Envelope Extraction Morphological Filter on Detecting Low Frequency Oscillations

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Abstract

Mathematical Morphology (MM) has been developed and applied widely in the field of image and signal processing due to its robustness in preserving the shape while suppressing noise[1]. By applying diverse combinations and calculations of morphological operators (MO), different objective signals can be extracted for analysis and diagnosis in power systems. Based on two basic morphological operators, *opening-closing* and *closing-opening*, a morphological filter (MF) with pre-designed structuring element (SE) has been implemented to detect low frequency oscillation (LFO) signals considering the effects of harmonics. The objective has been achieved successfully and the corresponding results are presented here.

What is LFO?

Low frequency oscillations are generator rotor angle oscillations having a frequency between 0.1-2.0 Hz and are classified based on the source of the oscillation. The root cause of electrical power oscillations is the unbalance between power demand and available power at a period of time[2]. LFOs can be formed into these two categories: local modes which has a range of 1.0 to 2.0 Hz and inter-area modes which has a range of 0.1 to 1.0 Hz. The existence of LFO phenomenon could lead to wide spread blackouts and it happens more and more frequently in recent years around the whole world. Therefore, due to the importance for dynamic stability and long-distance-transmission capability, effective detection and accurate extraction of LFO are significantly necessary in large-scale power systems.

Morphological Filters

MM, which is a non-linear approach, has been developed for several decades and it becomes an important method for signal and image processing. MOs are set transformations which are effective in processing signals or extracting desired features. Let S and G denote the input set and SE, respectively. Two basic operators of MM, *dilation* and *erosion* can be defined as follows respectively:

$$\delta_G(S) = S \oplus G = \bigcup_{g \in G} (S + g) \ ,$$

$$\epsilon_G(S) = S \ominus G = \bigcap_{g \in G} (S - g) \ .$$

By combining *dilation* and *erosion*, another two popular operators *opening* and *closing* are generated, presented respectively as:

$$S \circ G = (S \ominus G) \oplus G,$$

$$S \bullet G = (S \oplus G) \ominus G.$$

Consequently, *opening-closing* and *closing-opening* operators are given as:

$$f_{opening-closing} = S \circ G \bullet G \ ,$$

$$f_{closing-opening} = S \bullet G \circ G.$$

These two operators can constitute a new MF shown as:

$$f_{mf} = (f_{opening-closing} + f_{closing-opening})/2.$$

LFO signals result in the slight shape change of the envelope of the power system signal. As a consequence, the proposed MF can remove all the detail waveforms whose width are shorter than the length of the SE. In this application, the SE is selected as a flat one with its origin at the center. Furthermore, in order to extract LFO, the waveforms of the fundamental frequency component and its higher harmonics can be eliminated and the proposed MF can be regarded as the envelope extraction MF.

