Wavelet based Harmonic Analysis of Wind Connected System for Power Quality Improvement using STATCOM

J. Pardha Saradhi
Department of EEE
Bapatla Engineering College
Bapatla, India

R. Srinivasarao
Department of EEE
JNT University
Kakinada, India

V. Ganesh
Department of EEE
JNTUA College of Engineering
Pulivendula, India

***Abstract*— A wind farm under non linear load conditions, when connected to a power system creates the power quality problems of which the voltage variations and the harmonics are severe. Here in this research paper, a power system connected with a wind form is taken for the study of reactive power compensation and harmonic reduction capability of a static compensator (STATCOM) in the presence of non-linear load. The performance of the controller is studied under the presence of a non-linear load. At the point of common coupling the variation in voltage, power factor are measured with a switch connected to study the system both in the presence and absence of the compensating device. The harmonic components in the currents are studied using Wavelet transformation. Bi-orthogonal 4.4 wavelet at level 4 is used to decompose the disturbances in power quality signals. The entire system is simulated using MATLAB/SIMULINK software. The harmonic analysis also performed for the given and compares the performance of the proposed method with THD with the results obtained using wavelet harmonic analysis.**

***Keywords*— Wind farm, Harmonics, Compensator, STATCOM, Wavelet transformation**

I. INTRODUCTION

In an effort to meet the ever increasing demand for the electrical power the present day engineers and environmentalists are pointing towards the non-conventional energy sources such as the energy present in solar radiation, energy possessed by the wind currents, geo-thermal energy etc., in order to ensure the sufficient conventional source for the future generations. Hence the use of these non-conventional energy sources is growing rapidly all across the world. This also will slowly show a positive impact on the climate condition.

Along with the positive impacts the injection of these DGs [1] also creates some problems like voltage variations, harmonic injection etc. These negative results impact the functioning of the consumer's equipment and sometimes the power system may collapse. Hence in order to provide the end consumer a quality power, FACTS concept has been introduced. The FACTS devices help in enhancing the power handling and transfer capabilities of a power system. Also the FACTS devices offer many other features in power quality issues like power factor correction, voltage variation mitigation and power system stability enhancement. The revolution in using the FACTS parallel compensators led to the utilization of the static synchronous compensators (ST ATCOM).

Faster response, ability to compensate flickers, it's flexibility in compensation and minimum interaction between STATCOM and the power supply are the advantages of the STATCOM compared to other conventional FACTS devices.

Here in this paper the STATIC COMPENSATOR (STATCOM) is used to mitigate the problems that are raised due to the presence of the wind farm in a healthy power system with a non-linear load.

Wavelet based power quality analysis has been shown in [4], wavelet based fault identification in the presence of FACTS devices has been shown in [5].

II. WIND FARM DESIGN

The wind generation is based on constant speed topologies along with pitch control of the turbine blades. In the current scheme an induction generator is used because of its wide advantages like simplicity, no need of a separate field circuit, applicability for both constant and variable loads, and its natural protection capability against short circuit.

III. BANG-BANG CONTROLLER FOR STATCOM

A bang-bang controller is used to make the source current sinusoidal by injecting required current components into the grid. Hysteresis type of current control technique is employed here in this for a better control over the source current. The switching pulses required by the STATCOM are generated by this bang-bang controller which is realized using a hysteresis current controller. The STATCOM here is operated for controlling current and so the current control block in Bang-bang controller receives input current as reference and actual current.

The R.M.S voltage of the source is given in the equation below

$$V_{sm} = \left\{ \frac{2}{3} \left(V_{sa}^2 + V_{sb}^2 + V_{sc\}}^2 \right) \right\}^{\frac{1}{2}} \quad (1)$$

