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Research Article

Evaluation of Using RDFT Method for Grid Synchronisation

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***Abstract*—The proposed work measures the accuracy of synchronization inverters to grid using filtering technique. Where two algorithms of Recursive Discrete Fourier Transform (RDFT) are used, each one turned for a specific frequency. The algorithms are implemented using STM microcontroller. It is shown from the results, that this method can provide accurate calculations and can comply with the domestic standards of synchronisation. The need of such a method can be clear at load-side, as grid waveform can be distorted due to non-linear loads or heavy electronic loads with rectifier filter. Distorting grid with unwanted harmonics can make synchronisation difficult while using Zero Crossing Detectors (ZCD) or Phase Locked Loop (PLL). The RDFT tool, is a fast and accurate method to detect waveform by filtering out undesirable perturbation. STM32F4 microcontroller was used to implement the method and Results were obtained. The results show that using of two RDFT method provides high accuracy in comparison to other.**

***Index Terms*— Algorithms, Grid-tie inverter, Synchronisation, RDFT, Fourier.**

I. INTRODUCTION

Increasing the diversity of grid by connecting renewable energy sources with combination of non-linear loads, can cause huge impact on the quality of grid voltage. The effect is presented as DC component or as asymmetry that can represent as flattening out the sinusoidal waveform at load side. Such effect can make synchronisation to grid difficult. Where Zero Crossing Detectors (ZCD) can make wrong decision in case of DC component or perturbation presence, while Phase Locked Loop (PLL) can be saturated. Filtering the grid waveform from undesirable harmonic can be one of the solutions [1]. Recent researches have been published to study the use of Recursive Discrete Fourier Transform (RDFT) as a solution for grid synchronisation [2,3,4]. Using fast digital controllers can offer versatile methods implementation [5]. RDFT is one technique that offers high precision low execution time and easy to undistorted grid voltage follows the equation

$$v_{(t)} = V_m \sin(\omega t) \tag{1}$$

While the previous equation (1) can be modified according to Fourier theory to hold all odd harmonics.

$$v_{(t)} = V_{dc} + \frac{V_m}{h}\sum_{h=1}^{h=\infty} \sin((h\cdot\omega t)+\theta) \tag{2}$$

Where

- h represents the harmonics order
- θ phase shift
- V_{dc} the direct current component in grid
- V_m maximum voltage of the waveform
- ωt angular frequency of the waveform

from equation (2) all harmonics can be represented with respect to their frequency, voltage and phase shift. During the last twenty years many authors have published on grid synchronisation during atypical conditions. Combining the consequences of transient activity to the mains by add on a DC component was investigated by [6,7].

While a paper published by [8] presents two methods, one utilised the Discrete Fourier Transform (DFT) by matching window width to waveform period whereas the other relies on measuring the phase angle difference by matching its two phasors. [9] Focuses on estimating phase angle by relying on determining the error of the phase for positive sequence in three-phase power system. Determining the efficacious admission in frequency domain and evaluating the frequency that given by [10] whereas [11] determine the admission by de-assembling the waveform of the source waveform by the use of RDFT.

II. DISCRETE FOURIER TRANSFORM

One of the primary digital signal processing tools which used to filter out undesirable frequencies is DFT. This tool might be applied to gain the fundamental from distorted grid waveform.

$$V_k = \sum_{n=0}^{N-1} v_n \cdot e^{-j2\pi n \frac{k}{N}} \tag{3}$$

where k = 0, 1, 2, … , (N - 1) ; FFT bin width
N: number of elements or samples.
v_n: sampled value
Make reference to equation (3), DFT works by summing the samples value of the waveform for N number of samples. The intervals between points are set by sampling frequency f_s of the ADC of the microcontroller, Both N and f_s can set the bin-width to determine the component of desirable frequency value of the waveform as depicted in Figure1.
considering:

$$bin\ width = \frac{f_s}{N} \tag{4}$$

The waveform of grid in equation (1) can be reformed in complex formula as below [12]

$$\overline{V} = Ve^{-j\theta} = V\cos\theta + jV\sin\theta \tag{5}$$

When substituting (5) in (3), grid waveform might be presented as a vector and its real and imaginary component as below:

$$\Re_e V[k] = \sum_{n=0}^{N-1} v_n \cos\left(2\pi n \frac{k}{N}\right) \tag{6}$$

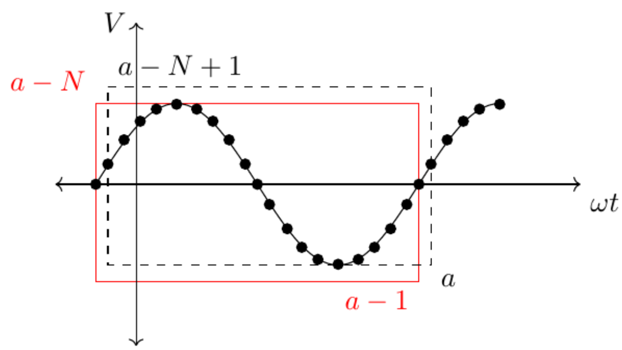

Fig. 1. FFT window width.

