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Transient Stability Analysis in Interconnected Power System for Power Quality Improvement

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Abstract:

Power industries worldwide move toward deregulation and competition. At the same time, electrical power systems are becoming more complicated. Even short interruptions in electrical supply can lead to serious consequences. Controlling the power many problems can be solved with enhancing the quality of the performance. The stability of an interconnected power system is its ability to return to normal or stable operation after having been subjected to some form of disturbance. *Power-system stability* is a term applied to alternating-current electric power systems, denoting a condition in which the various synchronous machines of the system remain in synchronism, with each other. Fault occurrence in a power system is due to transients. In this paper, an approach has been done to stabilize the system load flow analysis. The transients have been analyzed and have obtained a better result in a simple approach.

Introduction:

The purpose of a power system is to transport and distribute the electrical energy generated in the power plants to the consumers in a safe and reliable way. Aluminium and copper conductors are used to carry the current, transformers are used to bring the electrical energy to the appropriate voltage level, and generators are used to take care of the conversion of mechanical energy into electrical energy. Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance. Transient signals are one of the cause of instability. Transients occur when there is a sudden change in the voltage or the current in a power system. Transients are short-duration events, the characteristics of which are predominantly determined by the resistance, inductance, and capacitance of the power system network at the point of interest. In this work analysis of power transients has been attempted.

Causes of Transient:

Transients are disturbances that occur for a very short duration and the electrical circuit is quickly restored to original operation provided no damage has occurred due to the transient. An electrical transient is a cause-and-effect phenomenon. For transients to occur there must be a cause, some of the more common causes of transients:

- Atmospheric phenomena (lightning, solar flares, geomagnetic disturbances)
- Switching loads on or off
- Interruption of fault currents
- Switching of power lines
- Switching of capacitor banks

Stability:

The stability of an interconnected power system is its ability to return to normal or stable operation after having been subjected to some form of disturbance. With interconnected systems continually growing in size and extending over vast geographical regions, it is becoming increasingly more difficult to maintain synchronism between various parts of the power system. Random changes in load are taking place at all times, with subsequent adjustments of generation. If the oscillatory response of a power system during the transient period following a disturbance is damped and the system settles in a finite time to a new steady operating condition, we say the system is stable. If the system is not stable, it is considered unstable. This primitive definition of stability requires that the system oscillations be damped. This condition is sometimes called asymptotic stability and means that the system contains inherent forces that tend to reduce oscillations. This is a desirable feature in many systems and is considered necessary for power systems. The definition also excludes continuous oscillation from the family of stable systems, although oscillators are stable in a mathematical sense.

The reason is practical since a continually oscillating system would be undesirable for both the supplier and the user of electric power. Successful operation of a power system depends largely on the engineer's ability to provide reliable and uninterrupted service to the loads. The reliability of the power supply implies much more than merely being available. Ideally, the loads must be fed at constant voltage and frequency at all times. The first requirement of reliable service is to keep the synchronous generators running in parallel and with adequate capacity to meet the load demand. Synchronous machines do not easily fall out of step under normal conditions.

Transient Stability:

Each generator operates at the same synchronous speed and frequency of 50 hertz while a delicate balance between the input mechanical power and output electrical power is ma intained. Whenever generation is less than the actual consumer load, the system frequency falls. On the other hand, whenever the generation is more than the actual load, the system frequency rise. The generators are also interconnected with each other and with the loads they supply via high voltage transmission line.

An important feature of the electric power system is that electricity has to be generated when it is needed because it cannot be efficiently stored. Hence using a sophisticated load forecasting procedure generators are scheduled for every hour in day to match the load. In addition, generators are also placed in active standby to provide electricity in times of emergency. This is referred as spinning reserved.

The power system is routinely subjected to a variety of disturbances. Even the act of switching on an appliance in the house can be regarded as a disturbance. However, given the size of the system and the scale of the perturbation caused by the switching of an appliance in comparison to the size and capability of the interconnected system, the effects are not measurable. Large disturbance do occur on the system. These include severe lightning strikes, loss of transmission line carrying bulk power due to overloading. The ability of power syste m to survive the transition following a large disturbance and reach an acceptable operating condition is called *transient stability*.