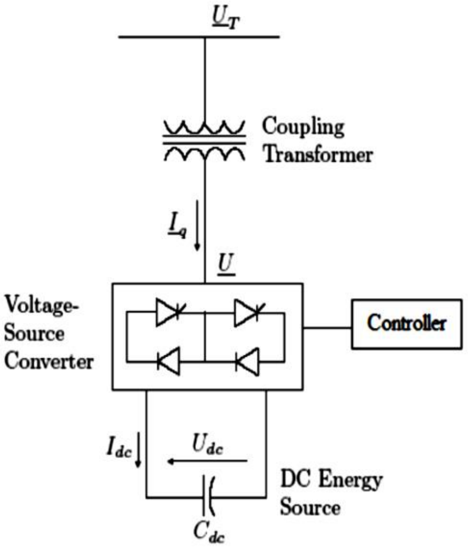

Fig.1: Basic STATCOM controller

And the in-phase vectors are

$$U_{sa} = \frac{V_{sa}}{V_{sm}}, U_{sb} = \frac{V_{sb}}{V_{sm}}, U_{sc} = \frac{V_{sc}}{V_{sm}} \quad (2)$$

The in-phase reference currents generated are given by,

$$i_{sa}^{*} = I.U_{sa}, i_{sb}^{*} = I.U_{sb}, i_{sc}^{*} = I.U_{sc} \quad (3)$$

Here I is proportional to the magnitude of filtered source voltage for respective phase. The source current is controlled to be sinusoidal.

The bang-bang controller shown below is also called as hysteresis controller. Bang-bang current controller is implemented in the current control scheme. The so called hysteresis controller produces the ON and OFF switching signals required for switching of IGBTs of the controller (STATCOM).

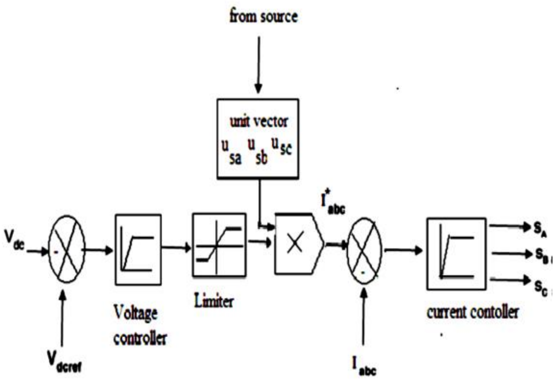

Fig.2: Controller for STATCOM

IV. WAVELET HARMONIC ANALYSIS

Wavelet tool is used in the present paper for the harmonic analysis of the output currents both in the presence and absence of the STATCOM. Basically wavelet analysis expands the given functions or waveforms into small signals, which are generated in the form of translations and dilations of a fixed function called the mother wavelet. A mother wavelet is a function that oscillates, has finite energy and zero mean value. Using wavelet transformations one can obtain both time and frequency information of the given signal, but Fourier transformation can only give the frequency information.

In the current paper Bi-Orthogonal 4.4 wavelet transformation is used at level 4 for decomposing the output source currents into approximate and detailed coefficients. As the approximate coefficient is close to the actual waveforms they are used to study the operation of the controller is studied.

Wavelet analysis gives DWT coefficients which start from separating the original signal s of length N to 2 set of coefficients: approximate coefficients CA1 by low pass filter and detail coefficients CD1 by high pass filter. The length of each filter is equal to half of original's length by down sampling function. The next step splits the approximate coefficients CA1 in two parts again by the same process but replace s by CA1 and producing CA2 and CD2 and so on.

The detail and approximate coefficients at scale j are written as CDj and CAj, which are used to detect the order of harmonics in distribution system. The sampling frequency selected is 1.6 kHz. In this paper, the fundamental frequency is 50 hertz and 4 level decomposition is made. [6]The sub band of output signal as follows.

CD1: 0.4 kHz ~ 0.8 kHz
CD2: 0.2 kHz~ 0.4 kHz
CD3: 0.1 kHz ~ 0.2 kHz
CD4: 0.05 kHz~ 0.1 kHz
CA4: 0 kHz ~ 0.05 kHz

The harmonic distortions included in the each frequency ranges can be detected by using approximation and detail coefficients which measure from sub-band harmonics in term of RMS values .Total Harmonics can be calculated by using

$$\mathrm{THD} = \frac{\sqrt{\frac{1}{N_j}\sum_n [CD_j(n)]^2}}{\sqrt{\frac{1}{N_4}\sum_n [CA_4(n)]^2}} \quad (4)$$

Where Nj is the number of detail coefficients at scale –j.

