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Research paper

Fast DC Offset Removal for Accurate Phasor Estimation using Half-Cycle Data Window

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Abstract

Background and Objectives: Current and voltage signals' distortion caused by the fault in the power system has negative effects upon the operation of the protective devices. One of the influencing factors is the existence of the exponential DC which can significantly distort the signals and lead to a possible malfunction of the protective devices, especially distance and over-current relays. The main problem is the lack of clarity about this component due to the dependence of its time constant and initial amplitude to the configuration of the electrical grid, location and resistance of faulty point. This makes it hard to extract the main frequency phasors of the voltage and current.
Methods: Considering the importance of a fast clearance of the fault, this paper offers a method for an effective and fast removal of the decaying-DC that employs a data window with a length that is equal to the half cycle of the main frequency, while the conventional methods mostly use data from one cycle or even more. The proposed method is based upon the extraction of the decaying-DC component's parameters.
Results: The efficiency of this method is compared to the conventional Fourier algorithm of Half-Cycle (HCFA) and the mimic filter plus the HCFA.
Conclusion: The outcomes display that the proposed method presents a better efficiency from the point of view of the speed and the accuracy of convergence to the final results.

Introduction

Fast fault clearance in the power system is a crucial requirement for the system operation. Its main purpose is to separate the grid faulty areas and to prevent the instability. This is performed by the operation of protective relays installed in the power system and has to happen in a fraction of a power frequency cycle. Input signals of different relays are filtered according to the protective logic and their operation by removing the unwanted quantities and only preserving the desired ones [1].

Since the most of the protective relays such as distance and over-current relays operate based on the main phasors of the voltages and currents, the employed digital protective algorithms should be designed so that they eliminate the DC component and harmonics. Otherwise, the proper function of the protective relay may be disrupted due to any these quantities. For instance, presence of the decaying-DC in the current signal will lead to reduction of the impedance obtained in the distance relay and the overreach phenomenon. Consequently, the relay reacts for a fault which has not happened in its operational zone.

Algorithms used in digital filters, known as phasor estimation algorithms, can structurally be classified as follows:

a) Algorithms based on the small window data, such as: i) The Sample and Its First Derivative method by Mann-Morrison [2], ii) The First and the Second Derivative method by Gilchrist-Rockfeller-Udern [3], and iii) Two Samples method by Mokino-Miki [4].
b) Algorithms based on the orthogonal such as: Fourier Filter algorithm [5], [6] and its products i.e. Cosine and Sinusoidal Filters as well as the Walsh Filter algorithm [7] and its products i.e. CAL and SAL.
c) The Least Error Squares algorithms (LES), such as: i) Integral LSQ Fit [8], ii) Power Series LSQ Fit [9], and iii) Multi-Variable Series LSQ technique [10].
d) Algorithms based on the Kalman Filter [11].

The conventional Discrete Fourier Transform, DFT i.e. the group (b) algorithm, is the most sought-after algorithm used in the digital protection because of its proper operation and the ease of implementation. DFT algorithms are classified into Half-Cycle and Full-Cycle algorithms.

The DFT cannot eliminate the DC component because of its non-periodic nature and large frequency spectrum. In the recent years, some algorithms are offered in order to eliminate or to weaken the adverse aspects of the exponential DC component in the output of the full-cycle algorithms [12]-[40]. In [12], a mimic filter with the Fourier algorithm is proposed to remove the DC component. In this method, if the time constants (τ) of the decaying-DC component and the mimic filter are the same, the impact of the DC component can be completely removed.

In [12], the decaying-DC parameters are calculated by two Full-Cycle successive outputs Discrete Fourier Transform (FCDFT). In the modified version of the method in [12] by the same authors [14], the effect of analog anti-aliasing filter i.e. production of additional decaying-DC has been overcome. The method proposed in [15] uses two parallel DFT filters, one of them is set to the main frequency and the other to the m^{th} harmonic. The latter is used for calculating the decaying-DC component's parameters.

In [16], two partial sums are employed for complete removing the DC component's effects. One of the partial sums is the sum of odd samples and the other is the sum of even samples during a full cycle of the power frequency. The amplitude and τ of the DC component in [17] are obtained by two mathematical expressions which directly use the values from four samples. This method, which can be used in both full-cycle and half-cycle data windows, requires two extra samples.

In [18], the phasor is computed from three consecutive DFT estimates by using a recursive computing. So, it requires two extra samples. The method in [19] eliminates the DC impact by means of the difference between the outputs of the FCDFT for even and odd samples. The method proposed in [20] calculates the value of the actual DC offset by integrating the input signal. And then, the DC component is subtracted from the main signal for each sample. In [21], the DC component impact is removed by combining the outputs of FCDFT for even and odd samples extracted by decimation of the full cycle data window by two and by four.

