Harmonic Analysis of Distributed PV System Under High and Low Irradiance

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***Abstract* – This paper presents a unique modelling of harmonics and comparison between high irradiance and low irradiance in PV system connected to a grid. The signals used are actual tested waveforms in a distributed PV system. The percentage error has been calculated for the individual parameters in both cases. The comparative study using Chirp Z transform (CZT) with 7 term B Harris Window will enable to model harmonics using this algorithm in the future. The paper shows the performance of the method proposed in different measurement conditions.**

***Index terms* – Chirp Z transform, Harmonic Analysis, Power factor**

I. INTRODUCTION

Distributed PV systems currently make an insignificant contribution to the power balance on all but a few utility distribution systems. Interest in PV systems is increasing and the installation of large PV systems or group of PV systems that are interactive with the utility grid is accelerating, so the compatibility of higher levels of distributed generation needs to be ensured and the grid infrastructure protected. The variability and non-dispatchability of today's PV systems affect the stability of the utility grid and the economics of the PV and distributed generation systems [1].

Hybrid power systems are combinations of energy conversion devices, that when integrated, overcome limitations that may be inherent in either. Hybrid systems can provide a steady community-level electricity service, such as remote electrification with the possibility of up gradation to the grid. Due to their high levels of efficiency, reliability and long term performance, these systems can also be used as an effective backup solution to the public grid in case of blackouts or weak grids.

But, the power quality problems in Hybrid systems is a major issue over the last few years. Power quality surveys indicate the seriousness of the power quality problems and their economical impact on the consumers and utilities. Although investigation is in progress in the field of power quality, no steps were taken to predict the power quality problems of power systems.

Power quality problems include [2], [3]

- Short interruptions
- Long Interruptions
- Voltage dips and swells
- Harmonics
- Surges and transientsUnbalance, flicker, earthing faults and EMC problems.

Current harmonics are produced by nonlinear behaviour of sensitive loads. The network impedance along with current harmonics produce voltage distortion at the consumer end. Hence, the estimation of harmonic content in the output voltage of a hybrid power system is important to improve the power quality at the consumer end.

The objective of this paper is to analyse the harmonic contents of the output of a distributed PV system using labview. In this paper, the actual tested waveforms in a distributed PV system [4] is modelled using labview for low irradiance and high irradiance conditions. The algorithm used for processing the voltage signals is ChirpZ Transform with 7 term B Harris window.

II. PRINCIPLES OF CHIRPZ TRANSFORM

The major requirement in power quality study is the ability to perform automatic power quality monitoring and data analysis. Feature extraction is a major step in automatic disturbance classification. Spectral analysis using discrete fourier transform and fast fourier transform [5] have been applied for this purpose. The fast fourier transform (FFT) is one of the efficient algorithms for computing the discrete fourier transform and its inverse. In power systems, FFT finds application in analysis of the harmonic content of the output voltage .But the FFT has the following limitations.[6]

i) the output of the FFT ranges from 0 Hz to half the sampling frequency

ii) For 300 to 1600 HZ and sampling frequency 12 KHZ, the information outside the bandwidth is discarded,

iii) The CZT offers better resolution than the FFT over the frequency range of interest.

iv) The FFT is fast and while the CZT may offer better resolution and flexibility but it pays the price when it comes to speed.

v) However, if the number of samples acquired by the CZT is a power of two, the performance loss is minimal.

A computational algorithm[7] for numerically evaluating the Z transform of a sequence of N samples has been defined as the Chirp Z – transform (CZT) algorithm. Using the CZT algorithm one can efficiently evaluate the Z transform at M points in the Z pane which lie on circular or spiral contours beginning at any arbitrary point in the Z plane. The angular spacing of the points is an arbitrary constant and M and N are arbitrary integers. The algorithm is based on the fact that the values of the Z transform on a circular or spiral contour can be expressed as a discrete convolution. Thus well known high speed convolution techniques can be used to evaluate the transform efficiently.

The Chirp Z transform X_k of a signal x_n with n samples is given by

$$X_k = \sum_{n=0}^{N-1} x_n A^{-n} W^{(n2/2)} W^{(k2/2)} W^{-(k-n)2/2} \quad (1)$$

where k = 0,1,…..,M-1.

