Harmonic Analysis Algorithm Based On SVD Filter

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ABSTRACT

SVD (singular value decomposition) has been applied to design a FIR band-pass filter for both narrow and steep transitional bands, so as to simplify the complex execution on hardware when the harmonic algorithm that is based on FIR (finite impulse response) digital filter is used. First of all, a conventional method is used to obtain the coefficients of the band-pass filter (prototype), and some of the coefficients are arranged in a matrix. Then, the coefficient matrix is used to calculate SVD, based on which, a low dimensional and approximate expression of the matrix is accordingly obtained. Finally, according to the approximate expression of the matrix, the execution structure of the extrapolation filter is employed to design, approximately, the prototype of the band-pass filter. Simulation results show that the complex hardware execution of the harmonic algorithm can be simplified by using the proposed method to extract and analyze the harmonic waves.¹

INTRODUCTION

With the rapid development of power electronic technologies, the quality of electric energy has now been highly underlined because of the severe harmonic pollution in power system. Therefore, it is necessary to extract harmonic components from the power system to make follow-up analysis [1]. On the one hand, the measurement of high-voltage power is required to be more accurate, as it is related to the interests of three parties: power plant, power transporter and power consumer. On the other hand, online monitoring on both the quality and the usage of electric energy is of great significance to maintain a safe and reliable power grid as

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well as to ensure that the electric energy is reasonably tolled, and a great deal of on-site checking works can be saved thanks to the online monitoring results [2].

It is convenient to use Parks-McClellan optimal digital filter an applicable narrow and steep transitional band-pass filter [3]. The filter designed by this algorithm, however, has a higher order, implying that the execution on hardware is complex, which, as a result, will lead to a higher power consumption of the hardware system. To simplify the complex execution on hardware, SVD (singular value decomposition) has then been applied to design the band-pass filter for narrow and steep transitional bands.

**HARMONIC ANALYSIS ALGORITHM BASED ON SVD FILTER**

The SVD-based algorithm to design the narrow and steep transitional band-pass filter is constructed according to following steps:

Step 1: Continuous electric power signals are collected at the sampling frequency of \( f_{\text{sample}} \) and converted into digital signals \( x(n) \).

Step 2: Based on the sampling frequency \( f_{\text{sample}} \) and the harmonic component \( f_i \) as well as on actual conditions, the pass-band range \([f_{p1}, f_{p2}]\), the stop-band ranges \([0, f_s]\) and \([f_{s1}, 0.5 \cdot f_{\text{sample}}]\), the maximum pass-band ripple \( r_p \) and the maximum stop-band attenuation \( r_s \) of the narrow and steep transitional band-pass filter are determined.

Step 3: According to the sampling frequency \( f_{\text{sample}} \), the pass-band range and the stop-band range, as stated in Step 2, the normalized pass-band range \([2 \cdot (f_{p1}/f_{\text{sample}}), 2 \cdot (f_{p2}/f_{\text{sample}})]\) and the normalized stop-band ranges \([0, 2 \cdot (f_{s1}/f_{\text{sample}})]\) and \([2 \cdot (f_{s2}/f_{\text{sample}})]\) are obtained.

Step 4: According to the normalized pass-band range, the normalized stop-band range, the maximum pass-band ripple \( r_p \) and the maximum stop-band attenuation \( r_s \), the narrow and steep transitional band-pass filter \( h(n) \) is designed by using a conventional method, where, \(|n| \leq N_F \) and \( N_F \) can be any positive integer. The length of this FIR filter is \( 2 \cdot N_F + 1 \).

Step 5: Decompose singular values of the matrix \( H \):

\[
H = \sum_{i=1}^{r} \mu_i \cdot v_i^T \cdot \lambda_i
\]  

(1)
where, $\lambda_1, \lambda_2, \ldots, \lambda_r$ are singular values of the matrix.

Step 6: Given that the rest singular values can be ignored if compared to the $l$ maximum singular values, the matrix $H$ can be approximately expressed as:

$$H \approx \sum_{i=0}^{l} \mu_i \cdot \mu_i^T \cdot \lambda_i$$  \hspace{1cm} (2)$$

$$H \approx [\mu_0, \mu_2, \ldots, \mu_r] [s_0, s_2, \ldots, s_R]$$  \hspace{1cm} (3)$$

According to (3), the harmonic components for analysis can be extracted. The SVD-based algorithm to design the narrow and steep transitional band-pass filter is similar to the technique that is based on the periodicity of filter coefficients to design the low-pass FIR filter (extrapolation) [4-5]. Both have the same filtering execution structure. But, parameters in our algorithm are obtained by decomposing singular values as well as by searching on computer.

**SIMULATION**

To prove that the SVD-based narrow and steep transitional band-pass filter designed by using our algorithm is accurate to extract harmonic components from signals, the following simulation is conducted. The signals to be analyzed is expressed as:

$$x(t) = 5 \cdot \sin (2 \cdot \pi \cdot f_0 \cdot t + \phi_0) + 2 \cdot \sin (2 \cdot \pi \cdot f_1 \cdot t + \phi_1) + 3 \cdot \sin (2 \cdot \pi \cdot f_2 \cdot t + \phi_2)$$  \hspace{1cm} (4)$$

$f_0 = 50Hz$ , $f_1 = 75Hz$ , $f_2 = 100Hz$ , $\phi_0 = 0$ , $\phi_1 = 0.5 \cdot \pi \cdot 75$ , $\phi_2 = 0.5 \cdot \pi \cdot 100$ , the sampling frequency $f_{sample} = 2000Hz$ ; and the length of data record is 0.5s. The 50Hz and 75Hz harmonic components of band-pass filter 2 and 4 designed by our algorithm and the Parks-McClellan algorithm are extracted, respectively.
Figure 1 shows the 50Hz harmonic components of band-pass filter 2 designed by our algorithm and the Parks-McClellan algorithm, respectively. Figure 2 shows the 75Hz harmonic components of band-pass filter 4 designed by our algorithm and the Parks-McClellan algorithm, respectively. It can be seen that both algorithms can achieve a basically same effect.

CONCLUSION

In this study, SVD has been applied to the conventional algorithm (namely, the Parks-McClellan optimization FIR filter designing method) to design the band-pass filter for both narrow and steep transitional bands. The SVD-based algorithm has simplified the complex execution on hardware and, therefore, lowered the complexity of the hardware execution of the harmonic algorithm that is based on FIR digital filter.
REFERENCES