The FCDFT output in [22] is corrected by integrating the input signal in a full cycle data window. To consider the changing frequency scenario of the electric network, [23] proposes LES method iteratively which fulfills the steady state and dynamic performance criteria of the IEEE standard for Synchrophasor Measurements for Power Systems [24]. The proposed method in [23] requires extra memory for storing LES filter coefficients of various frequencies.

The method in [25] computes the amplitude of the main frequency component by combining the FCDFT outputs filters for odd and even samples. In [26], the decaying-DC parameters are calculated by integrating the fault current signal in a full cycle. Then, the DC is subtracted from the main fault current.

The method in [27] uses MATLAB's fsolve function to estimate the fundamental frequency fault signal component which is developed for two cases including i) decaying-DC with known time constant, and ii) unknown time constant. For improving the fault location estimates, [28] removes the effect of the DC component by curve fitting by means of Non-Linear Least Squares method. Algorithms based upon wavelet transform [29] and neural network [30] have been utilized for the protection and phasor estimation applications.

Recently, phasor estimation under dynamic conditions has been under investigation. The methods in [31]-[33] propose dynamic phasor estimation which consider the off-nominal frequency condition. These methods may produce more accurate results for phasor estimation. However, they entail higher computational burden. In one of the most recent algorithms in this category, the DC amplitude and time constant are calculated by applying Hilbert transform and integrating the fault current signals within one cycle [33]. Hilbert transform has been utilized due to its effectiveness in the analysis of time-varying signals. Over the past few years some studies are conducted to forecast phenomena with uncertainties [34]-[37]. In [34] Gaussian model, in [35] ensemble learning based method and in [36] deep learning-based approach are used for forecasting.

All of the above methods are proposed for the full cycle algorithms and there are only few methods proposed for the half cycle algorithms. Half-cycle algorithms have a higher convergence speed, in the order of two times faster than full cycle methods. Among the most important half-cycle algorithms, the Half-Cycle DFT algorithm (HCDFT) and the combination of digital mimic filter and the HCDFT algorithm can be nominated. These methods are unable to completely remove the effects of the DC component [38].

One of the recently proposed methods to extract the phasor by means of the half-cycle data window is presented in [39] in which three offline look-up tables have to be created prior to processing the input signal for determining the decaying-DC component's parameters and removing its effects from the main signal. The look-up tables should be referred to during the online process which in turn increases the computational burden.

The method in [40] proposes a general modified DFT algorithm, so that it is possible to employ the method in both HCDFT and FCDFT algorithms. In this method, two successive outputs of the imaginary and real part filters are combined to eliminate the DC impact. In the method proposed in [40], three parallel filters are used. In addition, the data window length for HCDFT will be $n/2+1$, where n is the number of samples per cycle. A hybrid algorithm based upon integration and half-cycle DFT is proposed in [41]. This method computes the DC component parameters and the unwanted share of DC in the phasor estimation. However, it requires two movements in the sampling window.

In this paper, a method is presented to improve the efficiency of the Half-Cycle algorithm against the DC component. In the proposed method, the influence of the decaying-DC is entirely eliminated by means of its parameters' estimation. The proposed method can be used for a wide range of decaying-DC time constants and it is not dependent on the amount of the time constant.

This paper is structured as follows: the first section introduces the problem description, the second section formulates the proposed method, the third section evaluates the performance of the proposed methods, and the final section concludes this work.

Problem Description

The unpredictable nature of the fault signals in the power grid makes the main component phasor estimation a challenging process. Under the usual operating conditions, the voltage and current signals are almost clear sinusoidal with the main frequency of the grid. However, after failures or disturbances in the grid, these waveforms are distorted containing decaying-DC, harmonics, and the non-main frequency components [15].

The reactive-resistive feature of the network results in the generation of decaying-DC signal. The DC component considerably impacts the current signal where it has an insignificant influence of the voltage signal. There have been reports on up to 15% error in the phasor estimation by the deteriorative effect of DC component on the calculations [12]. Besides, DC component parameters cannot be determined with a high level of certainty. For instance, its time constant can depend on the configuration of the grid, the resistance and the location of fault and is specified by means of the X/R ratio seen from the fault point in general. For highly resistive earth faults, decaying rate will be so high that the decaying-DC would decay in less than half a cycle in some cases.

Generally, decaying-DC time constant range of variation is from 0.5 a cycle up to 5 cycles. It is not an alternating signal and thus, contains a wide frequency spectrum. Therefore, convergence speed and accuracy of the digital filtering methods are affected which leads to errors in the estimated phasors. Fig. 1 shows the frequency spectrum of the DC component with different time constants.

