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IDENTIFICATION AND CLASSIFICATION OF POWER QUALITY DISTURBANCES USING WAVELETS

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IDENTIFICATION AND CLASSIFICATION OF POWER QUALITY DISTURBANCES USING WAVELETS

by

MOHAMED CAMARA

June 2015

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APPROVAL PAGE

This is to certify that I have read this thesis written by Mohamed Camara and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Electrical and Electronics Engineering.

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Mohamed CAMARA

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ABSTRACT

This thesis is about the analysis of voltage disturbances in the time and frequency scale using wavelet transform to evaluate the power quality (PQ) events. It investigates the characteristics of signals produced on a time frequency plane. Five common power quality events (load interruption, load reenergizing, capacitors switch, transient's effects, and nonlinear load) are going to be discussed. These illustrations give the premise to further portrayal of other power quality occasions. Moreover, important time and frequency segments are broken down and analyzed. The entire technique is executed and tested over a sample representing the disturbances.

Keywords: Voltage Disturbances, Power Quality (PQ), Wavelets Transforms, Transients, Linear/nonlinear Load interruptions, Capacitor Switching.

DALGACIKLAR KULLANILARAK GÜÇ KALİTESİ BOZUKLUKLARININ TANILANMASI, YERLERİNİN BELİRLENMESİ VE SINIFLANDIRILMASI

Mohamed CAMARA

Yüksek Lisans Tezi – Elektrik ve Elektronik Mühendisliği
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Tez Danışmanı: Yrd. Doç. Dr. Lokman ERZEN

ÖZ

Bu tez, güç kalitesi olaylarını değerlendirmek için, zaman ve frekans ölçeğindeki gerilim bozuklularının dalgacık dönüşümü ile analizlerini içermektedir. Zaman frekans düzleminde üretilen sinyallerin karakteristikleri incelenmiştir. Beş yaygın güç kalitesi olayı (yük kesintisi, güç yeniden yüklenmesi, kapasitör anahtarlama, geçici dalga etkileri, doğrusal olmayan yük) ele alınmıştır. Bu resimler, diğer güç kalitesi durumlarını resmetmeye dayanak oluşturmaktadır. Bunun yanında, önemli zaman ve frekans segmentleri bölünmüş ve analiz edilmiştir. Tüm teknik, bozuklukları temsil eden bir örneklem üzerinde yürütülmüş ve test edilmiştir.

Anahtar Kelimeler: Gerilim bozuklukları, güç kalitesi, dalgacık dönüşümleri, geçici dalgalar, doğrusal/doğrusal olmayan yük kesintileri, kapasitör anahtarlama.

To my family

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I sincerely trace my gratitude to Asst. Prof. Dr. Lokman Erzen for his honest guidance in my research activities. His generous attitude permitted me to learn a lot both theoretically and practically about my fields of interest.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION

CVT	constant voltage transformers
GHz	Gigahertz
H	Magnetic field strength
Hz	Hertz
I	Current
KV	kilo Volt
L	Length of a metal segment
nh	Nano -Henry
PCC	Point of compound Coupling
PQ	Power Quality
TDD	Total Demand Distortion
UPS	Uninterruptible power supplies
V	Applied voltage Wm
WT	Wavelet transform

CHAPTER 1

INTRODUCTION

Working with signals can be hard because it might be hard to interpret. Reason why we need to decompose the signal or transform it in order to see what it really represents. A common method is to use the Fourier transform described in Chapter 3.

But bear in mind that Fourier transforms cannot give a precise estimate of a signal a precise time and precise frequency. Either you get the frequencies information's of the signal or the time's, but not both simultaneously. To solve that issue, they introduced the wavelet transform.

The continuous wavelet transform is the most general WT.

The problem is that a continuous wavelet transform operates with a continuous signal, but since a computer is digital, it can only do computations on discrete signals.

The discrete wavelet transform was developed to accomplish a wavelet transform on a computer.

There exist numerous different wavelet transforms. I choose to work with the WT and I have briefly written about some of the wavelet transforms and more detail are given in Chapter 4; this is in order to give a clear picture of the topics, and also to get an idea of the differences.

Wavelets and wavelet transforms are used to investigate signals. The transformed signal work the same way as FT, is a decomposed version of the original signal, and can be converted back to the original signal with no information lost in the process.

When studying for instance a musical tone, one of the most important features is the frequency. To determine the frequency of the signal one must measure the period of the wave then calculate the frequency. The period of a wave is the time it takes for that particular wave to reach back it starting position.

Wavelets and wavelet transforms have many fields

1. In music: to know the frequencies of the tones and their representation

2. Seismic data: the frequencies can tell us what the ground is made of, the types of rocks and their composition in oil or etc.

Wavelets and its transform are used whenever one wants to have an idea of a given signal at a precise time and precise frequency.

3. Wavelet transforms are widely used in submarine sonar, to determine distances, speed, position and other information on other waterborne vessels and animals.

Wavelets are good for

4. removing noise from signals

5. detecting discontinuities breakdown points

6. self-similarity

7. images compressing.

CHAPTER 2

LITERATURE SURVEY ON POWER LINES

2.1 INTRODUCTION

Power quality analysis the waveform of electric power over the consumer devices. Synchronization of the voltage phase and frequency allows devices to perform in the optimum way with the highest performance. PQ is used to understand electric power feeding an electrical load to perform properly. An electrical device might glitch, fizzle or can even break down, without the correct power.

Numerous reasons could explain the low quality of an electric power .

The electric power companies uses AC PW generators mostly, transmission of electric power and distribution of electric power (which connects to electricity meter).The electricity flows inside the wires of the costumer until the load. The complexity of the flow to electricity from the production point to the consumption point added up with the weather conditions and others random factors give many opportunity to corrupt the quality of the electricity

"Power quality" is an advantageous term for some; because the nature of the voltage is really portrayed by the term. Voltage is basically the stream of vitality and the current requested by a heap is to a great extent.

The electric power quality ‘s problem is of main focus because

- The increase dependency of people on electricity.
- New equipments are more likely to be damage (sensitive) due to power quality variations.
- The invention of new equipments (switched mode power supply ,variable speed drives) has caused new problems into the supply system
- A small power break has large economic consequences on the industries.
- A longer interruption stops almost all operations in the society.

2.1.1 Cause of Power Quality Problems

Based on a recent survey, most PQ disturbances are caused because, of ground bonds, grounding, ground loops, ground current, neutral to ground voltages etc.

To know the issues with PQ demands many electronic test equipments. Here are some symptoms to indicate Power Quality problems:

- If an equipment keeps on not working correctly at everyday at the same time.
- . Electronic systems stop to operate on a frequent basis.
- During a thunderstorm, if the electronics equipments fail to work.
- Automated systems fail to work for no reasons.
- If Circuit breakers faults with no case of overloaded
- If an electronic device (system) work in a place but not in another place.

2.1.2 Problems and Issues of Power Quality

Many types of power quality problems exist. These problems might have same and/or different causes. One more thing to notice is that the different types of power quality problems may or may not happen at the same time. There is no right way to say the when and how or which PQ's disturbances will occurs for sure.

Typical power problems: Sag (Dip), Over voltage, Surge Swell, Frequency, Harmonics, Notching, , Transient (Surge) and under voltage (Brownout), Interruption (Blackout), Noise, Short Circuit.

2.1.2.1 Voltage Sags

Sags are a short reduction in the voltage amplitude (80-85%). It is caused mostly, starting of a motor, or capacitor switching by fuse/breaker operation. They are non-repetitive, or may repeat because of the recloses operation.

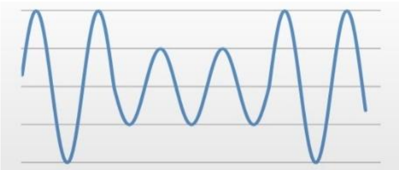

Figure 2.1. Waveform of voltage sag.

2.1.2.2 Power Interruption

They are generally short duration events , zero-voltage events and are less than 30 seconds. Interruption or a black out is when the voltage drops under 10% of the normal voltage value. An example is shown in Fig.1.2.

Interruptions have 3 classifications:

- temporary (3 seconds to 1 minute)
- Sustained (more than 1 minute).
- momentary (30 cycles to 3 seconds),

In spite of the fact that interferences are the most serious type of power issue, they are rarely happening. Where lists and under voltage regularly speak to more than 92% of force issue occasions, intrusions speak to under 4% of such issues

Figure 2.2. Waveform of power interruption.

2.1.3 Voltage Flicker

Voltage flicker is mostly caused by quick change in loads that require a large amount of reactive power.

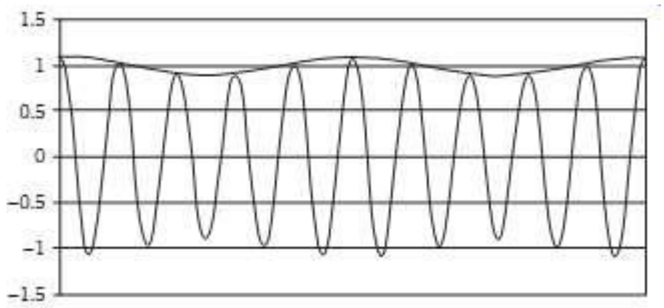

Figure 2.3. Waveform of voltage flicker.

2.1.4 Power Surges

A Power surge is when the voltage rises up to 110% or more of the normal voltage value. The most basic reason is shutting down of heavy electrical load.

2.1.5 High Voltage Spikes

A sudden voltage peak which might go up to up to 6,000 volts is called high-voltage spikes. They may have many causes but the most frequent on is lightning strikes.