V. TEST SYSTEM

A simple system with a source of AC currents is taken and the wind farm is developed by using an induction generator for which a constant is given as the input which is equivalent to the speed of wind. A non-linear load is considered to be at the load of the system. The harmonics are made to be introduced into the system by connecting a power electronic converter to the load. A STATCOM is connected at the point of common coupling of the source, wind farm and the load. This system is the designed with Bang-bang controller [6]based STATCOM .The Harmonic analysis is made at Source side by using THD method and wavelet based harmonic analysis. The power

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quality effecting and dependant variables like the currents, voltages and phase angles at different points in the system are measured.

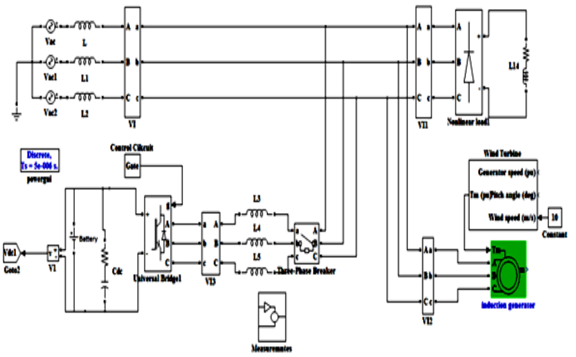

Fig.3: Matlab Simulink model of test system

To judge the performance of the STATCOM [7]in the system the system is first run without any controller. And later the controller i.e. STATCOM is connected and the control capability is analyzed in the presence of a load.

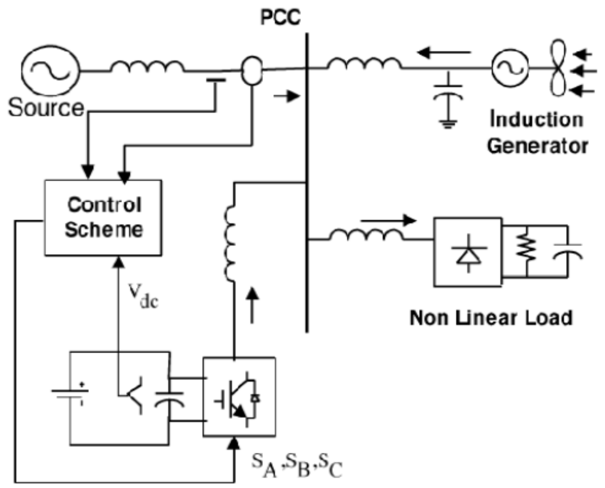

Fig.4: One Line Diagram of the Test System

VI. SIMULATION RESULTS

The test system is developed in the environment of MATLAB/SIMULINK. First the system is simulated with a non-linear load without the controller and the simulated results are as shown below.

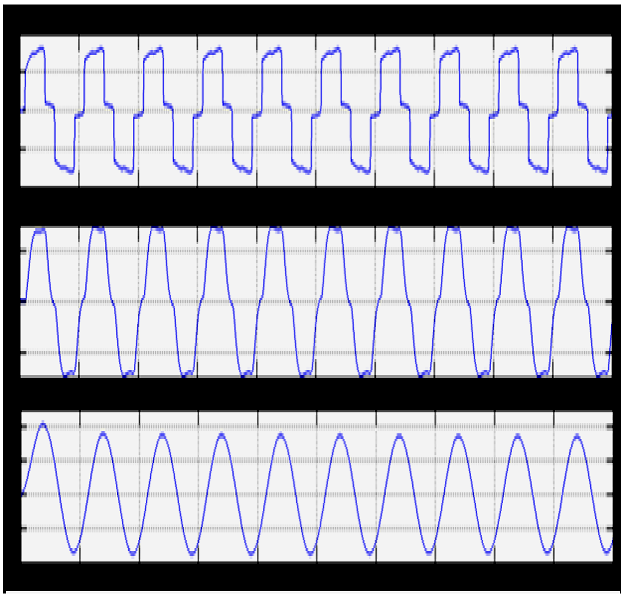

Fig.5: Source, load currents and phase voltage of controller

And from the above Fig.5 it is observed that the presence of the non-linear load made the source current non-sinusoidal even though the voltages are sinusoidal. The total harmonic distortion is observed from wavelet transform is to be 19.2%. From Fig.6 the same system is applied a multi resolution analysis is made using Bi-orthogonal 4.4wavelet and its value is observed that 22.7%.