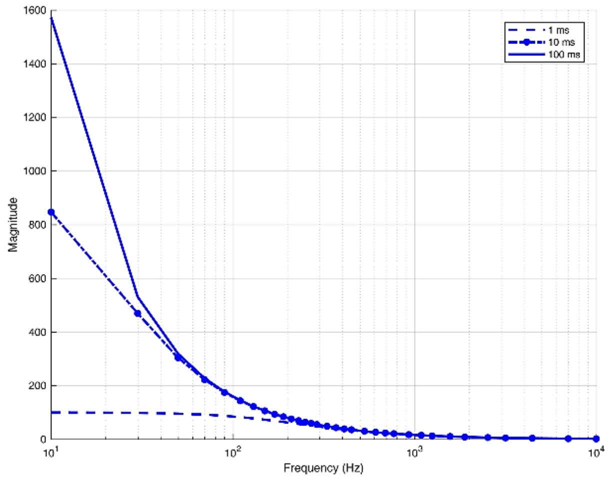

Fig. 1: Frequency spectrum of the DC component with various time constants.

As it can be observed, the ratio of low frequency component to high frequency one changes with the time constant. In other words, a fast decaying-DC contains less low frequency components compared to a slow decaying one.

The Proposed Method

In this part, the structure of the proposed method is introduced. First, influence of the DC component on the HCFA will be examined and then, for removing this effect a method will be presented.

A. Effect of the Decaying-DC Component

Let the input fault current signal contain: i) fundamental component, ii) first harmonic to p^{th} harmonics, iii) decaying-DC. It can be presented by the formula below:

$$i(t) = I_0 e^{-t/\tau} + \sum_{k=1}^{p} I_k . \sin(k\omega_1 t + \theta_k) \quad (1)$$

where I_0 is the DC amplitude and τ is its time constant. I_k is k^{th} harmonic amplitude, ω_1 is main angular frequency, ϑ_k is of k^{th} harmonic phase angle, and p is the largest order of harmonic that exists in the waveform.

It is assumed that the harmonic components that have higher orders than p have been eliminated in the input using the anti-aliasing low-pass filter. The analog to digital conversion is performed by an A/D converter as:

$$i(n) = I_0 e^{-nT/\tau} + \sum_{k=1}^{p} I_k . \sin(k\omega_1 nT + \theta_k) \quad (2)$$

where T represents the sampling time period and n points to the n^{th} sample.

The main frequency HCFA generates its output using the following equation:

$$\begin{aligned} HCdft_1^t &= \frac{4}{N}\sum_{n=0}^{\frac{N}{2}-1} i(n) \times (\sin\omega_1 nT + j\cos\omega_1 nT) \\ &= \frac{4}{N}\sum_{n=0}^{\frac{N}{2}-1} i(n) \times j \times e^{-j\omega_1 nT} \end{aligned} \quad (3)$$

where $HCdft_1^t$ is output of the main frequency HCFA for the total input signal, i.e., the signal that includes main frequency, harmonics, and the decaying-DC, and N is the quantity of samples per each cycle.

The harmonic components with odd order are eliminated by the HCFA and the input signal does not include even harmonics [42], the output will only contain the main frequency and the DC. The main frequency phasor will be found by removing the DC from the output of this algorithm. The output of main frequency HCFA for the exponential DC input can be calculated as follows:

$$HCdft_1^{dc} = \frac{4}{N}\sum_{n=0}^{\frac{N}{2}-1} I_0 e^{-nT/\tau} \times je^{-j\omega_1 nT} = \frac{4}{N} \times jI_0 \frac{1+e^{-NT/2\tau}}{1-e^{-T/\tau}e^{-j\omega_1 T}} \quad (4)$$

where $HCdft_1^{dc}$ is the output of main frequency HCFA; resulted from the DC component.

Once $HCdft_1^{dc}$ is determined, the output of main frequency HCFA for the main frequency component can be calculated using:

$$HCdft_1^{1f} = HCdft_1^t - HCdft_1^{dc} \quad (5)$$

where $HCdft_1^{1f}$ is the output of main frequency HCFA for the main frequency component which is the main frequency phasor.

According to (4), $HCdft_1^{dc}$ is a function of time constant and amplitude of the decaying-DC. Therefore, to obtain the output of the HCFA for the decaying-DC, these parameters have to be determined first.

B. Determining Decaying-DC Component's Parameters

As it was mentioned in the previous subsection, to obtain the main frequency phasors, the main frequency HCFA's output for the decaying-DC is required. According to (4), $HCdft_1^{dc}$ is a function of τ and amplitude of the DC component. Therefore, the mentioned parameters must be calculated first.