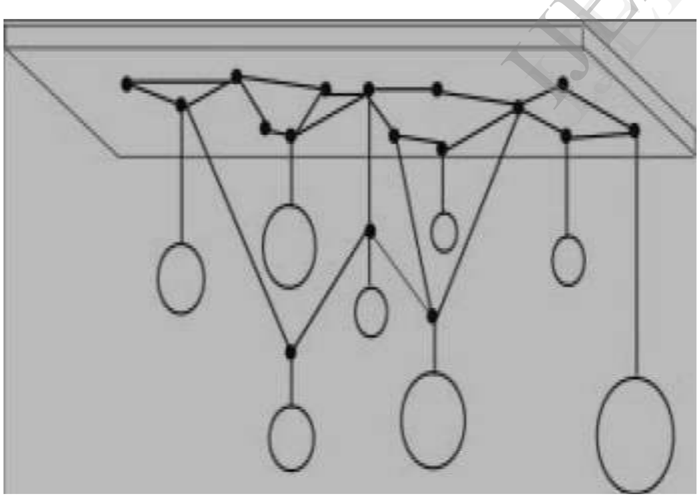
The physical phenomenon following a large disturbance can be described as follows.

Any disturbance in the system will cause the imbalance between the mechanical power input to the generator and electrical power output of the generator to be affected. As a result, some of the generators will tend to speed up and some will tend to slow down. If, for a particular generator, this tendency is too great, it will no longer remain in synchronism with the rest of the system and will be automatically disconnected from the system. This phenomenon is referred to as a generator going out of step.

Acceleration or deceleration of these large generators causes severe mechanical stresses. Generators are also expensive. Damage to generators results in costly overhaul and long downtimes for repair. As a result, they are protected with equipment safety in mind. As soon as a generator begins to go out-of-step, sensor in the system sense the out-of-step condition and trip the generators. In addition, since the system is interconnected through transmission lines, the imbalance in the generator electrical output power and mechanical input power is reflected in a change in the flows of power on transmission lines. As a result, there could be large oscillations in the flows on the transmission lines as generator try to overcome the imbalance and their output swing with respect to each other.

Mechanical Analogy:

A mechanical analogy to this phenomenon can be visualized in fig. 1. Suppose that there is a set of balls of different sizes connected to each other by a set of strings. The balls represent generators having a specific mechanical characteristic (that is, inertia). The strings represent the transmission line interconnecting the generators.



(Fig.-1 : Mechanical Analogy of Transient Stability)

Now suppose that there is a disturbance in which one of the balls is struck with a cue. The ball now begins to swing, and as a result, the string connected to the ball also oscillates. In addition, the other strings to which this string is connected are also affected, and this in turn affects the other balls connected to these strings. As a result, the entire interconnected system of balls is affected, and the system experiences oscillations in the strings and motion of the balls. If these oscillations in the strings become large, one of the strings may break away from the rest, resulting instability. On the other hand if the oscillation dies down and

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the entire system comes back to rest as in the situation prior to the ball being struck. This condition is analogous to a power system being “transiently stable”.

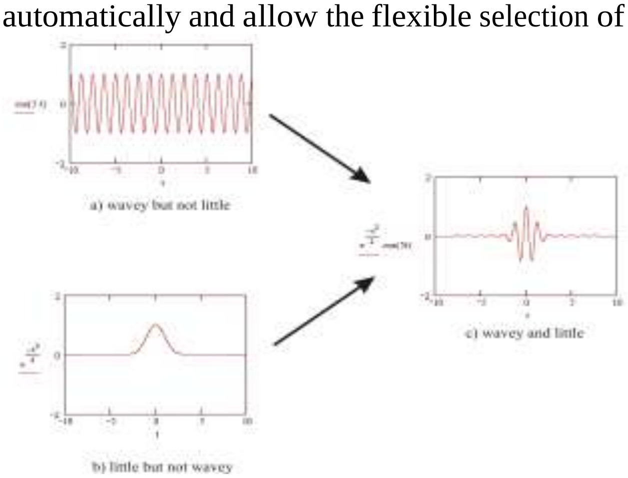
In a power system, an additional important characteristic in the operating condition, as the loading on the system increases, the system becomes more stressed and operates closer to its limits. During these stressed condition, a small disturbance can make the system unstable. Dropping a marble into a pitcher of water provides a suitable analogy to understand why the operating condition makes a difference in maintaining transient stability.

