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Original Research Article

DFHCI Based Wavelet Lifting Scheme for Islanding Detection

M. Shalini[1], T. Manjunath[2]

[1]PG Student/EEE, [2]Assistant Professor/EEE,
PSV College of Engineering & Technology, Tamil Nadu, India.

Corresponding Author: M. Shalini

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ABSTRACT

This paper proposes a novel method of wavelet lifting based three-phase grid impedance detection method based on dual-frequency harmonic current injection for islanding detection. Using wavelet transforms always results in time localization and hence the instant of islanding also can be detected with our proposed method. When the load mismatch occurs, it clearly reveals that there exists an impedance mismatch in power distribution systems. This is a serious problem in power delivery. Hence in this method based on dual-frequency harmonic current injection (DFHCI) is injecting two non-characteristic symmetric harmonic currents, and then according to the different harmonic voltages caused by different frequency harmonic currents, all three-phase impedances can be calculated accurately. The implementing algorithm of the presented method is derived and its performance is analyzed in detail. Simulation and experiments are carried out under grid impedance balanced and unbalanced conditions. Theoretical analysis and experiment results proved that the proposed method is practically feasible by MATLAB.

Index Terms: *Wavelet lifting, Harmonic current injection, Impedance unbalance, dual frequency.*

1. INTRODUCTION:

As the composition of power systems changes with the increased use of distributed generation (DG), the ability to maintain a secure supply with high power quality is becoming more challenging. The increased use of power electronic converters as part of loading systems could cause further power quality problems: [1-3] converters act as strong harmonic current (or voltage) sources. The information on power system parameters (particularly the net power system impedance to source) at any instant in time is central to addressing these problems.

For example, power system impedance monitoring is an important enhancement to active filter control. The impedance estimation can be embedded into the normal operation of grid connected power electronic equipment (PEE) such as sinusoidal rectifiers and active shunt filters (ASF). PWM harmonics associated with PEE, as measured in the active filter line current or voltage at the point of common connection (PCC) can provide non-invasive estimation of power system impedance changes, although it is not accurate enough to provide a suitable value for control. A small disturbance introduced by a short modification to the PEE's PWM strategy can be used to excite the power system impedance and the associated voltage and current transients can be used to determine more exactly the supply impedance back to source, Zs. This invasive method is only triggered when the non-invasive method determines a significant change in Zs.

The previous estimation strategy required that the PEE line current and PCC line voltage be measured for 160 ms before the transient injection, and 160 ms post-transient in order to get a suitable frequency resolution for the impedance measurement (6.25 Hz). The analysis proposed in this paper would substantially reduce the period for data capturing to 5 ms post transient, and reduce pre-transient data requirement. This is because the Continuous Wavelet Transform (CWT) is used to process voltage and current transients for calculating the supply impedance. [4-7] The proposed method therefore has the potential to determine the change in the supply impedance within half a supply cycle.

This paper introduces the concept of real-time impedance estimation, and then describes how CWT is used to significantly speed up impedance estimation, demonstrating this capability with experimental results. The paper then goes on to describe how this estimation technique may be used to locate faults inside and outside a defined power "zone." Fault identification and location is an important application of real-time impedance estimation, and may find use in renewable/distributed energy systems, and power grids for more-electric aircraft and more-electricships.

II.ISLANDING PHENOMENON:

Islanding refers to the condition in which a distributed generator (DG) continues to power a location even though electrical grid power from the electric utility is no longer present. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices. For that reason, distributed generators must detect islanding and immediately stop producing power; this is referred to as anti-islanding.

III.WAVELET TRANSFORM:

The wavelet transform is similar to the Fourier transform (or much more to the windowed Fourier transform) with a completely different merit function. The main difference is this: [8-9] Fourier transform decomposes the signal into sines and cosines, i.e. the functions localized in Fourier space; in contrary the wavelet transform uses functions that are localized in both the real and Fourier space. Generally, the wavelet transform can be expressed by the following equation:

$$F(a,b) = \int_{-\infty}^{\infty} f(x)\, \psi^{*}_{(a,b)}(x)\, \mathrm{d}x \quad (1)$$

where the * is the complex conjugate symbol and function ψ is some function. This function can be chosen arbitrarily provided that obeys certain rules.