The current and voltage signals of the fault may consist main frequency, decaying-DC, high-frequency harmonics, and noise. Protective equipment use a filter with anti-aliasing low-pass features in each analog channel input to remove the high-frequency components. As a result, the components with the frequencies higher than the filter cut-off frequency of the anti-aliasing filter do not show up in the channel output.

Correspondingly, a Fourier filter of half-cycle set to a harmonic frequency higher than the low-pass filter cut-off frequency can be designed so that the main frequency and the other harmonics will not emerge in its output. Consequently, the output will only be influenced by the DC component. Time constant and Amplitude of the DC can be calculated by the output of the m^{th} harmonic frequency HCFA.

The Fourier filter of Half-Cycle is set to the m^{th} harmonic frequency. This frequency has to be higher than the low-pass filter cut-off frequency and lower than the half of the sampling frequency. Subsequently, output of the Fourier filter of Half-Cycle will only contain the effect of decaying DC and it goes as follows:

$$HCdft_m^{dc} = \frac{4}{N}\sum_{n=0}^{\frac{N}{2}-1} I_0 e^{-nT/\tau} \times je^{-j\omega_1 nmT} \quad (6)$$

With the assumption that the m^{th} harmonic is odd, one can rewrite the above equation as:

$$HCdft_m^{dc} = \frac{4}{N} \times jI_0 \frac{1+e^{-NT/2\tau}}{1-e^{-T/\tau}e^{-j\omega_1 mT}} \quad (7)$$

where $HCdft_m^{dc}$ is the outcome of the m^{th} harmonic frequency Half-Cycle Fourier filter.

Dividing (7) into imaginary and real parts results in the equations below, where $e^{-T/\tau}$ is substituted for E. The real part R is:

$$R = \frac{4}{N}\frac{I_0(1+E^{N/2})E\sin(\omega_1 mT)}{1+E^2-2E\cos(\omega_1 mT)} \quad (8)$$

and the imaginary part I is:

$$I = \frac{4}{N}\frac{I_0(1+E^{N/2})(1-E\cos(\omega_1 mT))}{1+E^2-2E\cos(\omega_1 mT)} \quad (9)$$

By using (8) and (9), the values for E and $(4/N)I_0(1+E^{N/2})$ can be calculated as:

$$E = \frac{R}{R\cos(\omega_1 mT) + I\sin(\omega_1 mT)} \quad (10)$$

$$\frac{4}{N}I_0\left(1+E^{N/2}\right)=\frac{R\left(1+E^2-2E\cos(\omega_1 mT)\right)}{E\sin(\omega_1 mT)} \tag{11}$$

The above equations use imaginary and real parts of the m^{th} harmonic frequency Half-Cycle Fourier algorithm's output and the specified values of $\sin(\omega_1 mT)$ and $\cos(\omega_1 mT)$. By placing (10) and (11) in (4), the main frequency Half-Cycle Fourier algorithm's output for the DC component is resulted. Finally, the main frequency phasor of the input signal, $HCdft_1^{1f}$, is achieved via (5).

In line with the above explanations, it can be observed that the proposed method requires two Half-Cycle Fourier filters; one set to the fundamental frequency and the other set to the m^{th} harmonic, where m is odd. The main purpose of using the m^{th} harmonic Fourier filtering is to acquire the parameters of decaying-DC. The needed calculations of the proposed method are: i) the implementation of two Fourier filters of Half-Cycle and ii) the calculations pertaining to (10), (11), (4), and (5). The proposed method flowchart is illustrated in Fig. 2.