1. Take a pitcher and fill it with the water to quarter its capacity. Now drop a marble in t he pitcher. The dropping of the marble is akin to a disturbance in the power system. In this situation no water from the pitcher will splash out, indicating the system is stable.
2. Now fill the pitcher with water close to it brim and drop the same marble into the pitcher. In this case, water will splash out, indicating the system is unstable.

In these two situations, the same disturbance was created. However, the system was operating at different conditions, and in the latter situation, the system was more stressed. Again, this analogy illustrates that the degree of stability is dependent on the initial operating condition.

Wavelet Transform:

The wavelet transform leads to the signal processing techniques with special characteristics that have been expected for a long time. The term "wavelet" literally means little wave because a wavelet decays quickly (little) with oscillations (wave) (see figure-2). Although countless functions may be little waves, the item wavelet is reserved for those little waves that are associated with a particular choice: narrow-band in frequency. Simply, wavelets are window functions not only in time domain but also in frequency domain. The wavelet transform represents a signal through wavelets. It is a linear transformation much like the Fourier transformation but with important differences: the wavelet transform can localize simultaneously in time and in frequency, adjust the window widths according to frequency automatically and allow the flexible selection of wavelets to match different applications.



(Fig.-2: Wavelet)

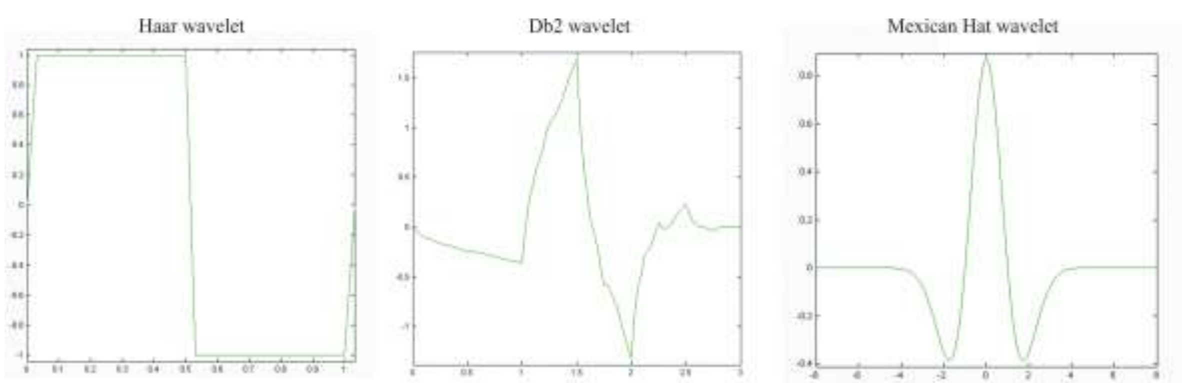
As a transient signal, its amplitude, frequency or both do not stay constant when time changes. Up to now, the Fourier transform based methods are generally employed for the processing of power transients, despite that the Fourier transform is only suitable for periodical signals. This is why there are still many unsatisfactory results and non unified definitions concerning the Fourier transform applications in power systems, although great deal of concerning work has been done. There is always the requirement for a more suitable method to process power transients.

With the development of the wavelet transform, it is naturally to explore and see how this promising approach works in power systems. Since 1994, the wavelet transform has been introduced into power systems and applied for the analysis and the classification of power quality events, protections, data compression, cable partial discharge measurement and so on. There is a sharp increasing tendency in the presentation about the wavelet transform applications in power systems. The wavelet transform is becoming a well-known method and is drawing more attention of electrical engineers.

Through, it is known that the wavelet transform is suitable for the analysis of power transients and has a big potential area in power system applications. However, it is noticed that the wavelet transform applications in power systems are still quite rough and limited:

- They are mainly on the introduction of the basic conceptions and theory of the wavelet transform but lack of detail explanations and practical application results.
- They are mainly with qualitative analysis but short of rationing criteria and sufficient verifications.
- They are mainly on the application of basic wavelet algorithm but hardly on the deep or extension theories such as wavelet singularity theory and improved algorithms etc.

Therefore, the situation is that the wavelet transform applications in power systems are very meaningful but just at the beginning, and there is a great deal of concerning research to do. The wavelet transform with its special characteristics, such as the time-frequency location, the auto adaptive to frequency, the flexible selection and the fast algorithms etc., opens a door towards a lot of possibilities and large developing field in power systems. However, it is not very easy to start understanding and using the wavelet transform because the wavelet transform is built up on the theories of modern mathematics and modern signal processing and the most the of published books about wavelet transform are the contributions of mathematicians. Figure-3 shows three different wavelets as examples. The Haar wavelet (the simplest wavelet) and the Db2 wavelet (one of Daubechies wavelets) are discrete while the Mexican Hat wavelet is continuous.