As it is seen, the Wavelet transform is in fact an infinite set of various transforms, depending on the merit function used for its computation. This is the main reason, why we can hear the term "wavelettransform" in very different situations and applications. There are also many ways how to sort the types of the wavelet transforms. Here we show only the division based on the wavelet orthogonally. We can use orthogonal wavelets for discrete wavelet transform development and non-orthogonal wavelets for continuous wavelet transform development. These two transforms have the following properties:

1. The discrete wavelet transform returns a data vector of the same length as
2. The input is. Usually, even in this vector many data are almost zero. This corresponds to the fact that it decomposes into a set of wavelets (functions)
3. That are orthogonal to its translations and scaling. Therefore we decompose such a signal to a same or lower number of the wavelet coefficient spectrum as is the number of signal data points. Such a wavelet spectrum is very good for signal processing and compression, for example, as we get no redundant information here.
4. The continuous wavelet transform in contrary returns an array one dimension larger than the input data. For a 1D data we obtain an image of the time-frequency plane. We can easily see the signal frequencies evolution during the duration of the signal and compare the spectrum with other signals spectra. As here is used the non-orthogonal set of wavelets, data are correlated highly, so big redundancy is seen here. This helps to see the results in a more humane form.

Discrete Wavelet Transform:

The discrete wavelet transform (DWT) is an implementation of the wavelet transform using a discrete set of the wavelet scales and translations obeying some defined rules. In other words, [10-11] this transform decomposes the signal into mutually orthogonal set of wavelets, which is the main difference from the continuous wavelet transform (CWT), or its implementation for the discrete time series sometimes called discrete-time continuous wavelet transform (DT-CWT).

The wavelet can be constructed from a scaling function which describes its scaling properties. The restriction that the scaling functions must be orthogonal to its discrete translations implies some mathematical conditions on them which are mentioned everywhere. Moreover, the area between the function must be normalized and scaling function must be orthogonal to its integer translations.

After introducing some more conditions (as the restrictions above does not produce unique solution) we can obtain results of all these equations, i.e. the finite set of coefficients a_k that define the scaling function and also the wavelet. The wavelet is obtained from the scaling function as N where N is an even integer. The set of wavelets then forms an orthonormal basis which we use to decompose the signal. Note that usually only few of the coefficients a_k are nonzero, which simplifies the calculations.

Continuous Wavelet Transform:

Continuous wavelet transform (CWT) is an implementation of the wavelet transform using arbitrary scales and almost arbitrary wavelets. The wavelets used are not orthogonal and the data obtained by this transform are highly correlated. For the discrete time series we can use this transform as well, with the limitation that the smallest wavelet translations must be equal to the data sampling. This is sometimes called Discrete Time Continuous Wavelet Transform (DT-CWT) and it is the most used way of computing CWT in real applications.

In principle the continuous wavelet transform works by using directly the definition of the wavelet transform, i.e. we are computing a convolution of the signal with the scaled wavelet. For each scale we obtain by this way an array of the same length N as the signal has. By using M arbitrarily chosen scales we obtain a field $N \times M$ that represents the time-frequency plane directly. The algorithm used for this computation can be based on a direct convolution or on a convolution by means of multiplication in Fourier space (this is sometimes called Fast Wavelet Transform). [12]

The choice of the wavelet that is used for time-frequency decomposition is the most important thing. By this choice we can influence the time and frequency resolution of the result. We cannot change the main features of WT by this way (low frequencies have good frequency and bad time resolution; high frequencies have good time and bad frequency resolution), but we can somehow increase the total frequency of total time resolution. This is directly proportional to the width of the used wavelet in real and Fourier space. If we use the Morlet wavelet for example (real part – damped cosine function) we can expect high frequency resolution as such a wavelet is very well localized in frequencies. In contrary, using Derivative of Gaussian (DOG) wavelet will result in good time localization, but poor one in frequencies.