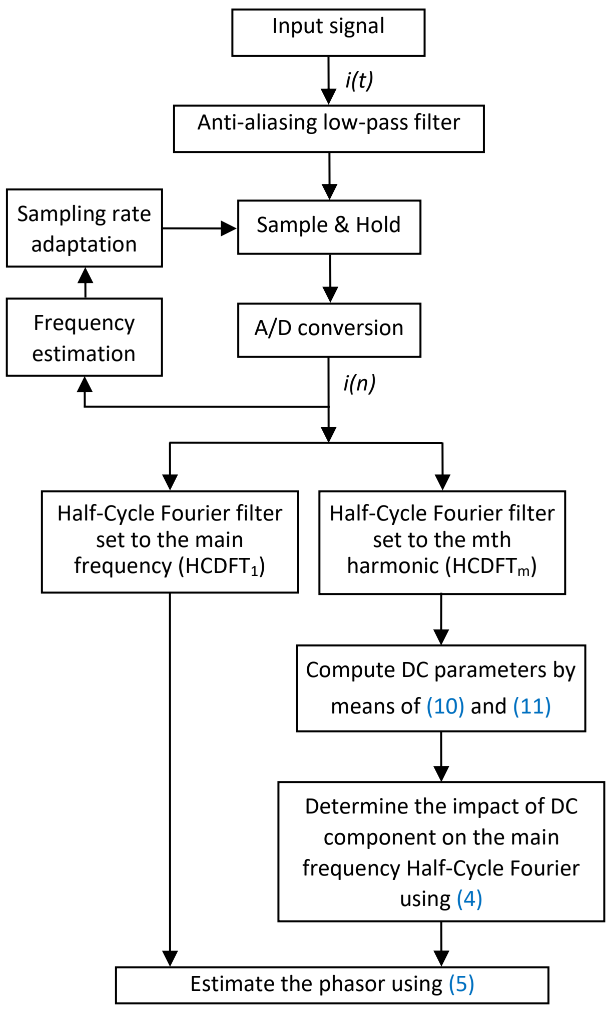

Fig. 2: The proposed method flowchart for the phasor estimation.

Results and Discussion

Algorithms efficiency is being assessed by the application of the following input signal:

$$i(t)=I_1\cos(\omega_0 t+\theta)-I_0 e^{-\frac{t}{\tau}} \tag{12}$$

in which I_0, amplitude of the DC component, and I_1, amplitude of the main frequency component are selected as 1 per-unit. $i(t)$ is applied to the various algorithms with a variable time constant of the decaying-DC component (τ) and their sensitivity versus τ variation is evaluated.

To make a comparison between different methods, the performance indices (PI_1 and PI_2) are utilized [12]. The performance indices are defined based upon the output of the digital phasor extraction filters for the input signal $i(t)$. $y(t)$ is the waveform of the filter's output for the applied input signal. $y(t)$ oscillates around 1 per-unit before permanently settling in this value. The first performance index PI_1 is calculated using the following equation:

$$PI_1(\tau)=\int_{T_0}^{NT}\left[1-y(t)\right]^2 dt \tag{13}$$

As soon as $y(t)$'s amplitude exceeds 1 per-unit, the integration starts (T_0) and proceeds until NT, which represents an integer number of the main frequency cycles. In the simulations, let N be 3. PI_1 represents the extent of the amplitude oscillations around the steady-state final value in the filter's output in the presence of the DC component in the input.

The second performance index PI_2 is equal to the highest overshoot percentage in $y(t)$'s amplitude. There is a straight relevance between this index and the protective devices' overreach potential.

$$PI_2(\tau)=\left(Max\left[y(t)-1\right]\right)\times 100 \tag{14}$$

As much as these indices get closer to zero, the higher quality of the tested algorithm is inferred. The input signal's sampling rate is 36 samples per cycle and the value for m is selected as 13 for the proposed method. The sampling window used in the simulations is the half of the main frequency cycle that means 18 samples.

The frequency response of the Half-Cycle Fourier filter set to the main frequency is presented in Fig. 3. As it can be observed, this filter cannot remove the decaying-DC component when used standalone. The time response generated by applying the input signal to the HCFA is illustrated in Fig. 4.

The values for the performance indices of the HCFA versus τ variation in the range of 0.5 cycle to 5 cycles are presented in Table 1.

If the current waveform passes a mimic circuit including a series resistor and inductor, the exponential decaying component will be removed or deteriorated in the circuit's output. The transfer function for the mimic circuit in the Laplace domain would be:

$$H_{mimic}(S) = K(1 + S\tau_1) \tag{15}$$

where τ_1 is the time constant which mimic filter is set to.

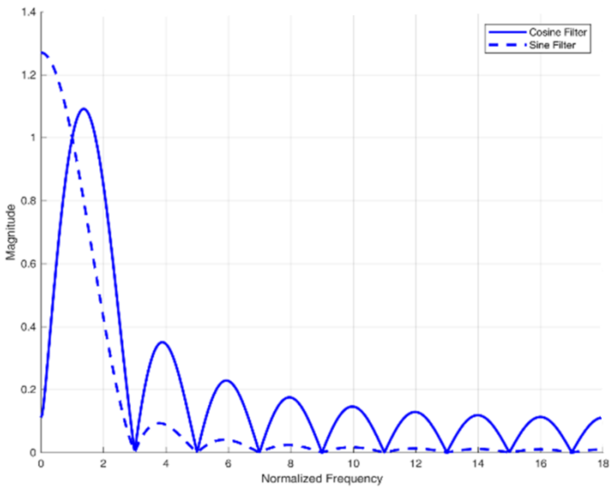

Fig. 3: Frequency response of the Half-Cycle Fourier filter for the main frequency.

