# Modelling and Analysis of DFIG Wind Turbine Harmonics Generated in Grids

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***Abstract* – In this paper an analytic technique for modelling harmonics is proposed for a DFIG wind turbine connected to the grid. An algorithm based on Hilbert transform for the analysis of harmonics in power systems is developed. The simulation results prove the effectiveness of the Hilbert Transform (HT) for power harmonic analysis in DFIG wind turbine connected to a grid.**

***Index terms* – Harmonic Analysis, Hilbert transform, power factor**

## I. INTRODUCTION

Wind energy is becoming a promising source of renewable energy. Technology has made it possible to implement variable speed wind turbines that are more efficient than fixed speed wind turbines. To utilize wind power generation efficiently one of the most reliable system is grid connected doubly fed induction generator. The DFIG brings the advantage of utilizing the turns ratio of the machine, so the converter does not need to be rated for the machine's full rated power. The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid-side converter (GSC) keeps the voltage of the DC-link constant.

A typical configuration is shown in Figure 1. In this structure the wind turbine transformer is delta star-wired with ungrounded star point. Such a transformer blocks zero sequence currents. [1]

DFIG controller design considerations have generally concentrated on providing an adjustable operating speed to maximize turbine power output, maintaining the required generator terminal voltage or power factor, and controlling the generator torque to match that of the wind turbine.

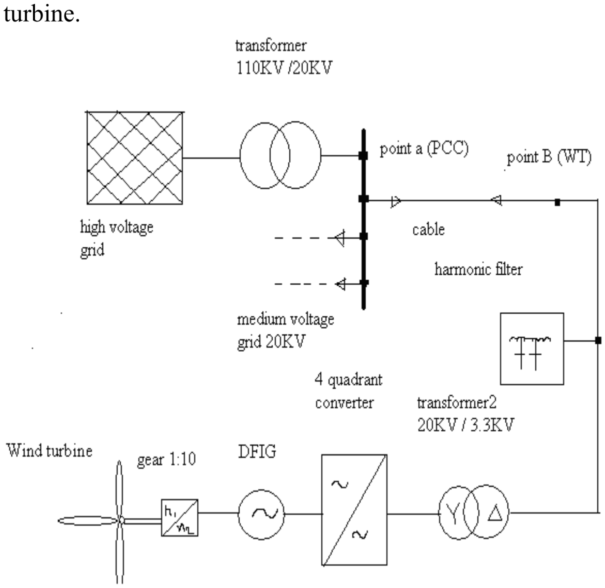



Fig.1. Configuration of a Grid Connected Wind Turbine

The DFIG allows the regulation of reactive power and the adjustment of angular velocity to maximize the output power by given wind speeds. The generator can also stay connected to the grid during voltage sags. Due to the fluctuating nature of the wind, the connection of wind generators to utility grid could lead to many disturbances such as : voltage fluctuations, flickers, harmonics, instability blind power regulations and transients.[2]. Power Quality issues in wind turbines can be classified in to two types, those from the grid that affects the DFIG and those from DFIG that affects the grid. The grid side power quality factors that affect the DFIG are [3]

- Voltage variations
- Frequency variations
- Voltage transients
- Voltage unbalance
- Voltage harmonics
- Black out

The DFIG side power quality issues that affect the grid are

- Reactive power consumption
- Generation of current harmonics
- Injection of fluctuating power

Wind turbines feeding in to the public grids must comply with several technical standards e.g. EN50160 and IEC 61000 [4,5]. In these standards limits are specified for the voltage and current harmonics. To ensure that these limits are not exceeded, the measurement and analysis of the harmonic content of the output voltage becomes essential. The purpose of the paper is the evaluation of harmonics mathematically [1]. In this paper an algorithm for modeling the harmonics is developed for a DFIG wind turbine connected to grid. The algorithm based on Hilbert transform is developed using Labview.

## II. PRINCIPLES OF FAST HILBERT TRANSFORM

Power quality disturbances can be analysed using wavelet transform and Hilbert transform algorithm. The latter is employed as an effective technique for tracking the voltage variations in distribution systems. The mathematical simplicity and accurate tracking of the HT facilitates its implementation for the control of disturbance mitigation devices. Compared to wavelet transformation HT is able to detedt disturbances even in the presence of noise and harmonic disturbances with high frequency components.[6]