2.1.6 Harmonics

Repeating twisting of the waveform mainly known as harmonics might be caused by many devices such as (non-linear power supplies, electronic ballasts and variable frequency drives,). There are some sorts of power conditioners like consistent voltage (CVT) transformers or ferroresonant , which can add critical harmonic distortion to the waveform.

Figure 2.4. Waveform of harmonics.

2.1.7 Frequency Variation

A frequency variation as it name explains means a change in frequency from the normally stable utility frequency of 50Hz. It could be created by temperamental unstable frequency sources or unpredictable operation of emergency generators.

2.1.8 Noise

Noise could be defined as a distortion of the voltage waveform (Fig. 2.5).It usually happens in high frequency signal. Brought about by unsettling influences on the utility system or by devices (for example, transmitters, switchgear and welders).

Noise can habitually go unnoticed. Regular or elevated amounts of noise can bring about device glitch, overheating etc..

Figure 2.5. Waveform of noise.

2.1.9 Notching

As indicated in the Fig. 2.6 notching is type of a disturbance which is of opposite polarity to the nominal voltage waveform. It usually goes on for under one-half cycle. It is caused by power conditioners or malfunctioning electronic switches or power conditioners are. It is not considered as a big issue, but it can bring about equipment, particularly electronics, to work despicably [4].

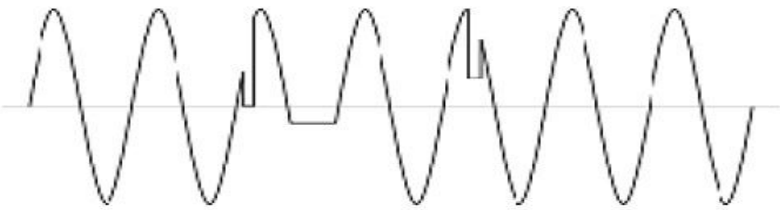

Figure 2.6. Waveform of notching.

2.1.10 Short Circuit

A short circuit is typically not seen a PQ issue but more as a risky operational fault. Short circuit alludes to a place where two "hot" lines are joined specifically (through little impedance) or one "hot" line is connected directly to the ground. It causes very high fault currents to move through the wires and most the equipments between the place of the fault and the incoming power line. If the fault is not corrected rapidly it may lead to melting even burning of electrical wiring and devices and dangerous overheating. The method used to avoid it is the use of a protective fuse or protective breakers or.

2.1.11 Swell

Any increment of the voltage above 110% of normal value is called a Swell. It lasts between one-half cycles to one minute as shown in figure below. They can also create untimely wear and equipment malfunction. The usual causes of swells could be switching capacitor banks on or the shutting off loads.

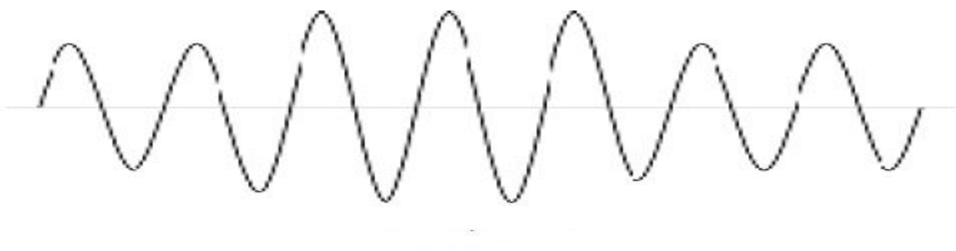

Figure 2.7. Waveform of swell.

2.1.12 Transients

Transients are brief timely (sub-cycle) disturbances which changes amplitude as shown in Figure. 1.8. Regularly called to as "surges", drifters are presumably most as often as possible pictured as a huge number of volts from a lighting strike that pulverizes any electrical gadget in its way. Transients could be caused by weather phenomena such as lightning or even by equipment operation or failure. Generally even low voltage transients, if the occur with any frequency, can bring harm to electrical components. The best way of protection from the damaging effects of high voltage transients is the use of properly sized industrial-grade surge suppressor

When there is a greatly fast voltage crest of up to 20,000 volts with time duration of 10 microseconds to 100 microseconds, switching transients can occurs. Switching transients happen in a so little brief time, to the point that they regularly don't appear on typical electrical test equipment. They are caused by static discharge stopping, arcing faults and machinery starting.

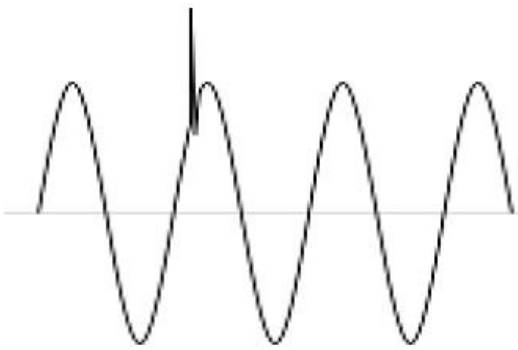

Figure 2.8. Waveform of transients.

2.1.13 Brownouts

A brownout is a steady lower voltage state. A case of a brownout is the thing that happens during high electrical demand in summer, when utilities can't generally meet the necessities and must lower the voltage to limit maximum power. At the point when this happens, systems could be subject to glitches, data loss and equipment failure.

2.1.14 Blackouts

A power failure or blackout is a zero voltage condition that lasts for more than two cycles. It might be brought about by tripping a circuit breaker, power distribution failure or even utility power failure. A blackout can cause or corruption of the system and equipment damage, and data loss.

2.2 STANDARDS POWER QUALITY

Power quality is an overall problem, and continuing setting new standards is an endless job. The current works in the harmonic standards guidelines development by the IEEE has shifted to completely change the Standard 519-1992.

2.2.1 IEEE 519

The limits on harmonic currents and voltages at the point of common coupling (PCC), or point of metering were established by IEEE 519-1992, Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, [7,8].

The limits of IEEE 519 are for:

1. Guarantee that the electric utility can provide moderately clean energy to the greater part of its clients;
2. The electric company should guarantee that it can protect its electrical equipment from loss of life from excessive voltage stress due to excessive harmonic voltage, overheating and excessive harmonic currents. Everything should be according to the IEEE 519 lists; from metering point with the utility and the limits for harmonic distortion at the point of common coupling (PCC). The limits for voltage distortion are 5% for THD and 3% for individual harmonics. There is no limit to any particular equipment, but , if a high amount of nonlinear loads happen to be used , there is a possibility that some harmonic suppression will be important.
3. IEEE 519 Standard for Current Harmonics

    - [120V- 69 kV] This concern odd harmonics General Distribution Systems; below current distortion point.

      Even harmonics are constrained to 25% of the odd harmonic limits [3,17]. For all power generation equipment, distortion limits points (are those with $I_{SC}/I_L<20*I_{SC}$) is the maximum short circuit current at the point of coupling "PCC".I_L is the maximum fundamental frequency 15-or 30- minutes load current at PCC

TDD is the Total Demand Distortion (=THD normalized by I_L)

- [69 kV-161 kV] are the General Sub-transmission Systems

Note that the harmonic limits change according to the I_{SC}/I_L,

I_l is the PCC the maximum demand load current at

I_{SC} is the PCC maximum short circuit current for

I_{SC}/I_L	h<11	11≤h <17	17≤h<23	23≤h<25	h≥35	TDD (%)
<50	2.0	1.0	0.75	0.3	0.15	2.5
≥50	3.0	1.5	1.15	0.45	0.22	3.75

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<25	TDD (%)
<20	4.0	2.0	1.5	0.6	5
20-50	7.0	3.5	2.5	1.0	8
50-100	10	4.5	4.0	1.5	12
100-1000	12	5.5	5.0	2.0	15
>1000	15	7.0	6.0	2.5	20

Table1: Harmonics :Current Distortion Limits

A. Voltage Harmonics IEEE Standard

- Voltage Distortion Limits IEEE-519 -

This standard concern typically the quality of the power. Example, IEEE 519 69 kV systems, obliges a confinement of5 % for total harmonic distortion and 3 % harmonic distortion for an individual frequency component.

Bus voltage	Individual V_h(%)	THDV(%)
V <69 kV	3.0	5.0
69≤V<161 kV	1.5	2.5
V≥161 kV	1.0	1.5

Table2: Harmonics Voltage Distortion Limits

2.2.2 IEC 61000-3-2 and IEC 61000-3-4

a) IEC 61000-3-2 (1995-03)

It indicates harmonic current's limits outflows pertinent to electronic and electrical devices which could have a maximum input current of 16 A for each stage, and proposed to be connected to public distribution systems of low-voltage.

b) IEC/TS 61000-3-4 (1998-10)

It indicates to electronic and electrical equipments which has an input current passing 16 A for every phase and expected to be connected to public distribution systems of AC low-voltage

- nominal voltage up to 600 V, three-phase, three or four wires
- nominal frequency 50 Hz or 60 Hz
- nominal voltage up to 240 V, single-phase, two or three wire

The suggestions indicate the data needed to empower a supply power to evaluate equipment in regards to harmonic distortion and to choose whether or not the equipment is worthy for association as to the harmonics distortion viewpoint.

The European guidelines, IEC 61000-3-2 & 61000-3-4, putting current harmonic limits on equipment, are intended to ensure the protection consumer's equipment. The previous is confined to 16 A; the recent augments the extent over 16 A.

2.2.3 IEEE Standard 141-1993

An intensive investigation of fundamental electrical-system considerations is displayed. Direction is given in configuration, development, and congruity of a general system to accomplish security of life and safeguarding of property; effortlessness of operation, consideration and upkeep ,unwavering quality; voltage regulation in the use of gear; and adaptability to allow advancement and extension.

2.2.4 IEEE Standard 142-1991

It shows an intensive analysis of grounding problems and the methods used to solve them. More information could be found on a separate chapter for grounding sensitive equipment [17, 20].