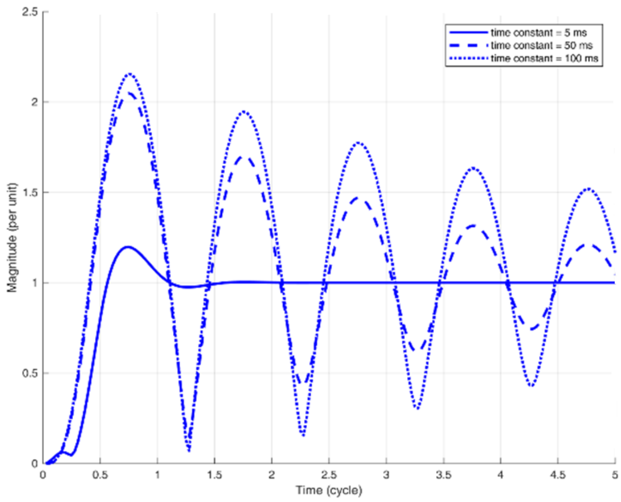

Fig. 4: Time response of the HCFA.

Table 1: Performance Indices for the HCFA

Time constant (mSec)	*PI*$_1$	*PI*$_2$ *(%)*
10	2.8692	49.1603
20	9.9800	78.5331
40	22.6705	99.7476
60	31.7330	108.1275
80	38.0549	112.6007
100	42.5512	115.3807

If the decaying component's time constant is equal to τ_1, its effect will be eliminated in the output of the mimic filter and if the time constant has a different value, its effect will be significantly reduced. The mimic circuit including a resistor and an inductor can also be digitally modeled. In the case S is replaced using the following equation, the Z domain representation of the mimic circuit's transfer function can be obtained:

$$S = \frac{1 - Z^{-1}}{\Delta T} \tag{16}$$

where ΔT is the sampling period.

The time constant is set to 50 ms in the mimic filter's design which is approximately located in the middle of its variation range. The digital mimic filter's frequency response is shown in Fig. 5. It is clear that the mimic filter is a high-pass filter that means boosting the high frequency components. Therefore, it is prone to high frequency noise.

By combining the digital mimic filter and the HCFA, the performance of the HCFA in confronting with the decaying-DC can be improved to some extent. The frequency response of the combination of digital mimic filter and the HCFA is presented in Fig. 6. The time response obtained by applying the input signal to the combination of the mimic filter and the HCFA is illustrated in Fig. 7.

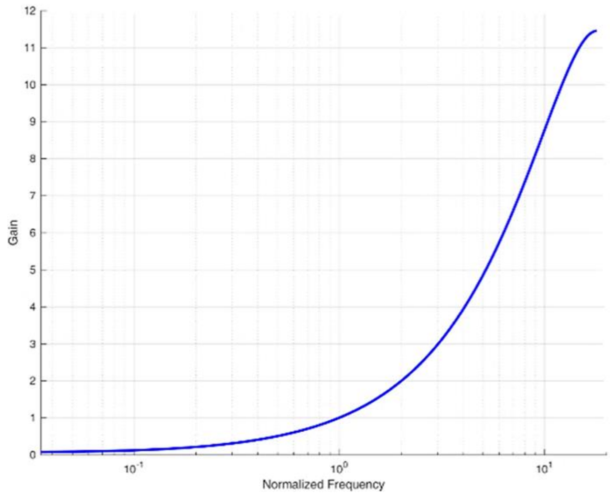

Fig. 5: Digital mimic filter's frequency response.

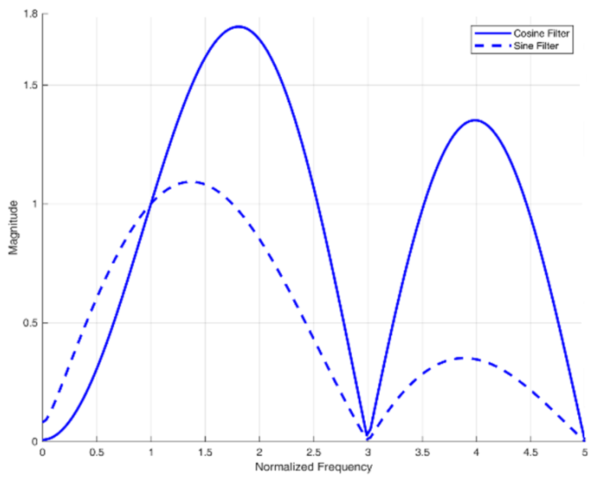

Fig. 6: Frequency response of the digital mimic plus the HCFA.