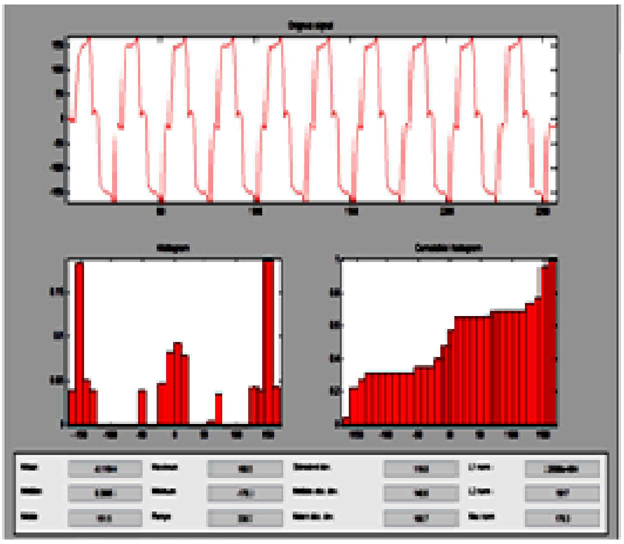

Fig.6: Wavelet analysis of approximated source current at Bi-Orthogonal 4.4 at level 4

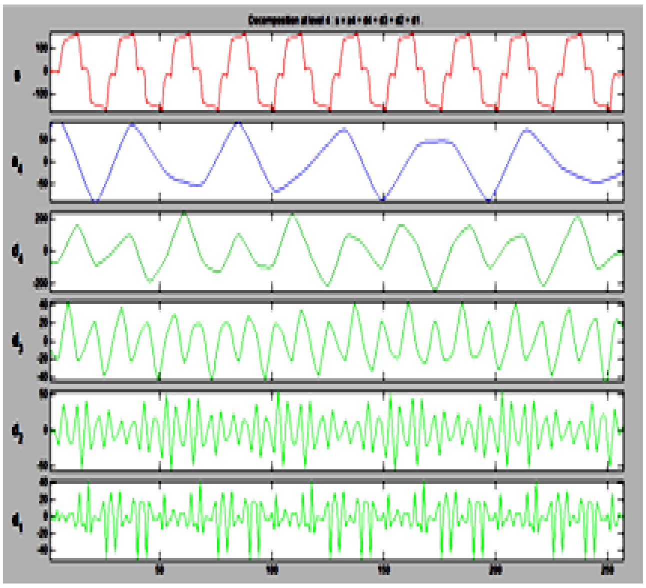

Fig.7: wave form decomposition of approximated source current

Fig.7 gives the approximate and detailed coefficients by using bi-orthogonal wavelet at level-4.

Further the bang-bang controller based STATCOM is designed for harmonic reduction in the source current. The can also do the THD reduction, power Quality improvement such as keeping the voltages, currents, power factor etc., in their limits. The simulated results of the test system with the STATCOM by using Bang controller are as shown in the figure below

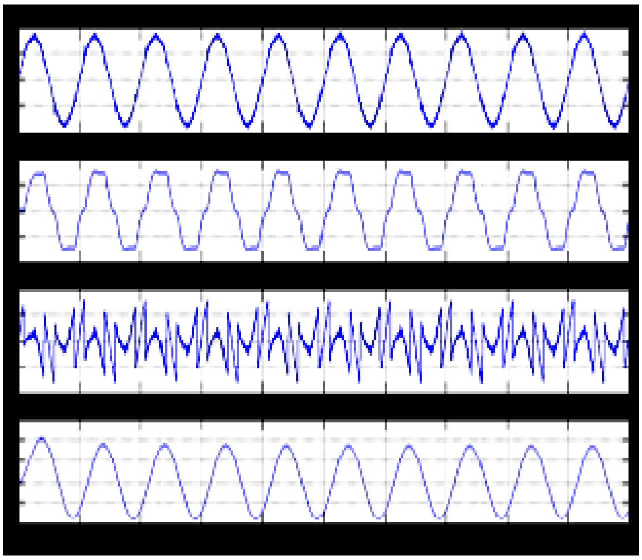

Fig.8: Source, load and STATCOM currents and phase voltage of compensator

The waveforms in the above figure are the source current, load current, the compensator current and the phase voltage of the controller.