The power system impedance to source is measured by injecting a disturbance onto the system at PCC and analyzing the transient response using measured voltages and currents. The disturbance in this case is manufactured by manipulating two successive PWM cycles in the operation of PEE such that they appear to inject a very short disturbance. For this work, PEE is an active shunt filter as illustrated in Fig.1. The presence of the ASF filter inductance (in Fig.1) results in a short current spike, of approximately 1 ms long and 20 A peak, injected into PCC as shown.

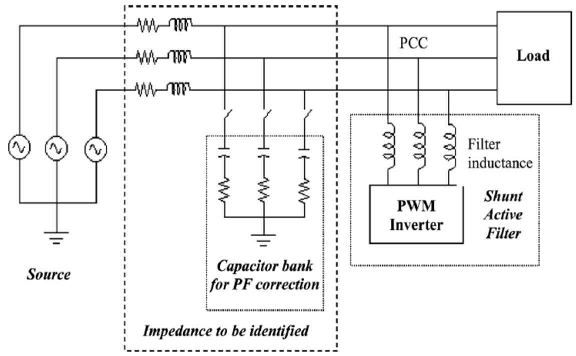

Fig.1: Existing system

Previous methods for analyzing data have included the use of a simple Digital Fourier Transform (DFT) on the measured data and the use of Welch's Averaged Period gram Algorithm. In both techniques, 8 cycles of pre-transient measurement data are subtracted from 8 cycles of transient data to compensate for the system fundamental and other harmonics frequencies normally present in the system voltage. The impedance estimates at harmonic frequencies are discarded and an interpolation routine is used to determine the impedance to source at such frequencies describe how the estimated impedance at 5th, 7th, and 11th harmonic frequencies are used to generate reference signals for ASF. The excellent control of the filter demonstrates how an active shunt filter can operate in standalone or sensorless mode (where sensorless means that ASF does not require an explicit measurement of supply or load currents).

In order to calculate power system quantities, one needs to analyze amplitudes and phase differences between the related voltages and currents. Complex wavelet bases are capable of delivering instantaneous amplitudes of voltages and currents as well as instantaneous phase angles. Using this information, alternative system impedance definitions can be found with time and frequency localization properties. In a single-phase system, the complex wavelets transform will yield two series of complex wavelet coefficients for voltage and current. Using these coefficients, instantaneous values of amplitude and phase are derived for different sub-bands.

$$v_w\ (\tau, s) = v_w\ (\tau, s)\angle\varphi_{vw}\ (\tau, s) \qquad (2)$$

$$i_w\ (\tau, s) = i_w\ (\tau, s)\angle\ \varphi_{iw}\ (\tau, s) \qquad (3)$$

Using the instantaneous voltage and current amplitude and the instantaneous phase difference between voltage and current, complex wavelet based system impedance is identified as

$$Z_w(\tau, s) = \frac{v_w\ (\tau,s)}{i_w\ (\tau,s)} \qquad (4)$$

In this case, the system impedance is defined in the wavelet domain. For calculation, a series of impedances are considered at different scales and time, and an average value is estimated over the first half cycle (0.01 second) of the system impedance in the frequency ranges of interest. This can be done by mapping each level of scale to the pseudo-frequency f_s as:

$$f_s = \frac{f_c}{S.\Delta t} \qquad (5)$$

Where f_c is the center frequency of the wavelet in Hz, is thescale level, and delta t is the sampling period.The averaging of the estimated impedance will smooth the signal without using any particular threshold. Alternatively, taking the local maxima of CWT coefficients at each scale would provide similar results.

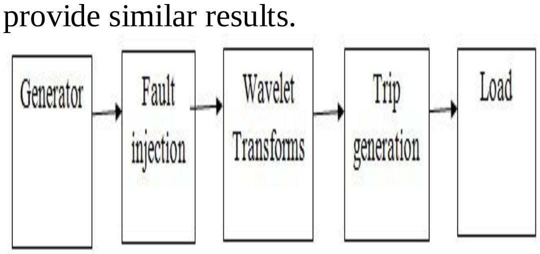

Fig.2: Block diagram of proposed system

The block diagram above indicates that a fault is injected in between the grid and the load so the wavelet transform detects the fault and generates a trip which in turn avoids the high inrush currents to the load, this condition will refer to damage of electrical equipment. Hence this condition is detected through wavelets.