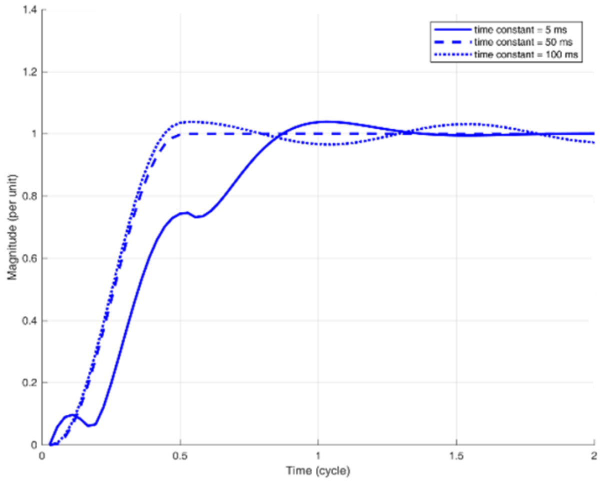

Fig. 7: Time response of the combination of digital mimic filter and the HCFA.

Performance indices for the combination of digital mimic filter and the HCFA are presented in Table 2.

Table 2: Performance Indices for the Combination of Digital Mimic Filter and the HCFA

Time constant (mSec)	PI_1	PI_2 (%)
10	0.054969	7.2968
20	0.046537	5.7402
40	0.004078	1.4166
60	0.003376	1.1969
80	0.021745	2.8038
100	0.044052	3.8010

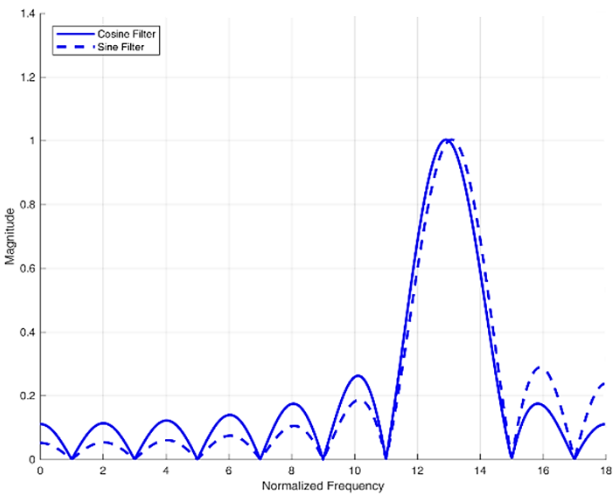

Fig. 8: Frequency response of the Fourier filter set to the 13th harmonic.

By using two parallel Half-Cycle Fourier filters, impact of the DC component upon the extracted phasor can be totally eliminated. As it was mentioned before, one of these Half-Cycle Fourier filters is set to the m^{th} harmonic (m=13) and the other is set to the main frequency. Fig. 8 demonstrates the frequency response of the Fourier filter set to the 13th harmonic.

The time response obtained by applying the input signal to the proposed algorithm is shown in Fig. 9.

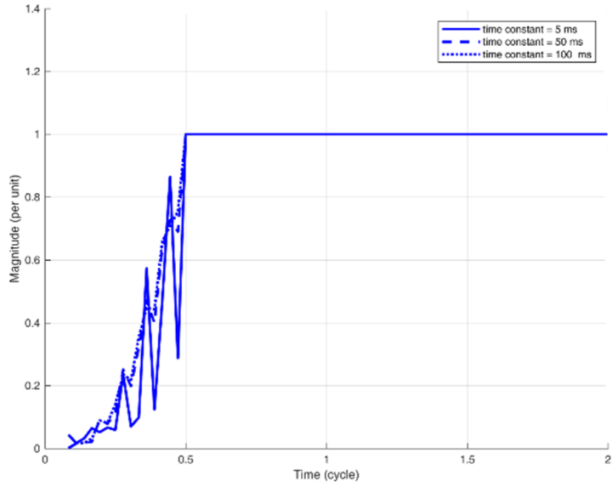

Fig. 9: Time response of the proposed algorithm.

For the proposed algorithm the values of the performance indices for τ variation in the range of 0.5 cycle to 5 cycles are presented in Table 3.

Table 3: Performance Indices for the Proposed Algorithm

Time constant (mSec)	PI_1	PI_2 (%)
10	0.00	0.00
20	0.00	0.00
40	0.00	0.00
60	0.00	0.00
80	0.00	0.00
100	0.00	0.00

By a careful examination of the time responses obtained from different methods, it can be observed that the Half-Cycle Fourier filter and the combination of digital mimic filter and the Half-Cycle Fourier both have overshoots in their outputs. Whereas, the proposed method does not have such overshoots and as soon as the data window fills with the valid fault data, its output reaches the desired value. In addition, the proposed method generates favorable responses for different time constants and it is not dependent on the value of the τ.