$$ImV[k] = -\sum_{n=0}^{N-1} v_n \sin\left(2\pi n \frac{k}{N}\right) \tag{7}$$

III. RECURSIVE DISCRETE FOURIER TRANSFORM

The RDFT is a computational solution to simplify the implementation of DFT, since the RDFT has been used widely in phase detection. RDFT is considered as high-speed algorithm used for power system applications because it is computationally efficient [13]. By applying the recursive solution to the equation 3, the RDFT output will be V[k] for a constant k.

$$V_{k-1} = \sum_{n=a-N}^{a-1} v_n \cdot e^{-j2\pi \frac{n-1\cdot k}{N}} \tag{8}$$

$$V_k = \sum_{n=a-N+1}^{a} v_n \cdot e^{-j2\pi \frac{n-1\cdot k}{N}} \tag{9}$$

Thus

$$V_k^{NOW} = V_{k-1}^{PREV} - v_1 \cdot e^{\frac{-j2\pi n}{N}} + \cdots + v_N \cdot e^{\frac{-j2\pi nk}{N}} \tag{10}$$

that is simplified to

$$V_k^{NOW} = V_{k-1}^{PREV} + \left(v_n - v_{(n-N)}\right) \times e^{\frac{-j2\pi nk}{N}} \tag{11}$$

by comparing the previous equation to the original DFT, it is shown that only duo multiplications are required while determining an incoming value, and thus minimum time require leading to minimal delay during phase detection.

IV. THE PROPOSED MEASUREMENT OF FREQUENCY

Representing a waveform as a vector requires three parameters, these parameters are the magnitude, phase angle and the frequency. The RDFT tool is used to find the three parameters. Because the grid frequency fluctuating around 50 Hz, the proposed implementation used two bins method tuned at 48 Hz and 52 Hz as shown in Fig. 2, where the intersecting point of response of each bin represents the desired frequency to monitor. Tunning the RDFT for monitoring a specific frequency, the number of specimens should be an integer according to the following equation

$$f(measured) = \frac{k \cdot f_s}{N} \tag{12}$$

The Execution of the RDFT will generate magnitude that will vary according to sinc function property for each bin-width. The two sinc functions responses having the same centre at the chosen frequencies and having an two extents of Hb, and Ha.

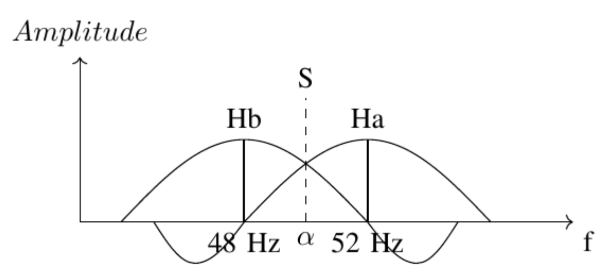

Fig. 2. Selected frequencies measurements with divergence of 4 Hz.

If tested waveform with frequency of 50 Hz then both RDFT will have the same magnitude. But if the frequency of the tested signal is drifted then the magnitude of the RDFT filter will be different. This variation can be used to find the frequency by following mathematical derivation.

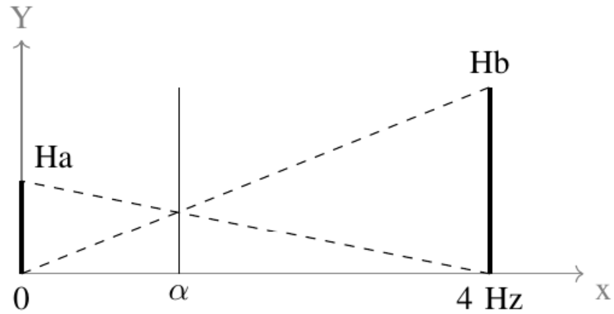

Fig 3: Measurement of selected frequencies points at divergence of 4 Hz

According to fig. 3, the triangle (0,Ha,4 Hz)

when x = 0 → y= Ha

x = 4 → y = 0

$$ya = Ha - \frac{Ha}{bin\ width} \times x \tag{13}$$

$$yb = 0 + \frac{Hb}{bin\ width} \times x \tag{14}$$

To find the intersecting point α, let Ya = Yb, then

$$x = bin\ width \frac{Ha}{Hb + Ha} \tag{15}$$

Where: x symbolizes the frequency divergence along 4Hz bin width. While the signal phase angle of each RDFT is calculated using atan (inverse tangent) function,

$$\theta_g = atan \frac{Img}{real} \tag{16}$$

V. THE TEST RESULTS

To validate the method a test was carried out to examine accuracy of the algorithms, the error of measuring frequency is shown in Fig.4.