The proposed system is depicted in the above Fig 3 were the parameters like voltage and current are measured at some particular point and hence these measured parameters are used to calculate the impedance which in turn is evaluated by means of wavelet lifting technique.

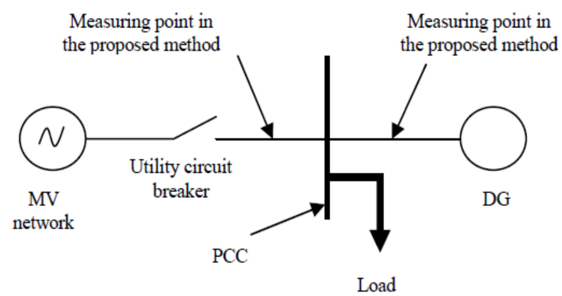

Fig.3: Proposed system

WAVELET LIFTING SCHEMES:

The lifting scheme is a technique for both designing wavelets and performing the discrete wavelet transform. Actually it is worthwhile to merge these steps and design the wavelet filters while performing the wavelet transform. This is then called the second generation wavelet transform. The technique was introduced by WimSweldens.

The discrete wavelet transform applies several filters separately to the same signal. In contrast to that, for the lifting scheme the signal is divided like a zipper. Then a series of convolution-accumulate operations across the divided signals is applied. The basic idea of lifting is the following: If a pair of filters (h, g) is *complementary*, that is it allows for *perfect reconstruction*, then for every filter *s* the pair (h', g) with $h'(z)=h(z)+s(z2)\cdot g(z)$ allows for perfect reconstruction, too. Of course, this is also true for every pair (h, g') of the form $g'(z)=g(z)+t(z2)\cdot h(z)$. The converse is also true: If the filter banks (h, g) and (h', g) allow for perfect reconstruction, then there is a unique filter s with $h'(z)=h(z)+s(z2)\cdot g(z)$.

Each such transform of the filter bank (or the respective operation in a wavelet transform) is called a lifting step. A sequence of lifting steps consists of alternating lifts, that is, once the low pass is fixed and the high pass is changed and in the next step the high pass is fixed and the low pass is changed. Successive steps of the same direction can be merged.

IV. PROTECTION OF DISTRIBUTED GENERATION:

The impedance measurement is used to identify the proximity of a grid fault to PEE. This measurement is used to decide whether PEE should ride through certain remote faults to avoid nuisance trips. Islanding may also be detected.

The grid connection codes state that if a fault is detected usually through the Rate of Change of Frequency (ROCOF) measurement- the distributed generator must be disabled. However, with the increasing interest in microgrids and other sustainable energy systems, it may be preferable to operate at the presence of certain faults (i.e., those outside the zone) and only shut down the zone if the fault occurs within the zone.

V. SIMULATION RESULTS:

The simulation consists of wind, solar and an interconnection with macro grid. A fault is created at time 0.03 and the voltage waveforms are exported to workspace to apply for wavelet transforms.