Hilbert transform is a linear operator, which takes a function u(t), and produces a function H(u)(t), with the same domain. It is a basic tool in fourier analysis and provides a concrete means for realising the conjugate of a given function or fourier series. Further more in harmonic analysis, it is an example of a singular integral operator and of a fourier multiplier. The Hilbert transform is also important in the field of signal processing where it is used to derive the analytic representation of a signal u(t). The Hilbert transform can be thought of as the convolution of a signal u(t) with the function h(t) = 1/(πt). Because h(t) is not integrable, the integrals defining the convolution do not converge. The Hilbert transform of a function or a signal u(t) is defined as

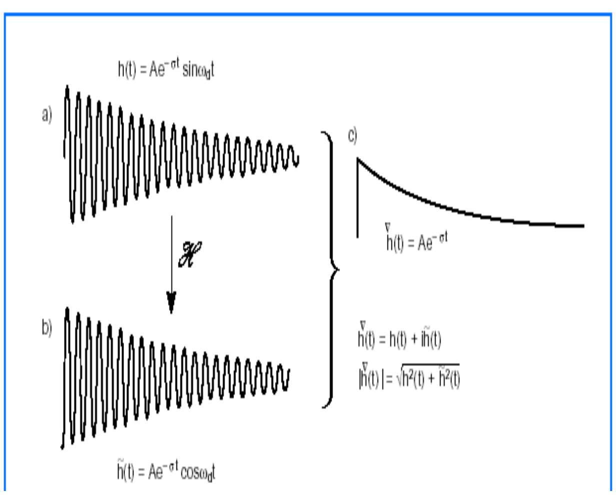
$$H(u)(t)=p.v\int_{-\infty}^{+\infty} u(\tau)h(t-\tau)d\tau = (1/\Pi)\, p.v\int_{-\infty}^{+\infty} u(\tau)/(t-\tau)d\tau \qquad (1)$$

where p.v is the Cauchy principle value,
provided this integral exists as a principle value. Alternatively by changing the variables, the principal value integral can be explicitly written as

$$H(u)(t)= -(1/\Pi)\lim_{\varepsilon\downarrow 0}\int_{\varepsilon}^{\infty} (u(t+\tau)-u(t-\tau)/\tau)d\tau \qquad (2)$$

The Hilbert transform is used to calculate a new time signal h1(t) from the original time signal h(t). The time signal h1(t) is a cosine function whereas h(t) is sine as shown in fig.2.1. The magnitude of the analytical signal $\hat{h}$ (t) can be directly calculated from h and h1. The magnitude of $\hat{h}$ (t) is the envelope of the original time signal and shown in c in fig.2.1. [7]. It has the following advantages over h(t).

1. Removal of oscillations allows detailed study of the envelope.
2. since $\hat{h}$ (t) is a positive function it can be graphically represented using a logarithmic amplitude scale to enable a display range of 1:10,000 (80 db) or more. The original signal h(t) includes both positive and negative values and is traditionally displayed using linear amplitude scale. This limits the display range about 1:100 (40 db)




## III. HAMMING WINDOW

A window function is a mathematical function that is zero valued outside a chosen interval. For instance, a function that is constant inside the interval and zero else where is called a rectangular window which describes the shape of its graphical representation. When another function or a signal (data) is multiplied by a window function, the product is zero valued outside the interval; all that is left is only the overlapped part. ie, the view through the window. Applications of window functions include spectral analysis, filter design and beam forming. In typical applications the window functions used are non negative smooth bell shaped curves though rectangle and triangle functions are sometimes used.[8]

The generalised hamming family of windows is constructed by adding one period of a cosine function to rectangular window. The benefit of adding the cosine function is to lower the side lobes. The cost of achieving this is that the main lobe doubles in width. The Two well known members of the Hamming family are the Hann window and the Hamming Window. The basic idea of thr generalised Hamming family can be seen in the frequency domain picture of fig.3.1.[9,10] The centre dotted waveform is the aliased sinc function. $0.5W_R(\omega) = 0.5M.asinc_M(\omega)$ (scaled rectangular window transform). The other two dotted waveforms are the shifts of the same functions $0.25\ W_R(\omega \pm \Omega_M)$. The sum of all the three functions give the solid line. The inferences from the diagram are that the side lobes are cancelled and the with of main lobe is doubled.

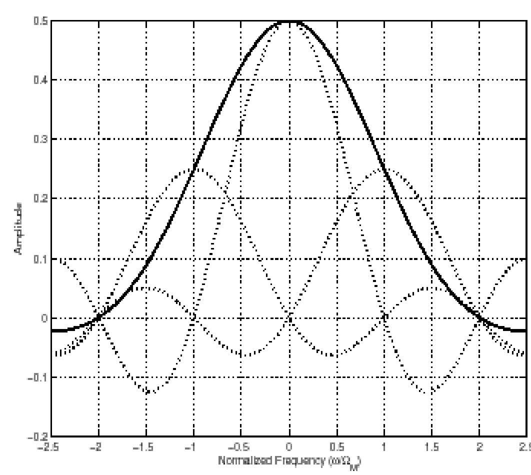



Fig.3.1. Construction of the generalised Hamming window

The equation representing the Hamming window is
$$w_H(n) = wR(n)\,[\alpha + 2\beta\cos(2\Pi n / M)] \qquad (3)$$

the Hamming window is determined by chosing α (with β = 1- α) to cancel the largest side lobe. The side lobe level is reduced by more than 40 dB.