2.2.5 IEEE Standard 446-1987

This standard is used for engineering purpose in the selection and standby power and systems application of emergency. Information about, virtually free of frequency operators and, Facility designers ,surges, and transients owners with guidelines for assuring uninterrupted power are all provided [8].

2.2.6 IEEE Standard 493-1997

The basics of reliability analysis used in the design and planning of industrial/commercial electric power distribution systems. It also covers most of the essential topics of power system reliability evaluation, reliability analysis by probability methods, cost of power outage data, equipment reliability data, etc. Standby power emergency , electrical preventive support and assessing and enhancing unwavering quality of the current plant are additionally tended to [8, 21].

2.2.7 IEEE Standard 1100-1999

It covers some installation maintenance, grounding, support practices for electrical power and recommended design. It could be used in industrial applications and commercial applications for sensitive electronic processing equipment [8, 13].

2.2.8 IEEE Standard 1159-1995

This standard is about some recommended methods to measure PQ events. There are many types of PQ measurement machines so to make the job of engineers easier, in different areas of signal processing, power distribution and transmission, it is important that they use the same language and measurement techniques For information about controlling and monitoring the AC power system's PQ, main definitions of PQ terminology, effect of poor PQ on customer, utility and equipments. [5, 8, 12, 13, 14].

2.2.9 IEEE Standard 1250-1995

PCs, PC like items, and gear utilizing strong state power change have made altogether new regions of force quality contemplations. There is an expanding mindfulness that quite a bit of some clients hardware isn't intended to resist the surges, and reclosing obligation present on run of the mill dispersions system.

2.2.10 IEEE Standard 1346-1998

A standard strategy for the specialized and budgetary examination of voltage droop similarity between procedure gear and electric force frameworks is suggested. The philosophy introduced is expected to be utilized as an arranging instrument to measure the voltage droop environment and procedure affectability

2.2.11 to Voltage Sag and Reliability Standards

The dissemination voltage quality standard i.e., IEEE Standard P1564 offers the suggested files plus the methods to portray voltage list execution and looking at execution crosswise over distinctive systems.

Another IEC Standard 61000-2-8 titled "Environment — Voltage Dips and Short Interruptions" was established later on. This principle gives extensive talk inside of the IEEE to abstain from clashing routines for describing framework execution in distinctive parts of the world

2.2.12 Voltage Flicker Standards

Improvements in voltage glimmer principles exhibit how the business can effectively arrange IEEE and IEC exercises. IEC Standard 61000-4-15 characterizes the estimation method, screen prerequisites to portray flash. The IEEE flash team chipping away at Standard P1453 is situated to receive the IEC standard as its own particular [2]

2.2.13 Standards Related to Custom

Power IEEE Standard P1409 is as of now adding to an application guide for custom force advances to give upgraded PQ on the appropriation framework. It is an imperative range for some utilities which might need to give upgraded PQ administrations [6, 7 , 4, 5].

2.2.14 Distributed Generation Standards

The new IEEE Standard P1547 gives rules to interconnecting appropriated era with the force system [5, 6, 11, 22].

CHAPTER 3

LITERATURE SURVEY ON WAVELETS

3.1 INTRODUCTION

"Wavelets" has been a very popular topic in numerous scientific and engineering fields. Some researchers view wavelets as a new way to represent functions, others as a technique for time-frequency analysis, and others think of it as a new mathematical subject.

Obviously, all of them are right, since "wavelets" is an adaptable apparatus with extremely rich mathematical and awesome potential for applications.

3.2 HISTORY AND USES OF WAVELETS

Wavelets have moved lately from math to engineering, with Information Engineers beginning to investigate the capability of this field in sign processing, data compression and specially noise reduction. The intriguing part about wavelets is that they are beginning to undermine a staple Mathematical technique in Engineering: the Fourier Transform. In doing this they are opening up another approach to comprehend signals.

At their most essential, wavelets are actually 'small scale waves or mini wave'. As opposed to being a wave that goes to infinity, similar to sin() or cos(), wavelets are a short "burst" of waves that rapidly fade away, similar to the picture underneath:

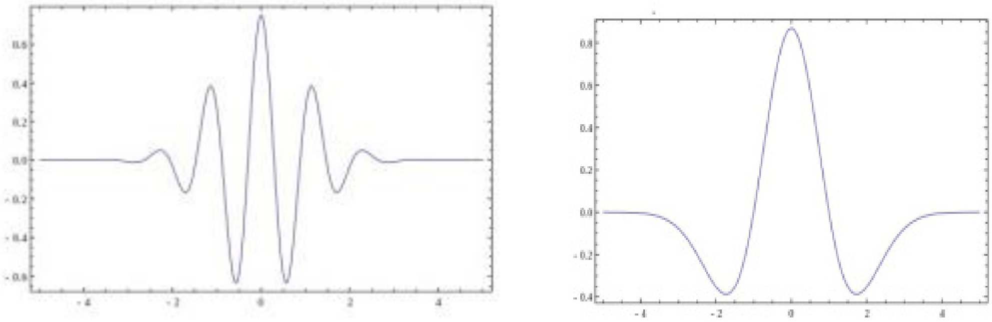

Figure 3.1. Wavelet waveform examples.

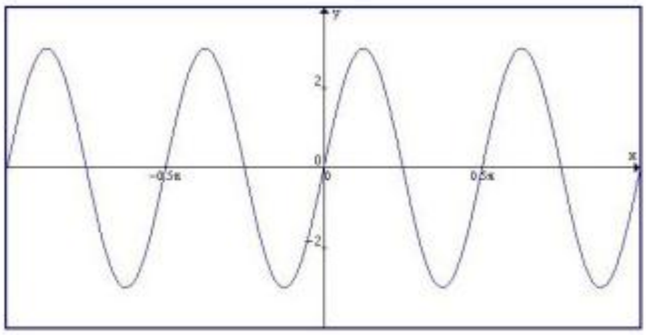

Figure 3.2. Sine wave going to infinity.

Because there are very few rules about what defines a wavelet, there are hundreds of different types. However they all take the form of a 'mini wave', fading to zero quickly.

3.3 FOURIER TRANSFORM AND HEISINBERG

3.3.1 Time, Frequency and Fourier Transform

In engineering, a signal is usually something you want to send or record. For instance it could be a clip of a voice recording, like the graph below:

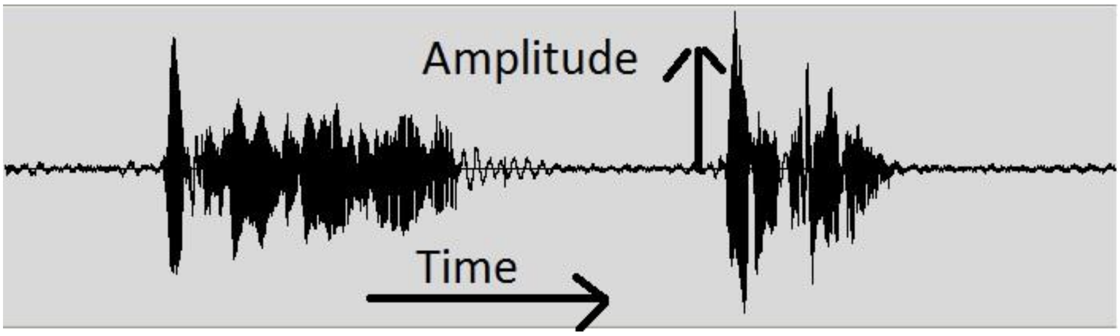

Figure 3.3. Voice signal time domain.

The picture of the voice is a signal in the time domain. This means that along the x-axis of this graph (left to right) is time, while on the y-axis (up and down) is the amplitude of the voice – how loud it is.

While plotting a signal in the time domain, it is often a nice way to visualize it a signal in the frequency domain. In the frequency domain, the signal's frequency of is on the x-axis, while the amplitude of the signal is still on the y-axis. Below, the bottom graph is a signal similar to the voice signal in the time domain. The line on the top graph is the same signal represented in the frequency domain. It's a summary of the signal's frequency over that time period.

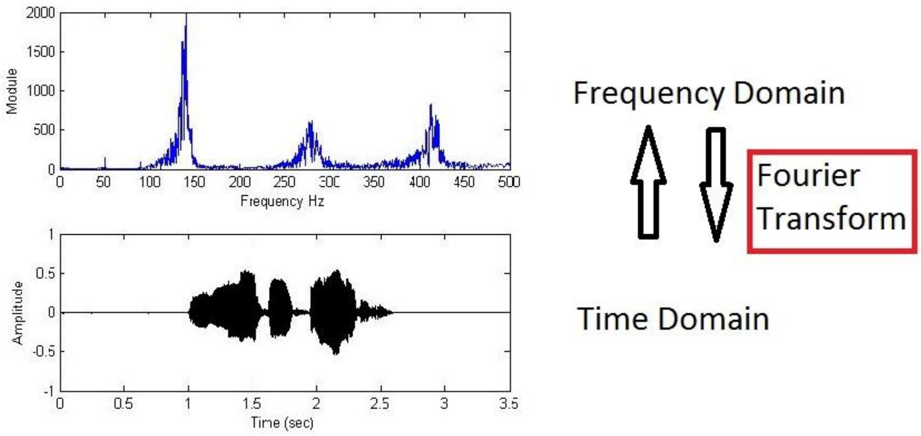

Figure 3.4. Fourier transform and inverse Fourier transform.

On the frequency graph, the three spikes would represent the low, medium and high tones of the voice. It's important to remember that the top graph only represents frequency and not time; it is merely another way of looking at the signal.