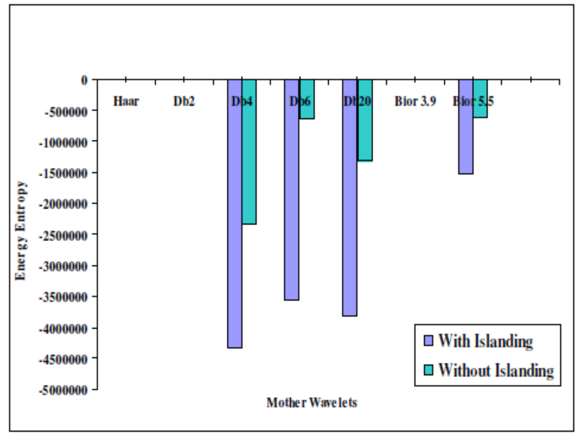

Fig.4: Comparison of energy entropy for various mother wavelets

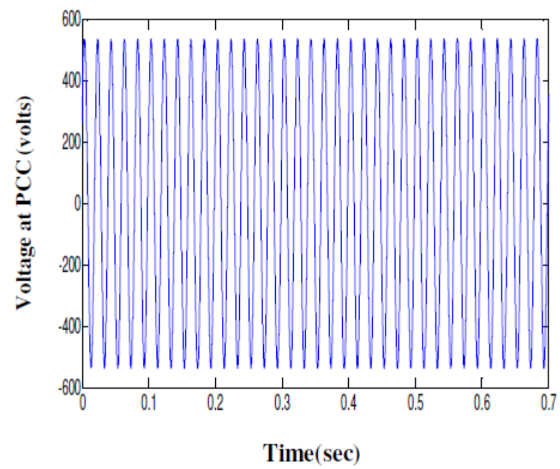

Fig.5: Voltage at point of common coupling(volt) on islanding

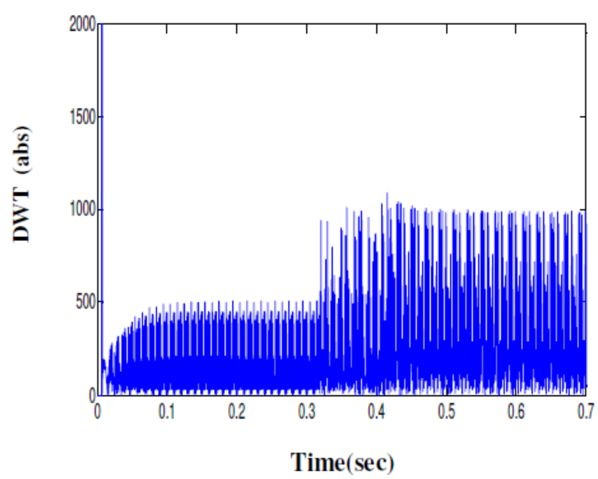

Fig.6: DWT of voltage at point of common coupling on islanding

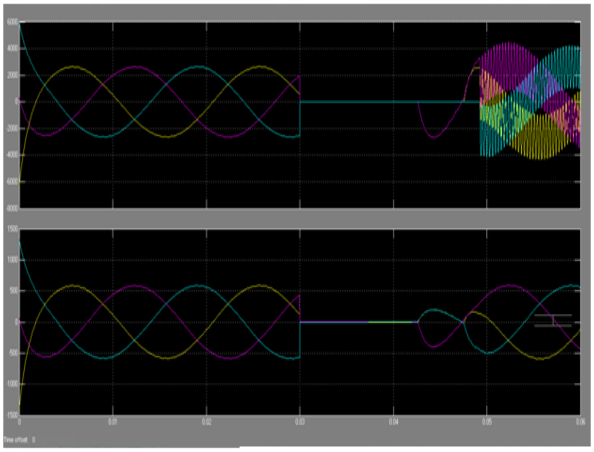

Fig.7: Output voltage, current with short fault at time 0.03 sec

VI. CONCLUSION

A new method for estimating power system impedance is proposed. The earlier method employs the CWT to derive the impedance from measured transient data. The main advantage with this technique is that the data capture time is significantly reduced compared to previous techniques, and offers the possibility of true on-line real-time impedance estimation for both power quality equipment, and embedded generation interfaces, thus improving their reliability and dynamic response, and also enhancing the quality and operation of distributed generation equipment. But impedance calculation takes an additional time. Hence we proposed the direct method of finding the detail coefficients and classifying it with neural networks.

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BIOGRAPHIES:

Mrs. Shalini received B.E (Electrical & Electronics Engineering) from ShirdiSai Engg College, Bangalore, India and currently a PG student in Power Systems Engg from PSV College Of Engg & Technology (TN), India. Areas of interest are Renewable Energy Resources, Electrical machines, PSOC, FACTS.

Mr. T. Manjunath received B.E(Electrical & Electronics Engg) from Adhiyaman Engg College, TN, India and M.E from A.C. Engg College, TN, India. Currently pursuing Ph.D. Areas of interest are Power System operation & Control, Renewable Energy sources.

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