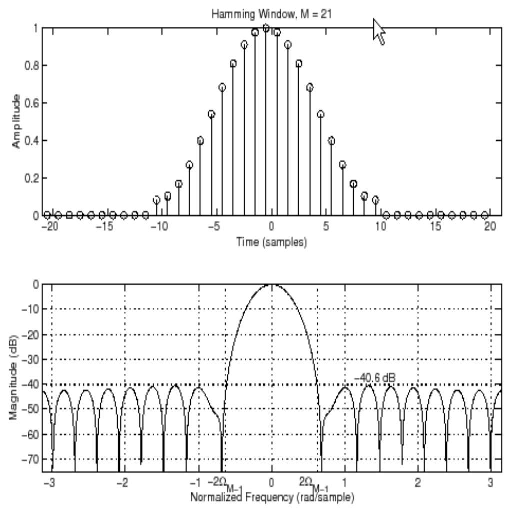



Fig.3.2 Hamming window and its transform

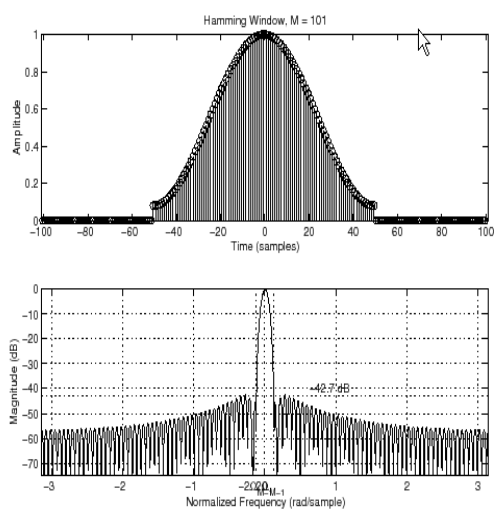



Fig.3.3 Longer Hamming window and its transform

## IV. ANALYSIS OF HARMONICS

Harmonics is measured at the point where the wind turbine feeds in to the grid and similarly harmonics are measured at the wind turbine transformer and its medium voltage cable[1].

Available measured harmonics is given in table 1

| Harmonic | feeding in (%) | Wind turbine transformer (%) |
|---|---|---|
| 50 | 100 | 100 |
| 100 | 1.9 | 2.9 |
| 150 | 1.4 | 2 |
| 200 | 1.5 | 2.5 |
| 250 | 1.4 | 2.1 |
| 300 | 10 | 12 |
| 350 | 1.9 | 3 |
| 400 | 0.8 | 0.9 |
| 450 | 1.2 | 1 |
| 500 | 0.3 | 0.4 |
| 550 | 1.2 | 2.1 |
| 600 | 0.3 | 0.3 |
| 650 | 1.3 | 1.2 |
| 700 | 0.2 | 0.2 |
| 750 | 0.25 | 0.3 |
| 800 | 0.15 | 0.13 |
| 850 | 1.2 | 1.8 |
| 900 | 0.2 | 0.2 |
| 950 | 0.35 | 0.5 |
| 1000 | 0.3 | 0.3 |
| 1050 | 0.12 | 0.1 |
| 1100 | 0.13 | 0.2 |
| 1150 | 1.1 | 1.1 |
| 1200 | 0.25 | 0.3 |
| 1250 | 1.3 | 1.2 |

Table.1.Harmonics measured at the grid feeding point and near the wind turbine transformer.

The generated current signal at the grid feeding point and at the wind turbine is given in figure 2 and 3.