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(Fig.-3: Examples of wavelets)

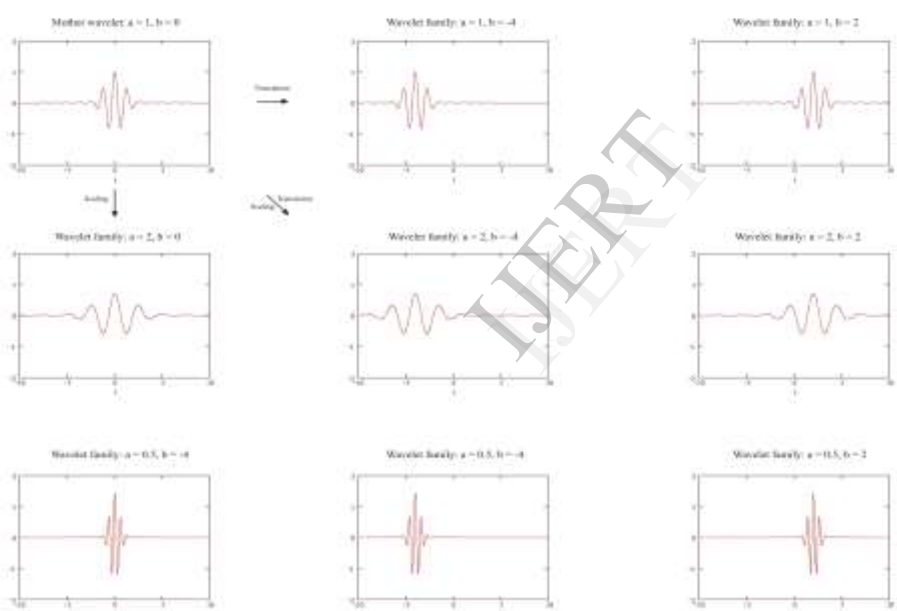
Mother wavelet, wavelet family and wavelet domain:

Any wavelet can be taken as a mother wavelet. A mother wavelet generates a wavelet family by scaling and translating. All members in one wavelet family have the same energy and the similar waveform as the mother wavelet.

Let $\psi(t)$ denote a mother wavelet, corresponding wavelet family $\psi_{ab}(t)$ is defined as

$$\Psi_{ab}(t) = a^{-\frac{1}{2}}.\Psi\left(\frac{t-b}{a}\right) \quad (1)$$

Where “a” represents "scale" and “b” represents "translation". Figure-4 displays the relation between a mother wavelet (Morlet wavelet) and it’s family. It can be seen that translation b is just a representation of time and scale a influences the duration so that has a direct relation with frequency.



(Fig.-4: Mother wavelet and wavelet family)

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Fourier Transform:

Nowadays, the Fourier transform is the most well known trans- form. Since 1822 Fourier created the theory and especially since 1965 the fast Fourier transform (FFT) was proposed, the Fourier transform has been applied in nearly all the engineering fields.

In mathematics, the Fourier transform of a function $f(t)$ is defined as:

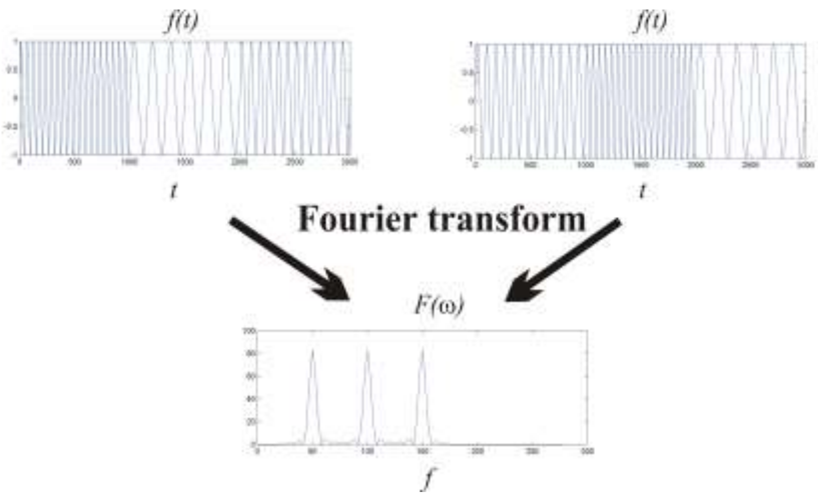
$$F(j\omega) = \int_{-\infty}^{+\infty} e^{-j\omega t}\, dt \tag{2}$$

It represents a signal with an orthogonal base $\{e^{j\omega t}\}$, which includes the sinusoids of different frequencies. In this way, the Fourier transform changes our view from time domain to frequency domain.