3.3.2 The Uncertainty Principle of Heisenberg

It so happens that a limitation of the Fourier Transform has to do with Heisenberg's Uncertainty Principle (which, as an Engineer, I am pretty uncertain about). In Physics the principle goes along the lines of: you can know where a particle is or how fast it is going, but not both. The process is a trade-off. If you want to become more certain about the position of the ball, you have to become less certain of the speed of the ball and vice versa.

The graph below is a representation of the uncertainty principle. The position of the ball is on the x-axis and the sped of the ball is on the y-axis. The red dot shows the actual speed and position on the graph, however you can see that it is surrounded by boxes. The boxes represent the uncertainty you have about each value.

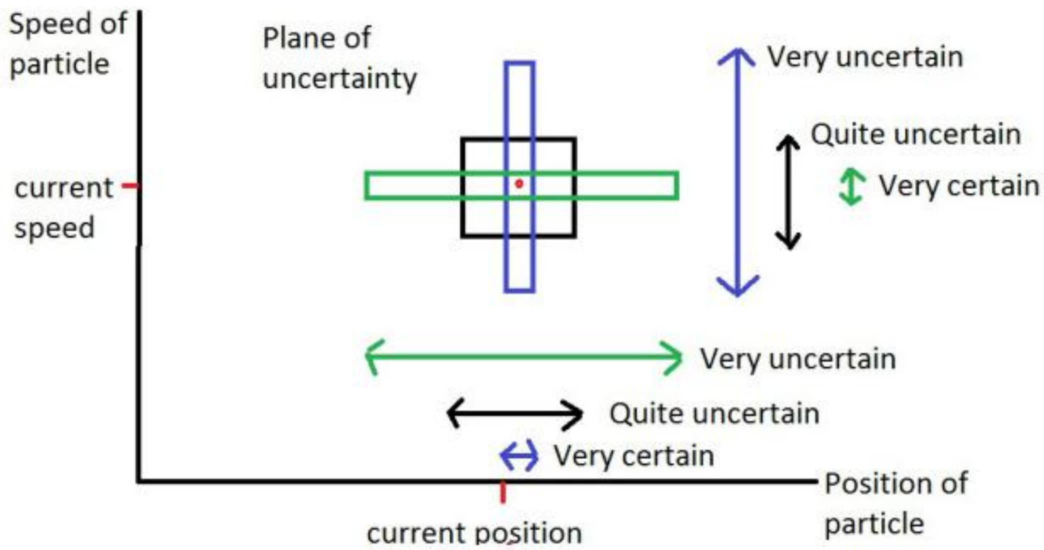

Figure 3.5:Uncertainity plane

Every box has the same surface. As the surface shows how uncertain you are about speed and position, it takes after that there is dependably a base measure of vulnerability in the estimation of both qualities. Case in point the blue box is tall and meager. The way that it is thin around the position of the ball shows that this estimation is really sure of the position. However to keep the case the same territory, it needs to extend along the y-pivot, showing that it is uncertain of the worth for the velocity.

This measure of uncertainty is additionally called resolution of the estimation.

The Fourier Transform has the same issue of determination. You can either make certain of the frequency or the time of a signal, yet not both. The chart beneath is the same as above, however with the frequency and time space supplanting the rate and position of the ball, as it helpful to consider it in the same way.

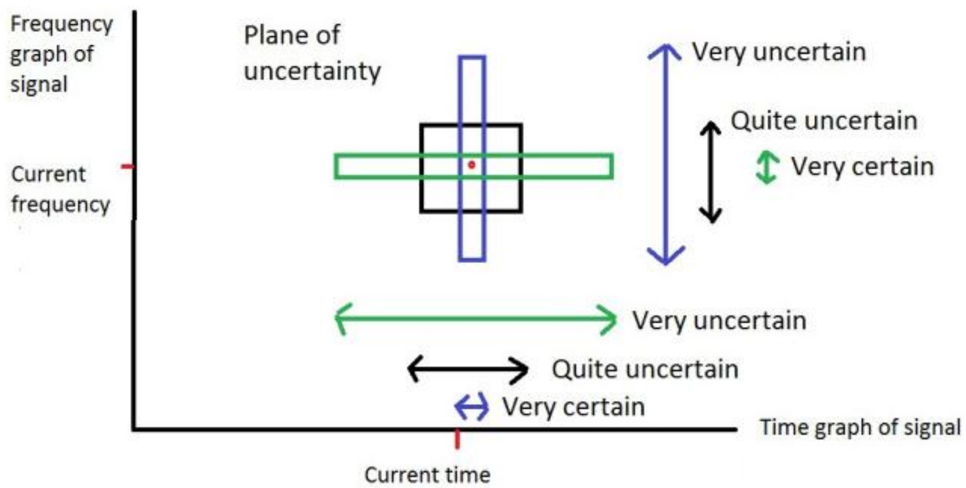

Figure 3.6. Fourier transform vs. uncertainty principle.

The issue with FT is when you are considering a real signal it would be helpful to know its instantaneous frequency. The instantaneous frequency is the exact and right frequency of a given signal at a precise minute/second in time. For example if I would like to know the exact frequency of a song tract at let’s say at “1 min 50.0423 seconds into the music track the sound is 1563.2 Hz”. Lamentably the Fourier Transform can't do this because that there exists a base measure of uncertainty between the frequency and time domains, as Heisenberg has a base measure of instability between the speed and position of a molecule (the boxes). You can know the minute/second in time you need to know the frequency for (blue box), but since there is a base uncertainty, the box of needs to extend crosswise over frequency, implying that you are uncertain of the frequency right then and there in time.

All you can do with a Fourier Transform is to test a scope (range) of time (for case, the time between 1 min 58 sec and 1 min 59 sec in a song) and discover a scope of frequencies that were played over that measure of time.

Instantaneous frequency may appear like a hypercritical issue in signal processing and frequently it is. Engineers have attempted to manage this issue with Fourier Transforms, however regardless they have the same issue.

3.3.3 Wavelet Transform and Wavelet Domain

The way we get the time and frequency components from the Fourier Transform is by decomposition of the signal (time domain) into a recipe of bunches of sin() and cos() terms added up. From that point a frequency diagram can be built.

Wavelet is a “scaled down wave or mini wave” while sin() and cos() are unbounded (they never go to zero and stay there till infinity). İn Fourier Transform the signal is deconstructed into waves that are endlessly long.

To overcome this issue a Wavelet Transform is utilized to deconstruct the signal into wavelets then those wavelets are added up together. Wavelets are more valuable they are constrained in time and frequency. Rather than a wavelet continuing on forever and having no restriction in time, it passes on rapidly.

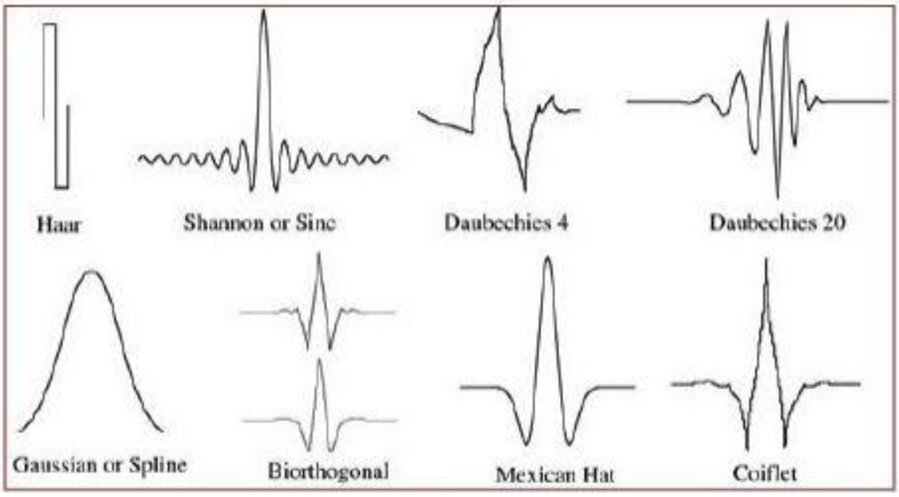

Figure 3.7. Examples of wavelet transform.

These waves are restricted in time, though sin() and cos() are not ; that they proceed for infinity. At the point when a signal is deconstructed into wavelets instead of sin() and cos () it is known as a Wavelet Transform. The diagram that can be broke down after the change is in the wavelet domain, instead of frequency domain.

This time restriction quality about wavelets is helpful to Engineers as it gives more resolution in the time domain. Rather than using an infinity wave, it is conceivable to model with a limited wave which you can "slide" along to time space. The capacity to slide the signal is what gives engineers a more exact representation of the signal and thus a better resolution in time.

How do wavelets handle low and high frequencies? For high frequencies a sin() wave gets squished together and for low frequencies the wave gets extended. The same goes for wavelets. This is taken care of by something many refer to as the scale of the wavelet. The photo underneath demonstrates the same wavelet at diverse scales:

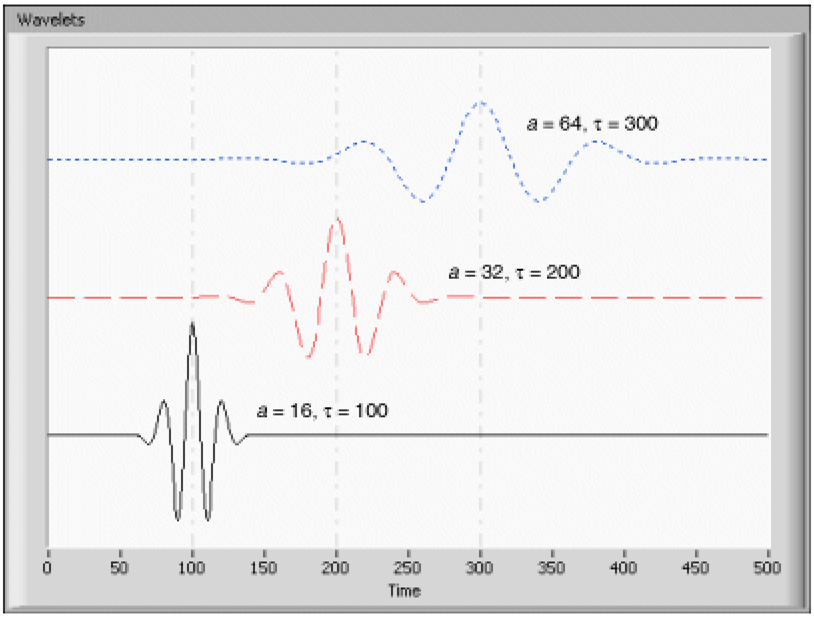

Figure 3.8. Wavelet equivalents of low, medium and high frequencies.