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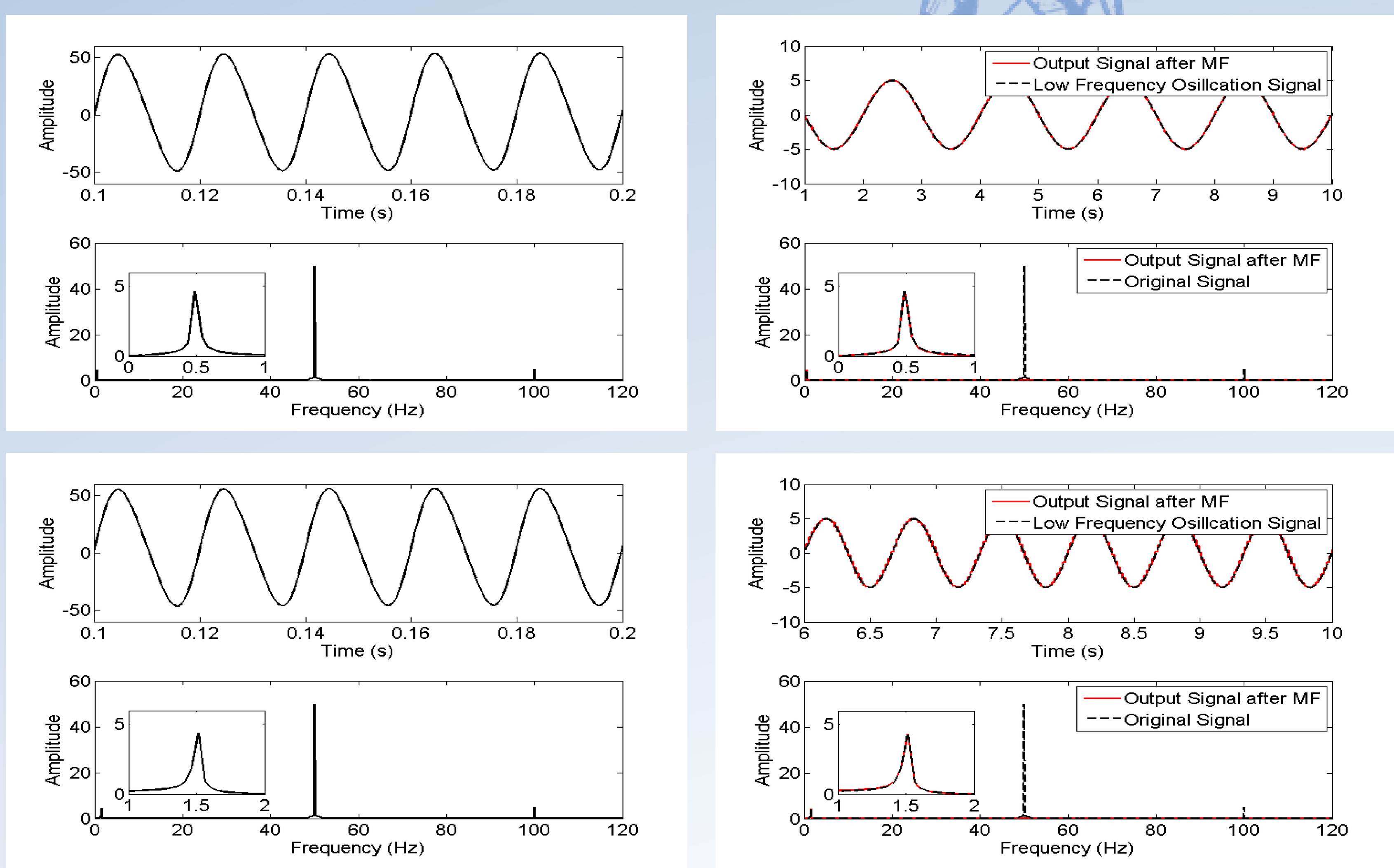
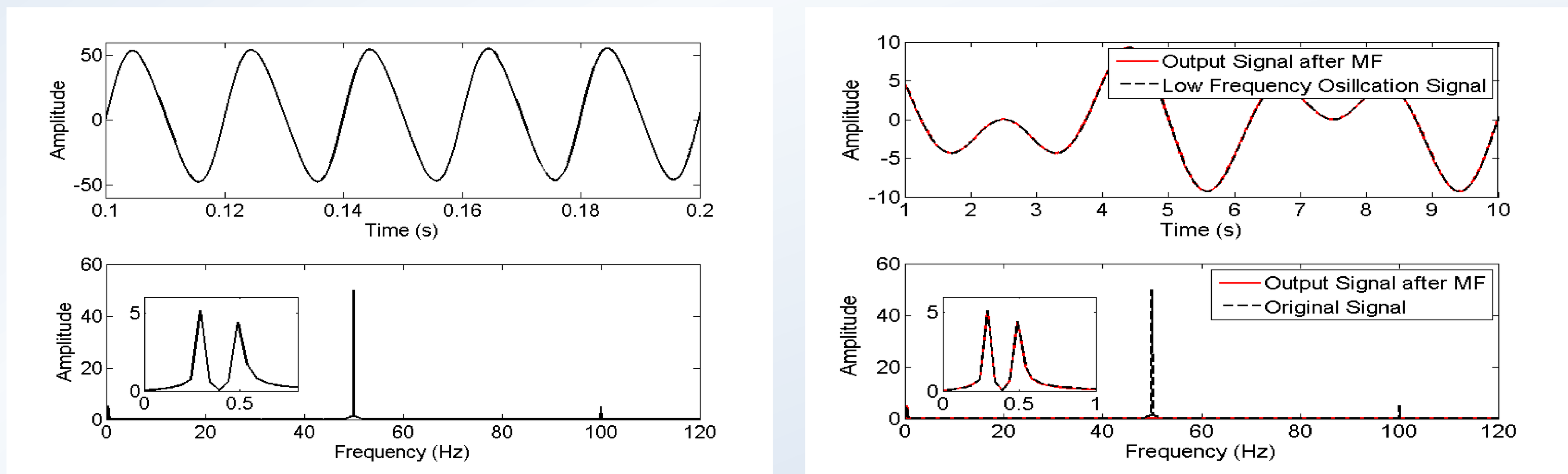
Simulation Results

The following waveforms and spectra on the left side present the input signal containing LFOs and harmonics. The corresponding output signals after MF are shown on the right. The simulation study is based on MATLAB.

- Scenario I Results:



- Scenario II Results:



In the first case, it is apparent that a single LFO signal is extracted successfully from the input signal and the fundamental frequency component and harmonic are also removed. In case II, by adding another LFO component into the input signal, the proposed method is still effective in detecting all the existed LFO signals using the same MF. The bandwidths for each frequency of LFOs are listed in Table I.

Table I Bandwidth of output signal using MF

Frequency of LFO (Hz)	Bandwidth Range (Hz)	Bandwidth (Hz)
0.3	0.28-0.31	0.03
0.5	0.48-0.51	0.03
0.8	0.77-0.82	0.05
1.0	0.97-1.03	0.06
1.2	1.17-1.24	0.07
1.5	1.50-1.53	0.03
2.0	1.99-2.02	0.03

Summary

A novel method based on MM has been proposed for detection and extraction of LFOs in power system. This approach uses an envelope extraction MF to detect the existence of LFOs using a flat-line SE. Furthermore, this method is effective for extracting different frequencies' LFOs and can be applied to a wide variety of signals found in power systems. Moreover, the comparison between a conventional method, empirical mode decomposition (EMD), and the approach described here has also been made and it is shown that MF achieves the same performance consuming less computational time.

References

[1] Z. Lu, Q.H. Wu and J. Fitch, A Morphological Filter For Estimation of Power System Harmonics, 2006.
[2] K. Prasertwong, N. Mithulananthan and D. Thakur, Understanding low-frequency oscillation in power systems, 2010.