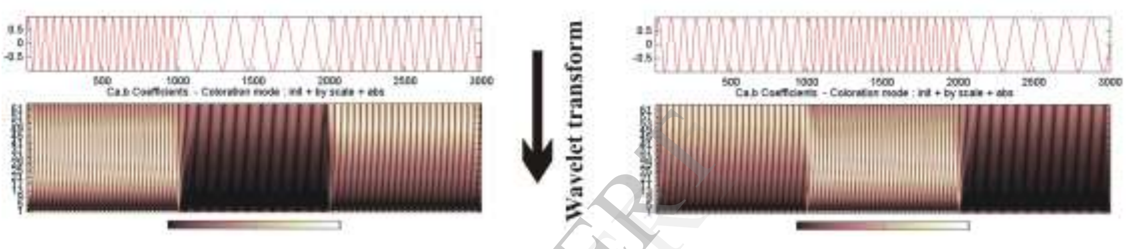
The Fourier transform is perfect and quite simple in mathematics. However, many people are still working on it and there are many concerned definitions, such as transient frequency and harmonics etc., still under the discussion in engineering. The reason is that the practical applications requires more than the theory has.

The Fourier transform transfers a signal into the frequency domain, the information evolving with time is lost completely. For example, two different signals have the same result through the Fourier transform, as shown in Fig.-5. It is impossible for the Fourier transform to tell when a particular frequency took place. Besides, the Fourier transform needs the information in an infinite amount of time, i.e. all the past, present and future information of a signal, just to evaluate the spectrum at a single frequency. Strictly, the Fourier transform is only suitable for handling periodic or time- invariant signals in practical applications. Unfortunately, most of signals in practice are non-periodic and time-variant and transient characteristics such as a sudden change, beginnings and ends of events are often the most important part of signals.

Therefore, it remains a challenge in practical applications how to analyze transient signals and how to obtain time information as well as frequency information simultaneously.



(Fig.-5 Different signals but same Fourier transform representation)



(Fig.-6: Wavelet Transform of two different sinusoids)

Continuous Wavelet Transform:

The continuous wavelet transform (CWT) of a function $f(t)$ is given by

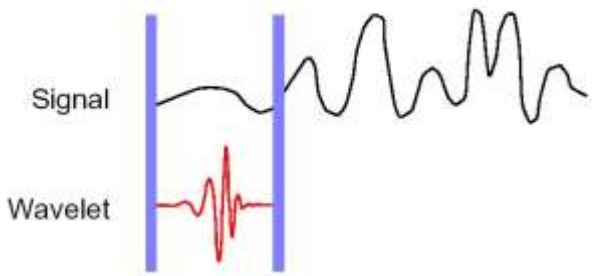
$$W_{\Psi} f(a,b) = \int_{-\infty}^{+\infty} f(t)\ \Psi_{ab}^{*}(t)dt \quad (3)$$

Where $W_{\psi} f(a,b)$ are wavelet coefficients $\psi_{ab}(t)$ represents a wavelet family created by a mother wavelet $\psi(t)$, a and b are the scale and the translation respectively, and the superscript "*" denotes complex conjugation because wavelets can be complex.