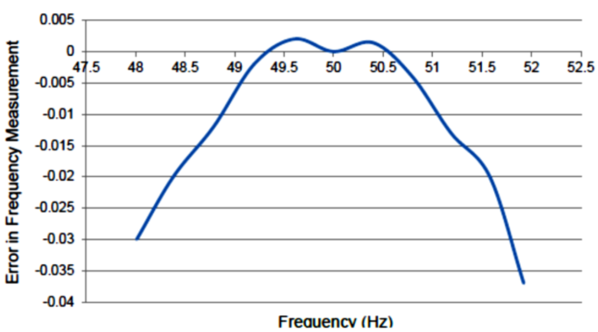

Fig. 4: Error of measuring the frequency

The previous figure shows the results of experimental test, while feeding the controller from adjustable frequency pure sinusoidal signal. It is shown that the error has limits of ±0.035Hz. This inaccuracy is produced due to the trimmed (truncated) signal. The truncation due to mismatching waveform period and bin width. As the existing grid fluctuates between 49.5Hz to 50.5Hz, then the actual error during normal operation is within the limits of 0 to ±0.025Hz.

By comparing previous result to [14], it is obvious that the frequency deviation occurred throughout measuring by the applied algorithm is below 0.17Hz, that is validated the performance.

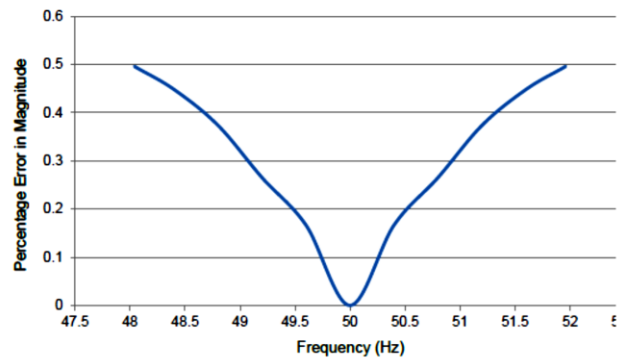

Fig. 5: The measured percentage of magnitude error

As determining the magnitude of the signal depends on the previous step, consequently the measured error can impact the magnitude calculations, as shown in Fig.5. The biggest error value presented is restricted to 0.5%. When the grid is operating with a margin of 49.5 Hz and 50.5 Hz. then, the error can be limited to 0:25. By comparing the calculated magnitude error to [15], it is shown that both researches have the same error value of 0.2 at ±2 Hz drift.

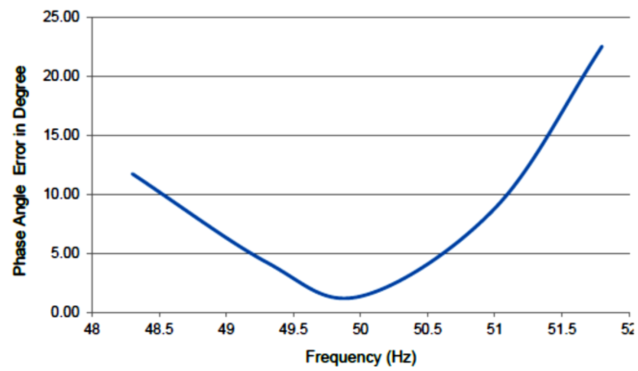

Fig. 6: Error of measuring the phase angle

Fig.6 shows phase angle error, this error is presented because it is related to the measured frequency. The error of the phase extends to 2.5º, this is compatible with the military and domestic standard for 400 V distribution system [16], [17] while the system is at upper frequency limits. Moreover, there is another factor that can affect the determination of phase angle, which is the signal treatment time which is correlated with the sampling frequency.

Fig.7 shows the used prototype to implement the DFT using STM32 discovery board fed from isolation transformer and transducer,

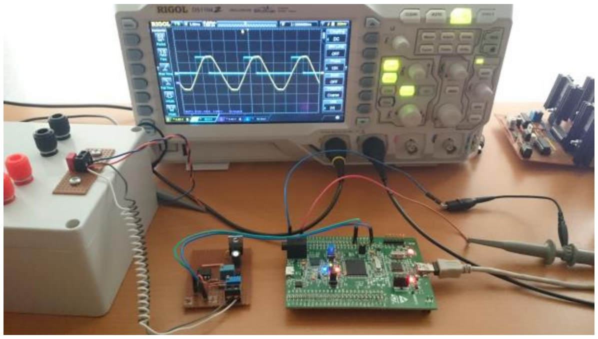

Fig. 7 : Used prototype to implement DFT

VI. Conclusion

Using RDFT tool with a finite window width may take out the fundamental component from disfigured signal by removing the unwanted high frequency and DC components.

Depending on the two-bin method to determine the main or fundamental component by carrying out the algorithm by the use of a microcontroller with 32-bit has successfully done. This microcontroller has the ability to determine the real time grid phasor. The aggregate efficiency of the system can be easily enhanced by increasing the sample rate or the sampling frequency. The test results showed that the algorithm operates within the domestic standers of synchronisation. Furthermore, the accuracy can be improved by linearising the results. Linearisation acts by adding correcting factor to the response.

Where the value of the correcting factor depends on the measured frequency. This step can reduce the error to minimum. The arithmetic derivation illustrates using the proposed method is precise, which can offer a reduction in time during execution. A small number of code lines is the real requirements for adopting this method if it is compared with PLL and ZCD

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