So when you utilize a Wavelet Transform the signal is deconstructed utilizing the same wavelet at distinctive scales, rather than the same sin() wave at diverse frequencies. As there are many distinctive wavelets, there are several distinct changes that are conceivable and consequently several unique domain. However every domain has “scale” on the x-axes instead of 'frequency', and gives better resolution in the time domain.

Engineers have begun data compression, image processing and noise reduction utilizing wavelets instead of frequencies. As a rule the Fourier Transform is what is known and favored, yet in specific circumstances a Wavelet Transform can outflank it. The detriment of Fourier development is, it has either frequency resolution or a time resolution. That implies, despite the fact that it is conceivable to focus every one of the frequencies of a signal; it’s impractical to have some information about them (like when they are suitable). To surpass this issue wavelets could be utilized. To understand how a wavelet decomposition can be constructed, analysis will be present the concept of a multiresolution.

3.4 MULTIRESOLUTION ANALYSIS

A multiresolution analysis (MRA) gives a system to analyze function at diverse scales. A multiresolution analysis is defined according to Mallat as:

A chain of nested closed subspaces, $\{Vj, j \in Z\}$ which satisfy the conditions below:

1. The spaces have trivial intersection:

   $f(x)_{j\in Z} \cap V_j = \{0\}$

2. The union is dense in $L^2(R)$:

   $f(x)_{j\in Z} \cup V_j = L^2(R)$.

3. The following scale relations exist:

   $$f(x) \in V_j \Leftrightarrow f(2x) \in V_{j+1}. \quad (3.1)$$

   $$f(x) \in V_0 \Leftrightarrow f(x - k) \in V_0,\ k \in Z. \quad (3.2)$$

4. There exists a function $\varphi(x) \in V_0$ such that the sequence $\{\varphi(x - k), k \in Z\}$ is an orthonormal basis of V_0.

In equations 3.1 and 3.2 imply (referring on the conditions given) $\{\varphi_{jk}, k \in Z\}$ is an orthonormal basis of V_j. Since $V_0 \subset V_1$, the function $\varphi(x) \in V_0$ can be represented as a linear combination of the functions from V_1 and so

$$\varphi(x) = \sum_{k\in Z} h_k \sqrt{2}\varphi(2x - k),$$

where h_k represents the coefficients,(where $k \in Z$), the indices k is called low pass filter.

The function $\varphi(x)$ is referred to as *scaling function or the father wavelet*.

In the case of MRA, we can define a *mother wavelet, ψ(x),* which will be use to explain the detail coefficients at each level j. Let W_j be the detail space to be the orthogonal complement of V_j in V_{j+1}, so that

$$V_{j+1} = V_j \oplus W_j.$$

Then $\{\psi(x - k), k \in Z\}$ forms an orthonormal basis for W_0, orthogonal to all functions in V_j . Since $\psi(x) \in V_1$, the function ψ(x) can similarly be represented as a linear combination of the functions from V_1.

$$\psi(x) = \sum_{k\in Z} g_k \sqrt{}\, 2\varphi(2x - k).$$

Here g_k represents the coefficients, $k \in Z$ are called the high pass filter. For final result of the Multiresolution conditions, $f(x) \in W_0 \Leftrightarrow f(2_j x) \in W_j$ and so $\{\psi_{jk}(x)\}$ is an orthonormal basis for W_j and so $\psi_{jk}(x) = 2^{j/2\psi}(2^j x - k), j, k \in Z$

3.5 WHAT IS WAVELET?

Wavelets are basis function which have the ability to represent a signal in both time and frequency domain together. They can be used for approximation like FT. The upside of wavelets is, they are limited in time and frequency reason why they could deal with a more extensive scope of signal compared to FT. A downside of wavelets is t, the wavelet transform can represent a signal at a discrete number of resolution levels. A wavelet basis is formed by dilating and translating a function the mother wavelet (ψ).

We could define mother wavelet (Meyer) as:

Let $m \in N$. Then for $x \in R$, a function ψ(x) is called a mother wavelet of order m if the the properties below are respected:

1. If $m = 0$, $\psi(x) \in L\,\infty(R)$. If $m \geq 1$, then ψ(x) and all its derivatives up to order m belong to $L\,\infty(R)$.

2. ψ(x) and all its derivatives up to order m decrease rapidly as $x \to \pm\infty$.

3. For each $k \in \{0, \ldots, m\}$,

$$\int_{-\infty}^{\infty} x^k \psi(x)dx = 0$$

4. The collection $\{\psi_{j,k}\}_{j,k \in Z}$ forms an orthonormal basis of $L^2(R)$, the $\psi_{j,k}$ being constructed from the mother wavelet using $\psi_{j,k}(x) = 2^{j/2}\psi(2^j x - k)$.

3.6 MOST USED WAVELET BASES

As explained above it is possible to get hundreds different types of wavelets and each of them having its own domain. But in this section we will focus only on the most 4 used wavelets: Haar wavelet, Daubechies 4 and 20, Gaussian, Shannon or sine, Biorthogonal and Mexican hat.

3.6.1 Haar Wavelets

Considered as the simple wavelet basis, the Haar basis, is formed from scaling & dilating the mother wavelet function. The Haar basis is shown in Figure 3.9 below.

$$\psi(x) = \begin{cases} 1 & x \in (0,1) \\ 0 & x \notin (0,1) \end{cases}, \quad \phi(x) = \begin{cases} 1 & x \in [0, 0.5) \\ -1 & x \in [0.5, 1) \\ 0 & \text{otherwise} \end{cases}$$

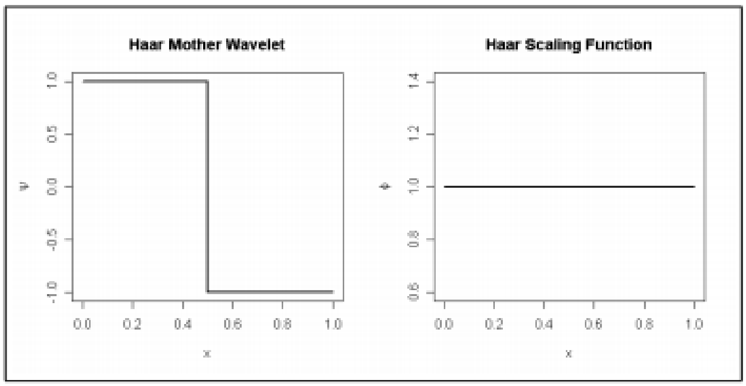

Figure 3.9. Haar mother wavelet & scaling function.

3.6.2 Meyer Wavelet Bases

In the frequency domain:

$$\widehat{\psi}(x) = \begin{cases} (2\pi)^{-\frac{1}{2}} & |x| \leq \frac{2\pi}{3} \\ (2\pi)^{-\frac{1}{2}} \cos\left[\frac{\pi}{2}\nu\left(\frac{3}{2\pi}|x| - 1\right)\right] & \frac{2\pi}{3} \leq |w| \leq \frac{4\pi}{3} \\ 0 & \text{otherwise} \end{cases}$$

where *v* is the smooth function.

$$\nu(x) = \begin{cases} 0 & x \leq 0 \\ 1 & x \geq 1 \end{cases}$$

with $\nu(x) + \nu(1 - x) = 1$.

The wavelet is of the form:

$$\widehat{\psi}(x) = \sqrt{2\pi} e^{\frac{ix}{2}} [\widehat{\phi}(x + 2\pi) + \widehat{\phi}(x - 2\pi)] \widehat{\phi}\left(\frac{x}{2}\right)$$

3.6.3 Daubechies Wavelets

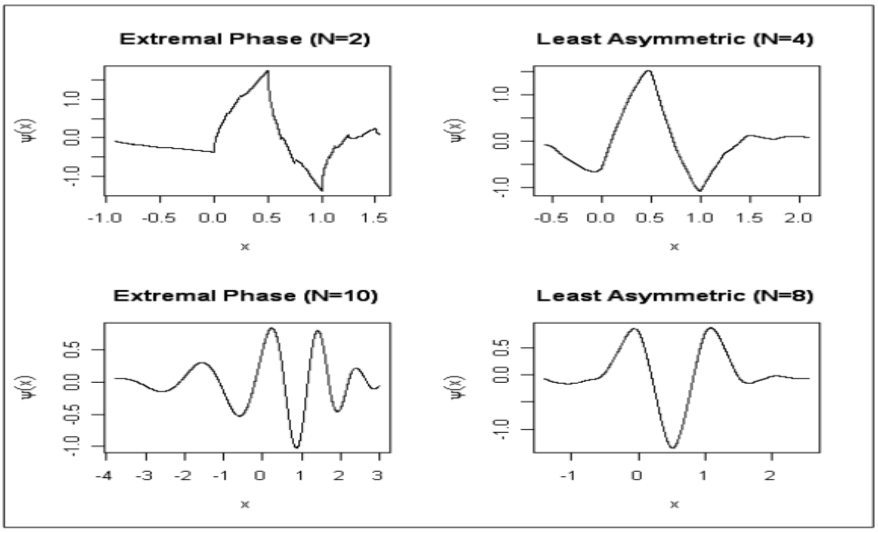

Figure 3.10. Daubechies family mother wavelets.