Calculation of the Continuous Wavelet Transform

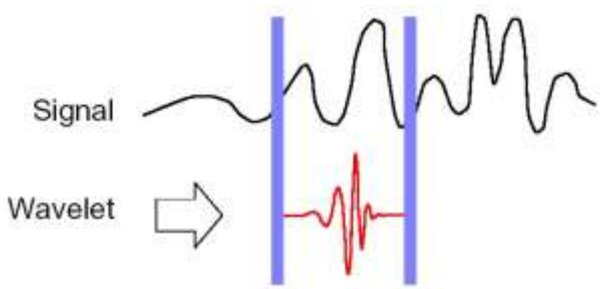
The calculation of the continuous wavelet transform is a quite simple process. There are five steps:

1. Chose a wavelet and locate it at the start section of the original signal.



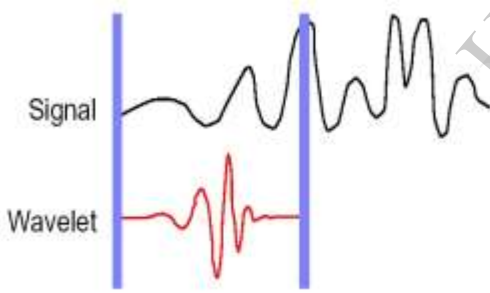
(Fig.-7: Step 1 of the continuous wavelet transform)

2. Calculate a wavelet coefficient according to Equation 3.
3. Shift the wavelet to the right and repeat step 1 and 2 until the whole signal is covered.



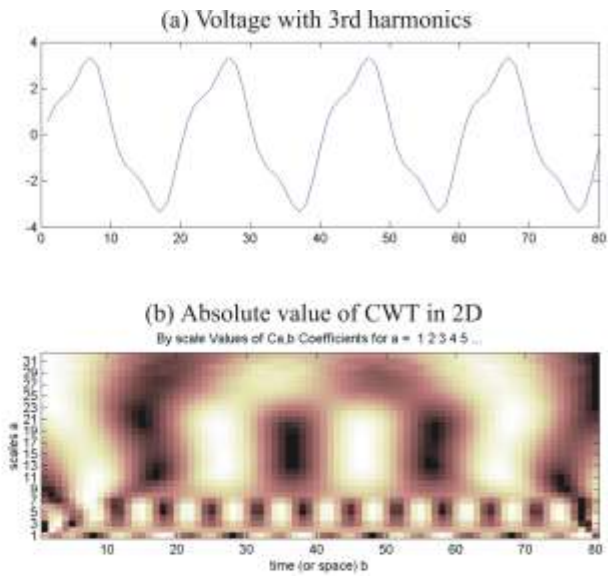
(Fig.-8: Step 3 of the continuous wavelet transform)

4. Scale the wavelet and repeat step 1 through 3
5. Repeat step 1 through 4 for all scales.



(Fig.-9: Step 4 of the continuous wavelet transform)

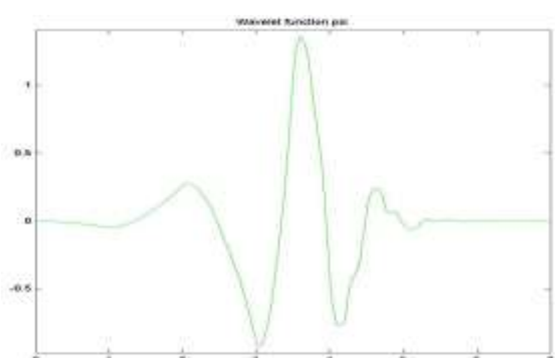
With the help of the wavelet transform, a one-dimensional signal can be represented in two-dimensional domain. Figure-10 shows, as an example, the wavelet domain representations of a power signal. Figure-10 (a) displays the signal which contains 3rd harmonic component. The signal is transferred into 32 scales through Morlet wavelet, where the relation between scale and frequency is: frequency = 800/scale. Figure-10(b) displays the wavelet representation on the time-scale plane in 2D, where the dark degree is proportional to the absolute value of the wavelet coefficients.



(Fig.-10: The continuous wavelet transform (Here: f=800/a, t=b)

Detecting and localizing a disturbance:

The wavelet which is used for this study was the "Daub4", which is shown in figure-11. The figure-12 shows a voltage which was distorted by a capacitor switching. Figure-12(a) is the voltage which is analyzed. Figure-12(b) is the wavelet approximated coefficient for level 5, (c) (d) (e) (f) and (g)are the detailed versions for levels 5,4,3,2 and 1. The detailed level 1 (figure-12(g)) of the transformed signal clearly shows a peak at t=400ms. The other wavelet levels have also experienced variations at the same time. This implies that some transient phenomena has occurred at this time. Therefore, it can be said that the disturbance has been detected and located in time. However this figure brings no sufficient evidences of what kind of disturbance occurred to this signal.