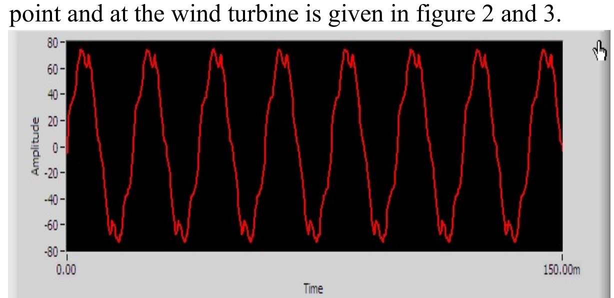



Figure 2. The current signal at the grid feeding point

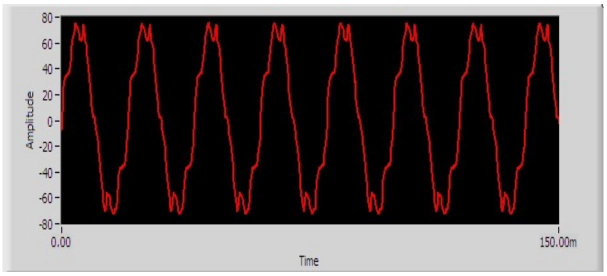



Figure 3. The current Signal at the wind turbine

The total harmonic distortion measured at both the points are 11.172% and 13.8035% respectively.

The fast Hilbert transform is now applied to harmonic values presented in table 1. The analysis done by Fast Hilbert Transform is presented in figure 4 and figure 5.

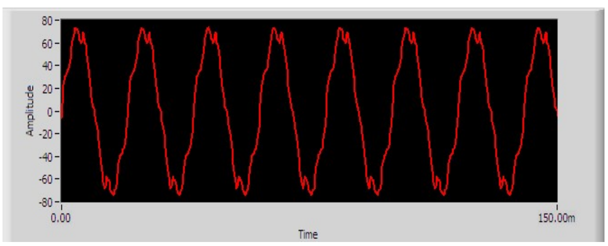



Figure 4. The measured current waveform at grid feeding point after inverse Fast Hilbert Transform.

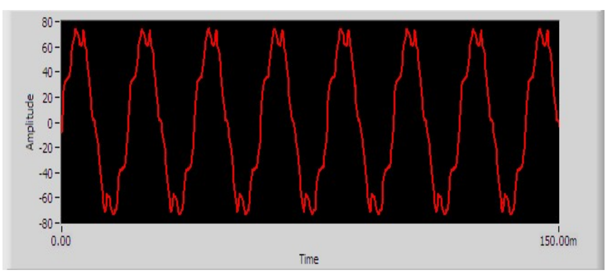



Figure 5. The measured current waveform at Wind turbine transformer after inverse Fast Hilbert Transform.

The total harmonic distortion measured after using fast Hilbert transform algorithm at the grid feeding point and at the wind turbine transformer are 10.3853% and 12.9236% respectively.

The harmonic components measured after Fast Hilbert Transform at the grid feeding point and at the wind turbine transformer respectively is represented in figure 6 and figure 7 respectively.

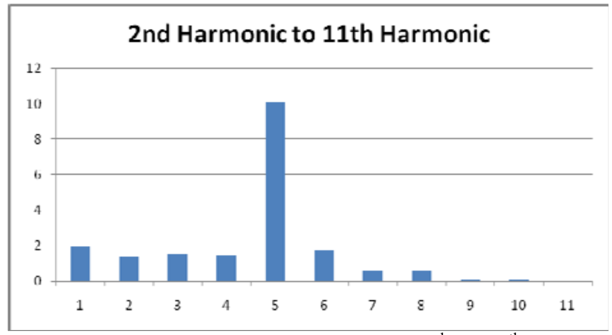



Figure 6. The harmonic components ( $2^{nd}$ to $11^{th}$ ) at the grid feeding point calculated using Inverse Fast Hilbert Transform.

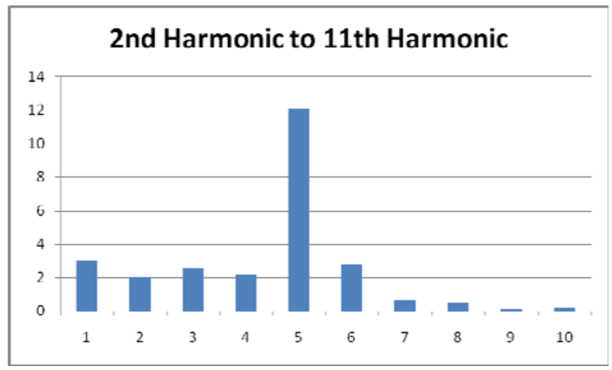



Figure 7. The harmonic components ( $2^{nd}$ to $11^{th}$ ) at the wind turbine transformer calculated using Inverse Fast Hilbert Transform.

## V. CONCLUSIONS

Currents fed into the grid and at the wind turbine transformer have a considerable harmonic content. Accurate estimation of harmonics is crucial to guarantee reliable operation of a power system with wind generation. Fast Hilbert transform is able to estimate accurately and could be used for analysis of harmonics of DFIG wind turbine systems.

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