3.7 DISCRETE WAVELET TRANSFORM

The discrete wavelet transform (DWT) is a productive algorithm for computing the wavelet coefficients of a discrete arrangement. The thought is channel the arrangement, utilizing the low and high pass filters connected with the wavelet basis to get the wavelet coefficients.

high pass filter G = $\{g_k\}$,

low pass filter H = $\{h_k\}$

g_k and h_k represent the filters's coefficients.

Let a function f set at $N = 2^J$ equally spaced time points $\{t_i , i = 0, . . . N - 1\}$. Let $c_{J,i} = f(t_i)$ for $i = 0, . . . , N - 1$. We can get the discrete wavelet transform of the series with:

$$\begin{aligned} c_{j-1,i} &= \sum_n h_{n-2i} c_{j,n} \\ d_{j-1,i} &= \sum_n g_{n-2i} c_{j,n} \end{aligned}$$

The subsequent wavelet change is the gathering of the subtle element coefficients at every level together with the smooth or father coefficient at the zero level.

3.8 INVERSE WAVELET TRANSFORM

Consider the WT as a matrix multiplication; the orthogonal matrix can be inverted to find the inverse transform., The Level of the mother and father coefficients are used to reconstruct the next finer level, after obtaining the inverse transform. The formula is as followed:

$$c_{j,k} = \sum_l h_{k-2l} c_{j-1,l} + \sum_l g_{k-2l} d_{j-1,l}.$$

The reconstruction is achieved by iterating this process and climbing the resolution levels back to the original data.

CHAPTER 4

CASES STUDIES FOR PQ DISTURBANCES

4.1. INTRODUCTION

The aim of power system is to supply energy or power to customer. Non linear loads, utility switching and fault clearing produce disturbances that affect the quality of this delivered power. Power quality means the quality of the normal voltage supplied to our homes, factories etc. It is based on the extent of variation of the voltage and current waveform from the ideal pure sinusoidal waveforms of fundamental frequency.

4.2. VOLTAGE SAG

Simple sag generator could be the product of two signal, e.g., check the figure below:

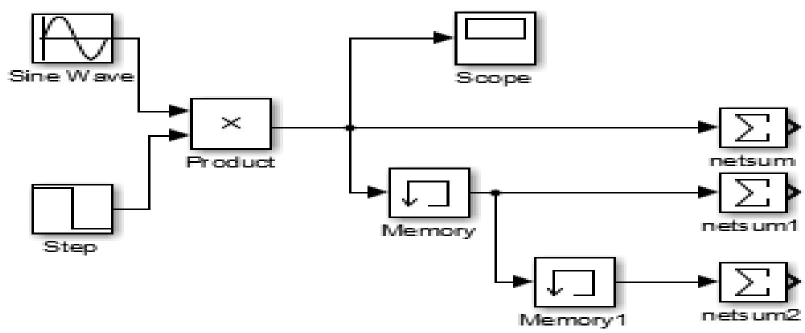

Figure 4.1. Simple sag generator.

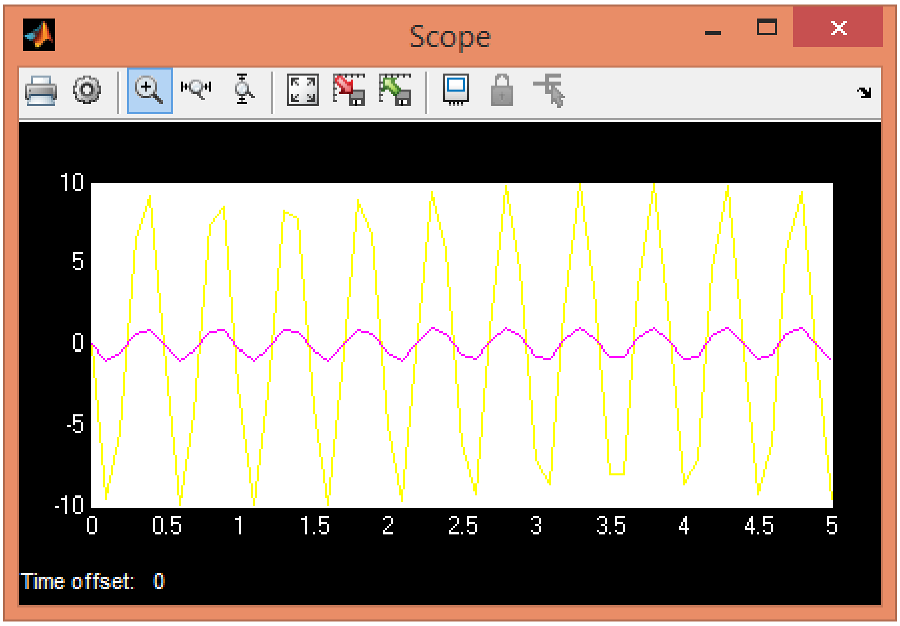

Figure 4.2. Simple sag generator output.

As you can see by taking the cross product of a simple sine function and a step function, we are able to obtain an output which behave exactly as voltage sag.

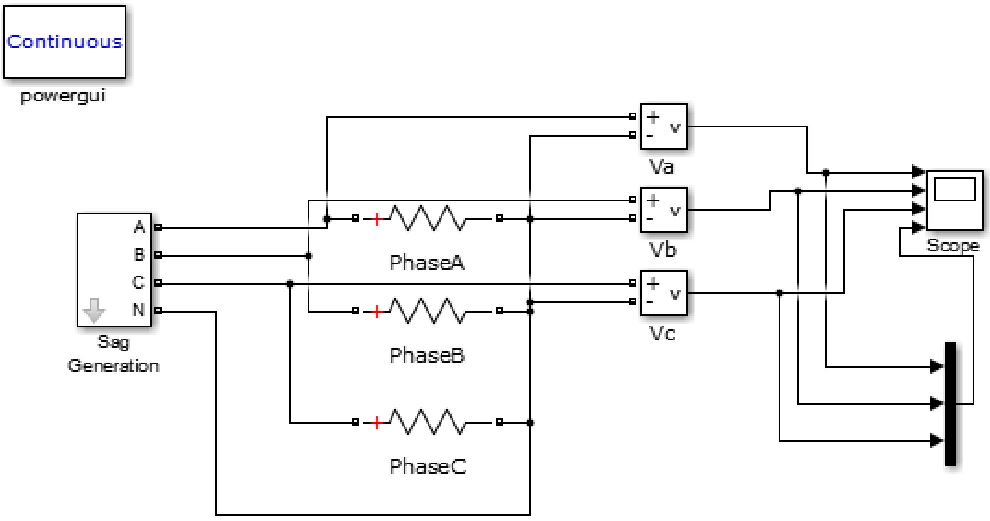

Figure 4.3. Voltage sag generator.

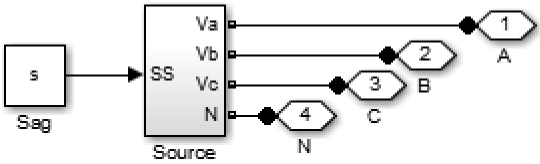

Figure 4.4. Subsystem of sag generator.

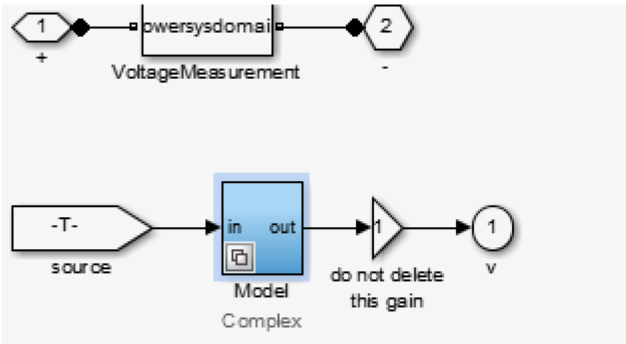

Figure 4.5. Subsystem of V_a, V_b, V_c.

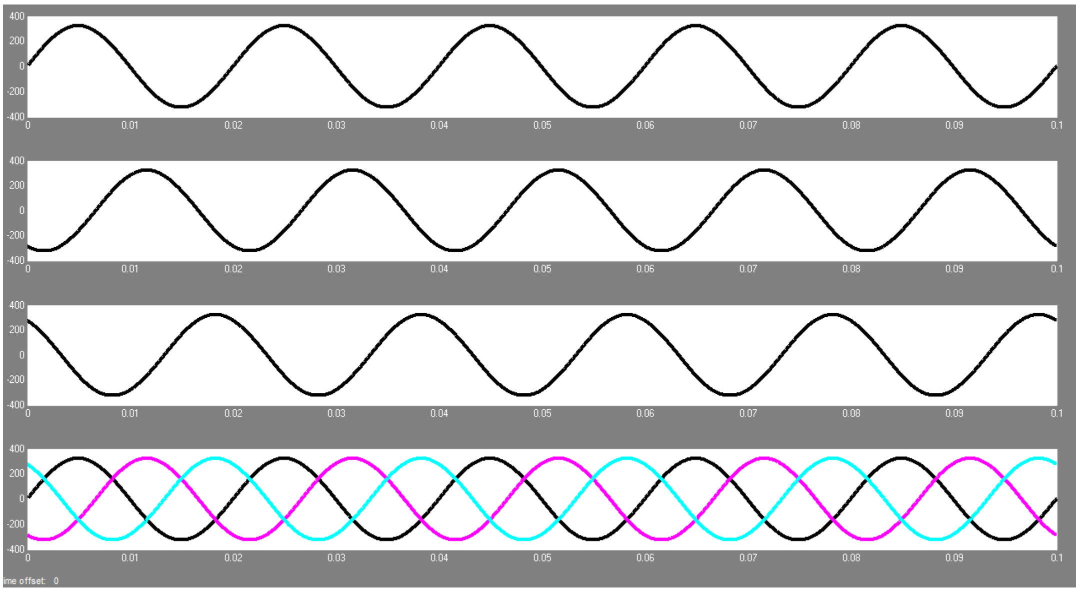

Figure 4.6. 3 phase waveform, same amplitude.

