradley University, Peoria, IL, USA from 2010 to 2013. Currently he is Assistant Professor with the Department of Electrical and Computer Engineering, California State University, Fresno since Aug. 2013. His research and teaching interests include power electronics, batter management, and digital signal processor(DSP) based control designs for hybrid electric vehicle and renewable/alternative energy applications.