(Fig.-11: Daubechies4 wavelet)

Results:

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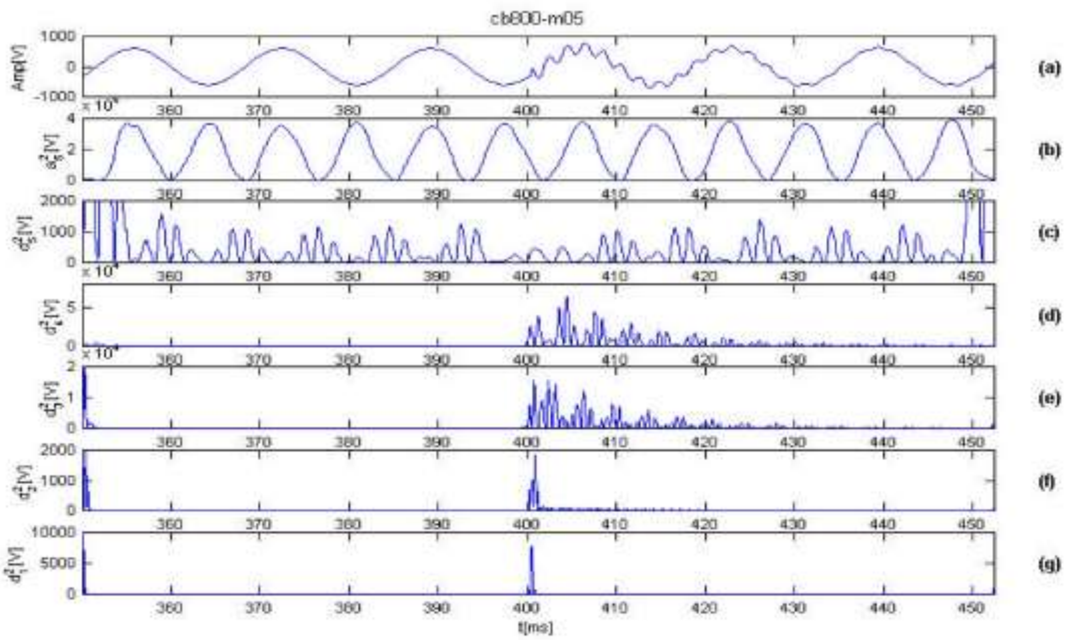
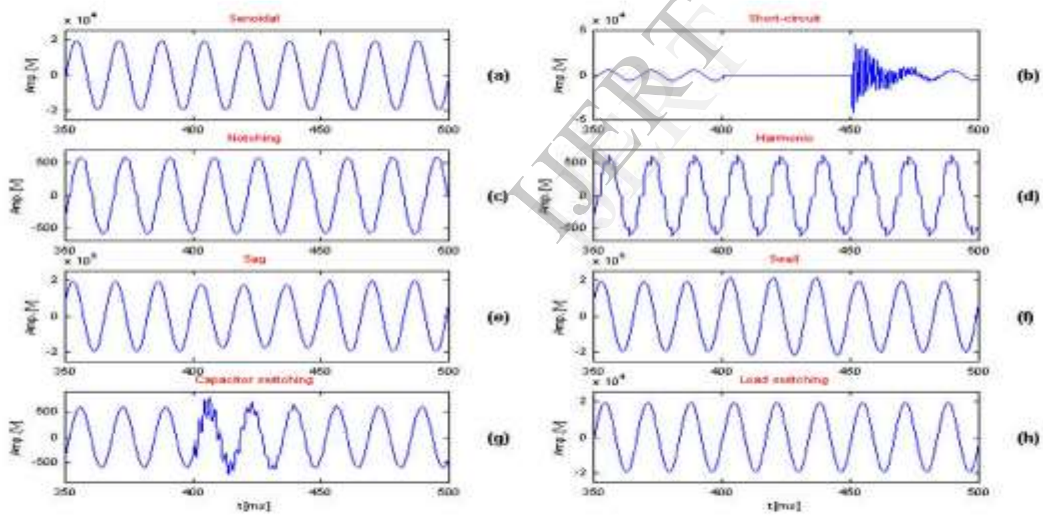


(Fig.-12:Detecting a disturbance, using Daubechies4 wavelet – wavelet coefficients squared)



(Figure 13: Some voltage signals with power quality disturbances)

Conclusion: In this way the stability of an interconnected power system can be analyzed and hence the quality of power transfer can be improved by reducing the various disturbances created due to transient phenomena.

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