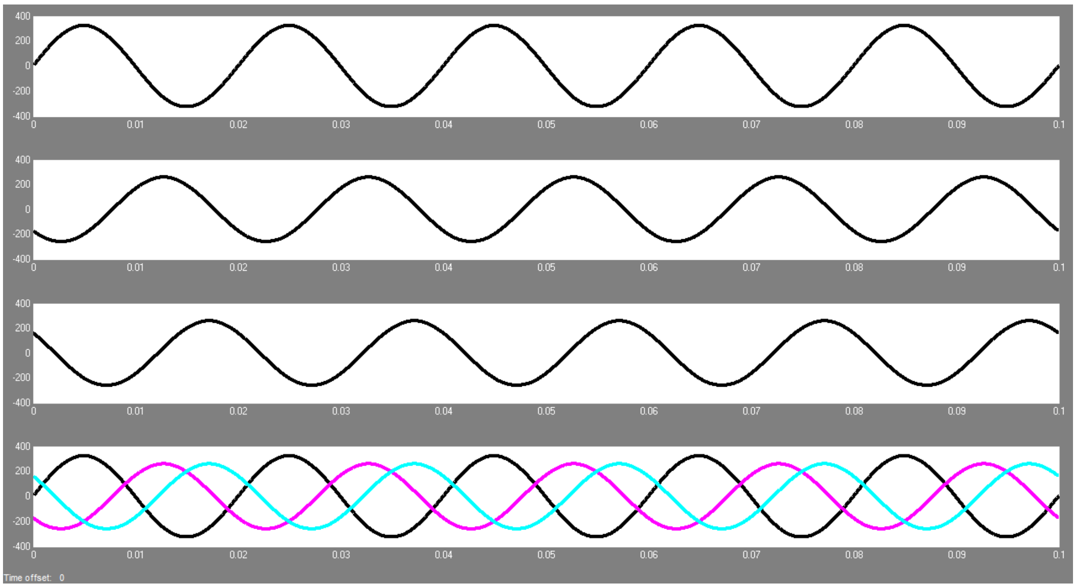

Figure 4.7. 3 phase waveform sag on phases B and C.

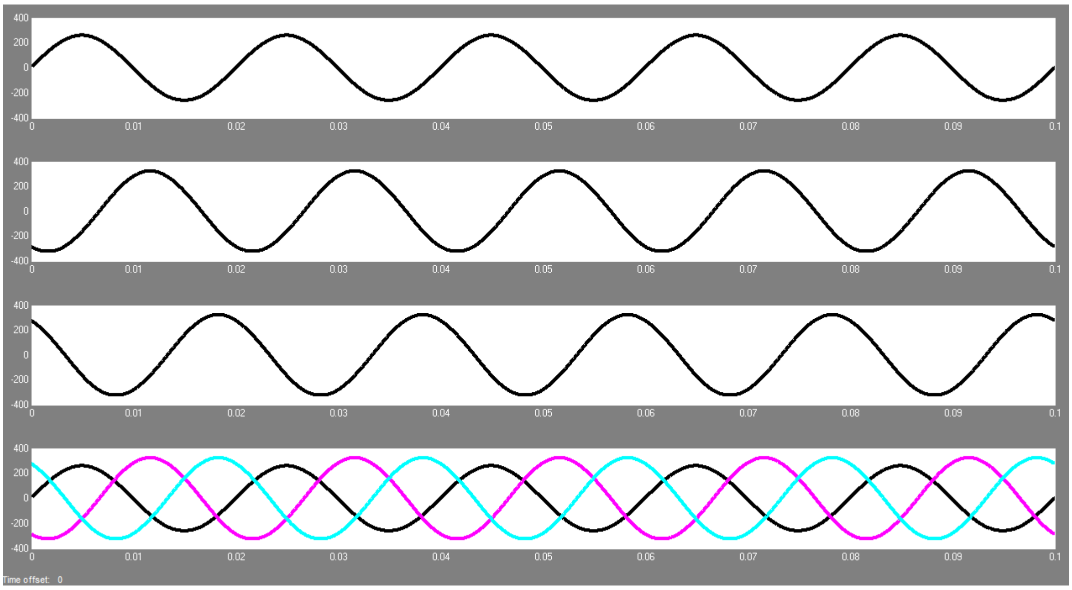

Figure 4.8. 3 phase waveform sag on phases A.

4.3. VOLTAGE SAG THEORETICAL CALCULATION

Voltage sag could be characterized in identifying and measuring the most applicable parameters of the disturbances, like: magnitude, phase-angle jump, duration, and waveform.

Voltage sag relies on upon deficiency clearing time gave by the electrical security in power system. It could be dictated by reproducing electrical protection conduct while managing disturbances in the system.

Phase-angle jump and magnitude are related to the fault line impedance and location. Their values could be found by simulation (system fault) at each nodes of a system.

Voltage profile shape is another trade mark. Non-rectangular sags are shown by demonstrating and recreating the starting of huge induction engines in power system.

It is possible to represent a voltage sag with a function

$$v(t) = \begin{cases} V_p sin(\omega t) if t < t_1 \\ V_{psag} sin(\omega t + \phi) if t_1 < t < t_2 \\ V_p sin(\omega t)\ if\ t > t_2 \end{cases}$$

Where

t_1: Time of sag initiation

V_{pgas}: Peak voltage during the sag

t_2: Time of voltage recovery

$\Delta t = t_1 - t_2$: Duration (8,33 ms<Δt< min)

V_p: Peak pre-fault voltage

Φ: Phase-angle jump

ω: Angular frequency

RMS value is found from the sine wave voltage

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{i=k} v_i^2}$$

v_i: Sampled voltages in time domain

N: Number of samples per cycle

In the simulations we used N = 256 samples per 60 Hz cycle the sample frequency 15,36 kHz.

4.4 THEORETICAL CALCULATION OF THE MAGNITUDE

The Fig 4.9 below is a basic model for calculating the magnitude of voltage sag during a three-phase fault on a radial system.

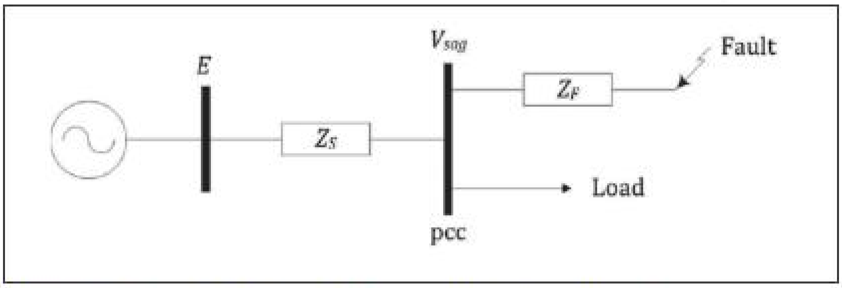

Figure 4.9. Voltage divider diagram voltage sag calculation.

Considering the current flowing in the load (before & during the fault) is negligible, the voltage would be:

$$V_{sag} = \frac{Z_F}{Z_S + Z_F} E$$

where

E: Source voltage

Z_S: Source impedance (the source - PCC)

Z_F: Feeder impedance (PCC - the fault point)

4.5 THEORETICAL CALCULATION OF PHASE-ANGLE JUMP

The voltage divider diagram in figure fig 4.9 could be used for phase-angle jump theoretical analysis. All we have to consider in that calculation are Z_S and Z_F as complex quantities.

The voltage source (per-unit calculation) E = 1, with $Z_S = R_S + jX_S$ and $Z_F + jX_F$. The Phase angle of Vsag, equivalent to the phase-angle jump is;

$$\bar{V}_{sag} = \frac{\bar{Z}_F}{\bar{Z}_S + \bar{Z}_F}$$

If $(X_S / R_S) = (X_F / R_F)$, $\Delta\Phi$ is automatically zero so no phase-angle jump. So we can conclude that we would have a phase angle jump if and only if the ratio X/R source is not the same as feeder ratio.

$$\Delta\phi = arg(\bar{V}_{sag}) = arctan\left(\frac{X_F}{R_F}\right) - arctan\left(\frac{X_S + X_F}{R_S + R_F}\right)$$

4.6 VOLTAGE FLICKER

Power-line flicker is an obvious change in brilliance of a light because of quick changes in the voltage of the force supply. The voltage drop is created over the source impedance of the network by the changing load current of a device. These oscillations in time produce flash or flicker. The impacts can extend from unsettling influence to epileptic assaults of photosensitive persons. Glimmer might likewise influence delicate electronic hardware, for example, TV recipients or modern procedures depending on steady electrical power.