The three step process involved in the computation of chirp Z transform are:

1. form a sequence Y_n by weighting the x_n according to the equation
   $$y_n = x_n A^{-n} W^{(n2/2)} \quad n= 0,1 ,\text{-----}N-1 \quad (2)$$
2. convolving Yn with the sequence v_n defined as
   $$v_n = W^{(-n2/2)} \quad (3)$$
   to give a sequence g_k
   $$g_k = \sum_{n=0}^{N-1} y_n v_{k-n} \quad k = 0,1, \text{------} M-1. \quad (4)$$
3. Multiplying g_k by $W^{(k2/2)}$ to give X_k
   $$X_k = g_k W^{(k2/2)} \quad k = 0,1, \text{------} M-1. \quad (5)$$

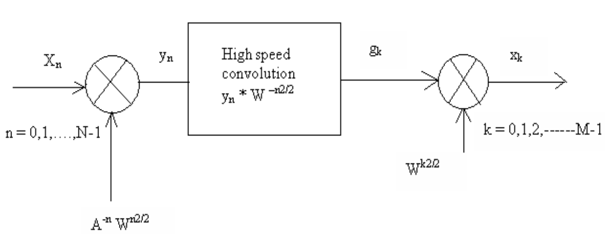

Fig.1. Illustration of the steps involved in the computation of Z transform using CZT algorithm

The freedoms offered by the CZT includes the following.

1. The number of time samples does not have to equal the number of samples of the z transform.
2. Neither M nor N need be a composite integer.
3. The angular spacing of z_k is arbitrary.
4. The contour need not be a circle but can be spiral in or out with respect to the origin.In addition the point z_o is arbitrary.

The limitations in using the CZT algorithm to compute the Z transform is due to the fact that we may require to compute the values of $W^{(n2/2)}$ for large values of n. The limitations in the contour distance is also due to the limitation in computation of $W^{(n2/2)}$.

The applications of the CZT algorithm include enhancement of poles for use in spectral analysis; high resolution narrow band frequency signals; and time interpolation of data from one sampling rate to any other sampling rate.

III. 7 TERM B HARRIS 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 Blackman Harris window family is a straight forward generalisation of the Hamming family. The generalised Hamming family was generated from a summation of three shifted aliased sinc functions. The Blackman Harris window family is generated by adding still more shifted sinc functions. The three term Blackman Harris window uses both degrees of freedom to reduce the side lobe levels. The equation for a three term Blackman Harris window is three term Blackman Harris window is

$$W(n) = a_o - a_1 \cos(2 \Pi n / N) + a_2 \cos (4 \Pi n / N) \quad (6)$$

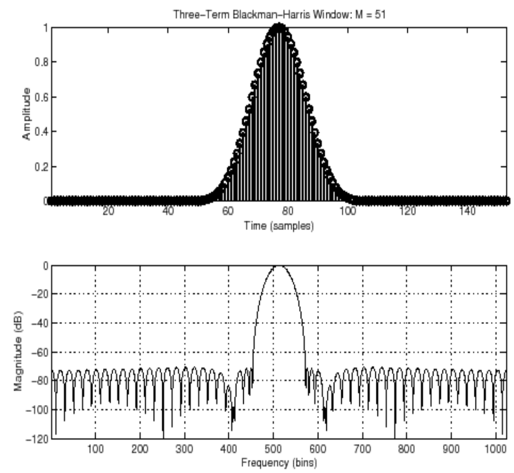

Fig.3.1. Three term Blackman Harris window and its transform

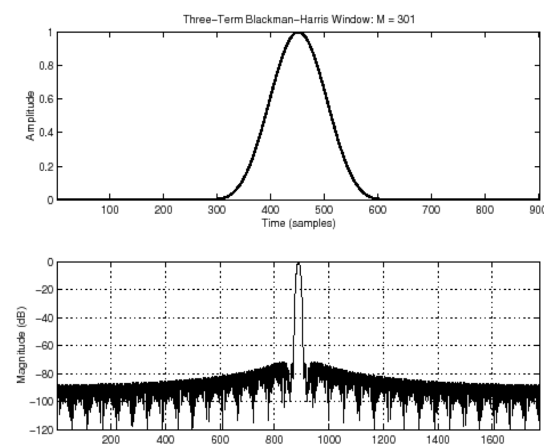

Fig.3.2. Longer three term Blackman Harris window and its transform

Fig 3.1 and 3.2 illustrates the three term and longer three term Blackman Harris and its transform [9]

The equations for a four term Blackman Harris [10] window is

$$W(n) = a_o - a_1 \cos(2 \Pi n / N) + a_2 \cos (4 \Pi n / N) - a_3 \cos (6 \Pi n / N) \quad (7)$$

The equation for a 7 term Blackman harris window is given by

$W(n) = a_o - a_1 \cos(2 \Pi n / N) + a_2 \cos(4 \Pi n / N) - a_3 \cos(6 \Pi n / N) + a_4 \cos(8 \Pi n / N) - a_5 \cos(10 \Pi n / N) + a_6 \cos(12 \Pi n / N)$.

In 7 term Blackman harris window, the side lobe levels are reduced when compared to 3 term and 4 term Blackman harris window. (8)

IV. ANALYSIS OF HARMONICS

A power quality analyser [4] was placed at the output of the 15 KW three phase photovoltaic system to measure the appropriate power quality parameters. The quantities measured include individual current harmonics, the Total Harmonic Distortion (THD) and rms values of voltage and current for a time period.