The presence of the STATCOM made the non-sinusoidal source current in the absence of controller into the sinusoidal wave thus we can say the harmonic reduction is done and the quality of power being supplied is also been improved. The STATCOM which is provides with a DC battery system injects the required current components into the line. The FFT analysis gave the THD in the source current as 3%. This says the controller is very effective in the reduction of harmonics.

The wavelet analysis of the source current in the Bi-Orthogonal 4.4 wavelet transform in level four is given below. The Harmonics are obtained by using Bi-Orthogonal 4.4 wavelet transform it its value is 3.6%.

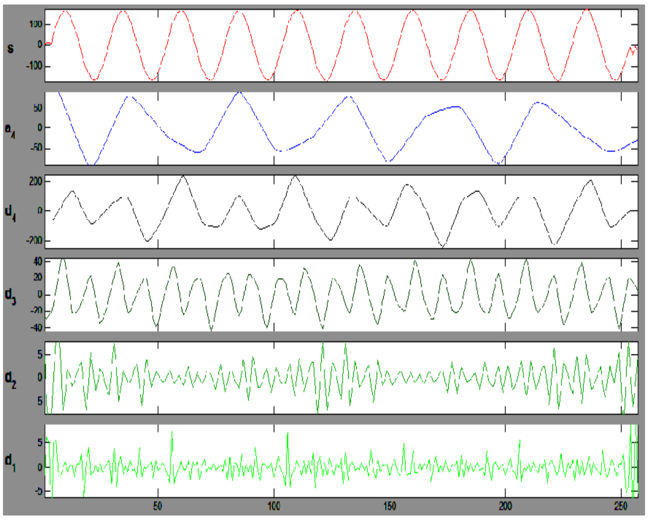

Fig.9: waveform decomposition of approximated source current

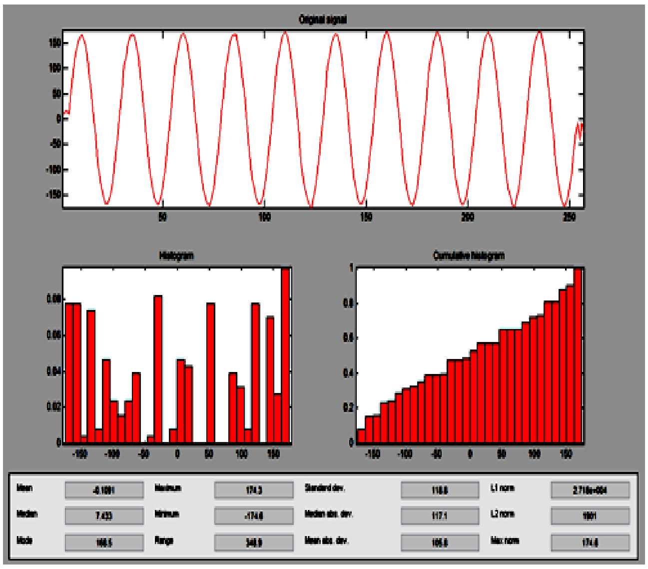

Fig.10: Wavelet analysis of approximated source current with Bi-Orthogonal 4.4 at level 4

The harmonics are obtained by using FFT analysis with and without controller. Similarly harmonic analysis also made with wavelet transform

Table.1: Harmonics obtained in the source side

Sl.No	Type of Current signal at Source side	By FFT technique	By Discrete Wavelet Transform (DWT)
1	Without any compensating device	19.2%	22.7%
2	With Bang bang controller based STATCOM	3%	3.6%

VII.CONCLUSION

This research paper is discussed in the presence of a non-linear load is modeled and simulated in the MATLAB/SIMULINK environment. The performance of the system with and without a controller (STATCOM) is studied and it is observed that the total harmonic distortion of the source current has been reduced to a greater extent. The wavelet tool box is used to decompose the source currents into the detailed and approximated coefficients and analyzed with Bi-Orthogonal 4.4 level 4 transformations. The results obtained from discrete wavelet harmonic analysis in the system network system are compared with THD obtained from FFT analysis.

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