More simulations are performed to have a more vivid representation of different algorithms' performance for a wider range of τ variations of the decaying-DC, where the τ varies from 1 to 120 ms. Outputs after filling their data windows with the fault data are shown in Fig. 10.

The highest deviation of the HCFA from the desired output is 49.18% which happens in 120 ms time constant. The highest deviation from the desired output for the combination of digital mimic filter and the HCFA is 25.40% happening in 5 ms time constant. The proposed method's output comes to the favorite value as soon as the data window fills with the first half cycle data.

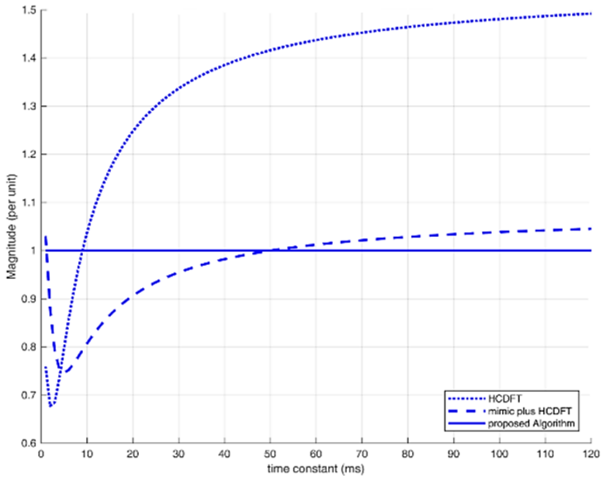

Fig. 10: The extracted phasor at the end of the fault's first half cycle.

Fig. 11 demonstrates the variations of the highest overshoot in the algorithms output as a function of the decaying-DC's time constant. The highest overshoot in the HCFA is 117.27% happening in 120 ms time constant. The highest overshoot in the combination of digital mimic filter and the HCFA is 7.39% happening in 11 ms time constant, whereas the highest overshoot in the proposed method is 2.59% happening in 1 ms time constant. As it can be observed, the proposed method does not generate a large overshoot for a wide range of the time constant variation.

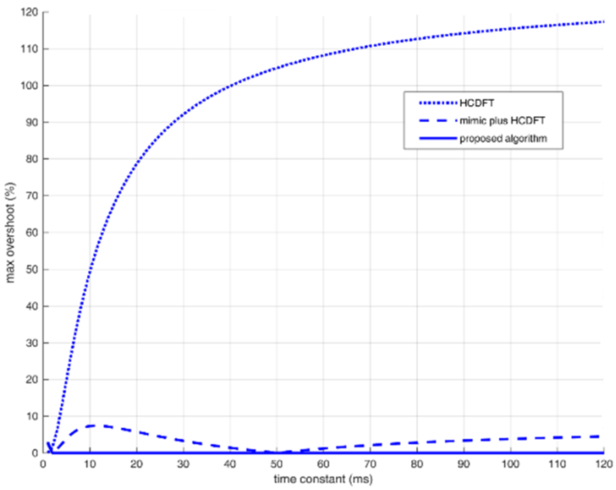

Fig. 11: The highest overshoot in the extracted phasor.

Conclusion

In this paper, a method for extracting the main frequency phasor was proposed which is favorably robust against the impact of the DC component. The proposed method estimates the phasors using a data window equal to the half cycle of the power grid's main frequency.

The proposed method utilizes two parallel filters set to different frequencies, so that after filling the data window with the fault data, precise and stable outputs are generated. In the proposed method, once the data window is filled with half-cycle data ($n/2$ of samples), the main phasor component is a computed, while in the presented method in reference [39] three look-up tables are referred to during online processing which causes an increase in computational work. The offered data window length for HCDFT method is $n/2+1$ in reference [40] which is one sample longer than that of our presented method.

Finally, in the proposed method of reference [41] it is necessary to move the data window two samples. As a result, the main phasor component will be calculated with a two-sample delay. Moreover, the Efficiency of the proposed method was compared to the HCFA and the combination of digital mimic filter and the HCFA which showed a higher speed and accuracy of the proposed method. The performance indices (PI_1, PI_2) are calculated for various algorithms and the indices are almost zero for the proposed method. The more these indices get closer to zero, the higher quality of the tested algorithm is inferred and therefore the desired performance of the proposed method is confirmed.

Author Contributions

Authors have had an equal contribution in the problem and data analysis, interpreting the results and writing the manuscript.

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Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

Abbreviations

DC	Direct Current
DFT	Discrete Fourier Transform
FCDFT	Full-Cycle Discrete Fourier Transform

HCDFT	Half-Cycle Discrete Fourier Transform
HCFA	Half-Cycle Fourier Algorithm

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