The amplitude of harmonics for low irradiance and high irradiance is given below.

Harmonic	Low irradiance(%)	High irradiance(%)
50	100	100
100	7.6	2.3
150	11.6	1.65
200	11.6	2.8
250	12.8	2.2
300	10	2.3
350	7.8	2.3
400	5.8	1.45
450	4.4	1.4
500	3.8	1
550	2.6	1.35
600	2.6	0.6
650	7.6	1.9
700	1.8	0.15
750	2.4	0.4
800	1	0
850	3.4	0.6

Table 1 Harmonic Voltage captured as % during low irradiance and High irradiance.

We developed a program in LabVIEW to model the voltage signal and subsequently apply the ChirpZ transform with 7 term B Harris window for the given input . The voltage signal generated by our program for low irradiance is shown in figure 2.

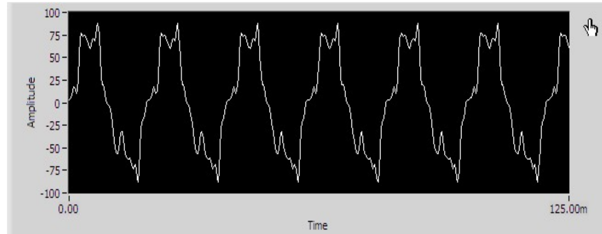

Figure 2. Signal with harmonics modelled during low irradiance.

Figure 3 represents the signal during High irradiance. From figure 2 and figure 3 it is clear that quantity of irradiance plays a crucial role in the signal quality.

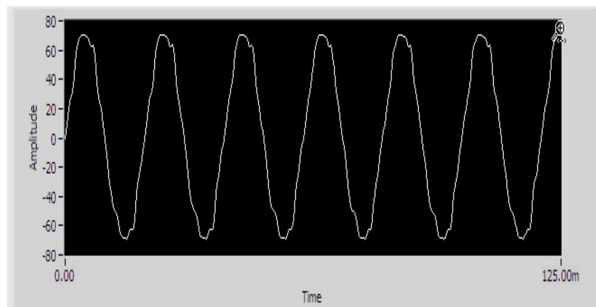

Figure 3. Signal with harmonics modelled during high irradiance.

Our LabVIEW program was applied to the modelled signal with ChirpZ transform and the modelled signal is shown in figure 4 and figure 5.

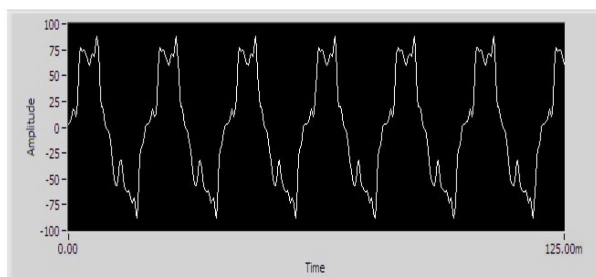

Figure 4. Modelled signal for low irradiance after ChirpZ transform was applied to the data in column 2 of table1.

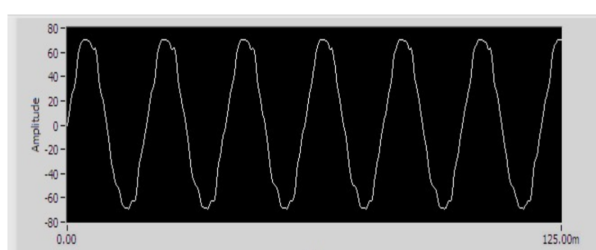

Figure 5. Modelled signal for high irradiance after ChirpZ transform was applied to the data in column 3 of table 1.

The resultant harmonics measured after application of ChirpZ transform along with absolute error is shown in Table 2.

Frequency in Hz.	% Voltage Low irradiance (ChirpZ)	% Voltage High Irradiance (ChirpZ)
50	96.03352	96.03367
100	6.82101	2.06412
150	11.14012	1.58492
200	11.6006	2.80018
250	12.29209	2.11273
300	8.97527	2.06431
350	7.49033	2.20869
400	5.80021	1.45006
450	4.22538	1.34444
500	3.4106	0.89753
550	2.49679	1.29644
600	2.60022	0.60008
650	7.29852	1.82464
700	1.61554	0.13463
750	2.30479	0.38414
800	1.00014	0.00011
850	3.26516	0.5762

Table 2. % Voltage calculated through Inverse ChirpZ transform for low and high irradiance.

V. CONCLUSION

This paper proposes the use of ChirpZ transform with 7 term B Harris Window for the analysis of harmonics in a photo voltaic system connected to the grid. The results obtained are promising and has the potential as an alternative processing method for harmonic analysis in photo voltaic system.

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