Here is a general waveform of a flicker:

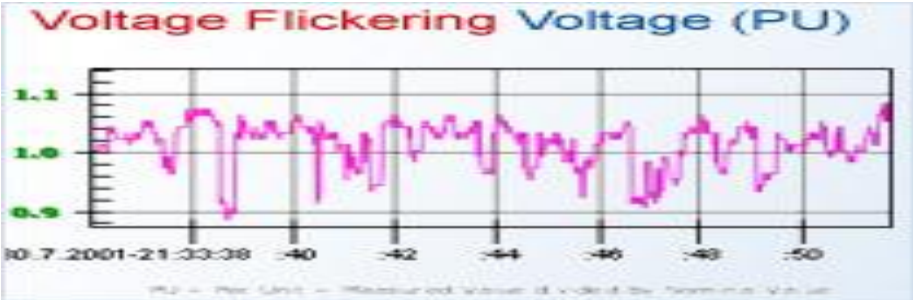

Figure 4.10. Voltage flicker.

In my thesis to simulate the voltage effect I used this code below:

```
function example_phase_control

% In this example the impact of different load switching methods is examined.
% The impaired line voltage signal is generated for the following
% scenarios:
% - hard swichting
% - soft switching using phase control with linear angle sweep
% - soft switching using phase control with non-linear angle sweep

clear variables

%% Configuration

U_LINE = 230;  % line voltage in Volts
F_LINE = 50;   % line frequency in Hz
FS     = 1000;  % sampling frequency in Hz
POWER = 1000;  % load in W

RAMP_LENGTH        = 1;  % in sec
SWITCHING_INTERVAL = 3;  % in sec
NUMOF_CYCLES       = 10; % number of switching cycles to simulate
```

```
CONST_LENGTH = SWITCHING_INTERVAL - RAMP_LENGTH;

FIGURE_TAG = 'example_phase_control';

%% Preparations

% one switching cycle consists of an OFF level phase, a rising ramp, an ON
% level phase and a falling ramp
cycle_ctrl = [...
  zeros(1, CONST_LENGTH * FS), ...
  linspace(0, 1, RAMP_LENGTH * FS), ...
  ones(1, CONST_LENGTH * FS), ...
  linspace(1, 0, RAMP_LENGTH * FS)];
ctrl = repmat(cycle_ctrl, 1, NUMOF_CYCLES);

%% Get or create browser figure handle
h_figure = findobj(0, 'Tag', FIGURE_TAG);
if (isempty(h_figure))
  h_figure = figure;
  set(h_figure, 'Tag', FIGURE_TAG);
end
figure(h_figure);
clf(h_figure);

%% Hard switching

p = (ctrl > 0.5) * POWER;
[u, fs, du] = power_to_line_voltage(p, FS, U_LINE, F_LINE);

Pst = flicker_sim(u, fs, F_LINE);

figure(h_figure)
subplot(3, 1, 1, 'parent', h_figure);
t = [0 : length(du) - 1] / fs;
plot(t, du, 'b', 'linewidth', 1)
hold on
t = [0 : length(p) - 1] / FS;
plot(t, double(p > 0), 'r', 'linewidth', 3)
set(gca, 'xlim', [0, 2 * SWITCHING_INTERVAL]);
grid on
title(sprintf('Example: No Power Pulse Shaping (Hard Switching)\nPst = %.2f', Pst))
xlabel('Time [sec]')
ylabel('Red: Power Level, Blue: Voltage drop [V]')

%% Phase control (linear angle mode)

[u, fs, du, rel_pow] = power_to_phase_control_line_voltage(ctrl, POWER, FS,
U_LINE, F_LINE, 'lin_angle');

Pst = flicker_sim(u, fs, F_LINE);
```

```
figure(h_figure)
subplot(3, 1, 2, 'parent', h_figure);
t = [0 : length(du) - 1] / fs;
plot(t, du, 'b', 'linewidth', 1)
hold on
plot(t, rel_pow, 'r', 'linewidth', 3)
grid on
set(gca, 'xlim', [0, 2 * SWITCHING_INTERVAL]);
title(sprintf('Example: Power Pulse Shaping using Phase Control (Linear Angle)\nPst =
%.2f', Pst))
xlabel('Time [sec]')
ylabel('Red: Power Level, Blue: Voltage drop [V]')

%% Phase control (linear power mode)

[u, fs, du, rel_pow] = power_to_phase_control_line_voltage(ctrl, POWER, FS,
U_LINE, F_LINE, 'lin_power');

Pst = flicker_sim(u, fs, F_LINE);

figure(h_figure)
subplot(3, 1, 3, 'parent', h_figure);
t = [0 : length(du) - 1] / fs;
plot(t, du, 'b', 'linewidth', 1)
hold on
plot(t, rel_pow, 'r', 'linewidth', 3)
grid on
set(gca, 'xlim', [0, 2 * SWITCHING_INTERVAL]);
title(sprintf('Example: Power Pulse Shaping using Phase Control (Linear Power)\nPst =
%.2f', Pst))
xlabel('Time [sec]')
ylabel('Red: Power Level, Blue: Voltage drop [V]')
```

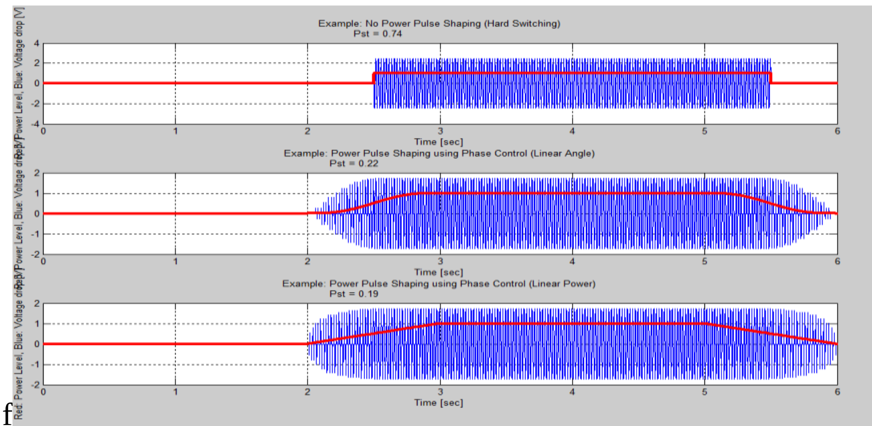

Figure 4.11. Voltage flicker output.

4.7 TRANSIENTS

In electrical engineering, oscillation is an impact brought on by a transient reaction of a circuit or the system. It is a transitory event going before the steady state causing a sudden change of a circuit.

Transient is a momentary (short time) of burst of energy in a circuit created by a sudden change of state.

The causes could be within the circuit itself or due to a close-by event. That disturbed event is what appear as (dying quick) oscillation.

Here is what it could looks like:

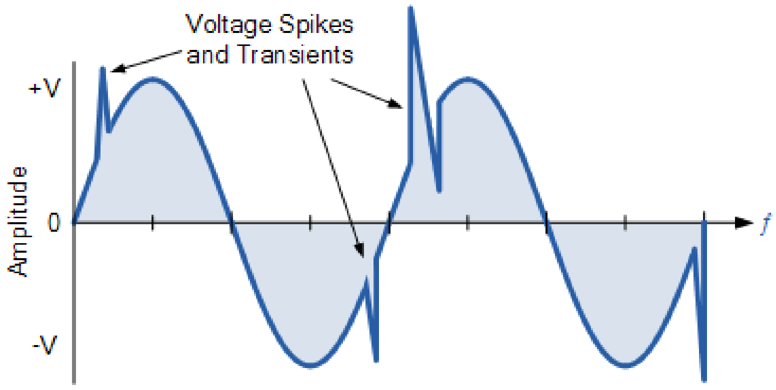

Figure 4.12. Waveform of voltage spike

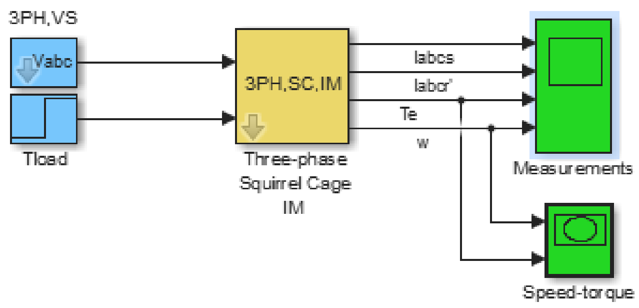

Figure 4.13. Model of a 3 phase squirrel induction motor.

Here is what lies behind the 3 phase VS Mask:

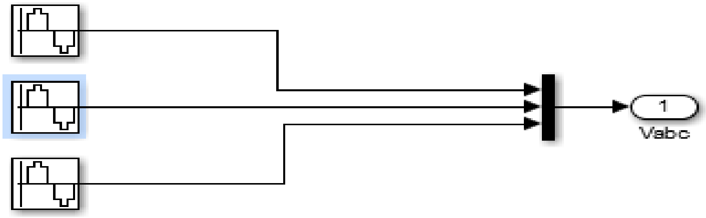

Figure 4.14. Schematic of 3 phase voltage source.

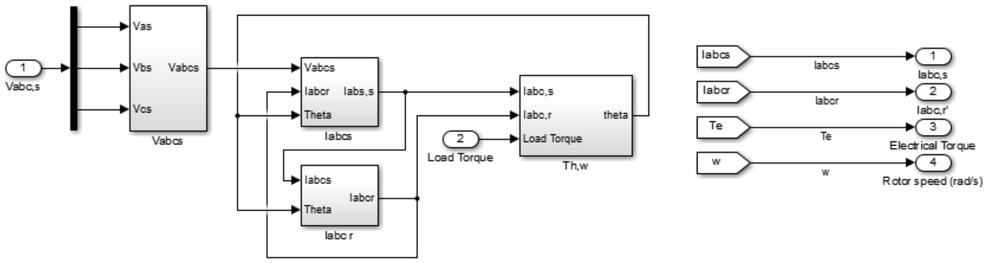

Figure 4.15. Schematic of 3 phase squirrel cage.

Simulation result:

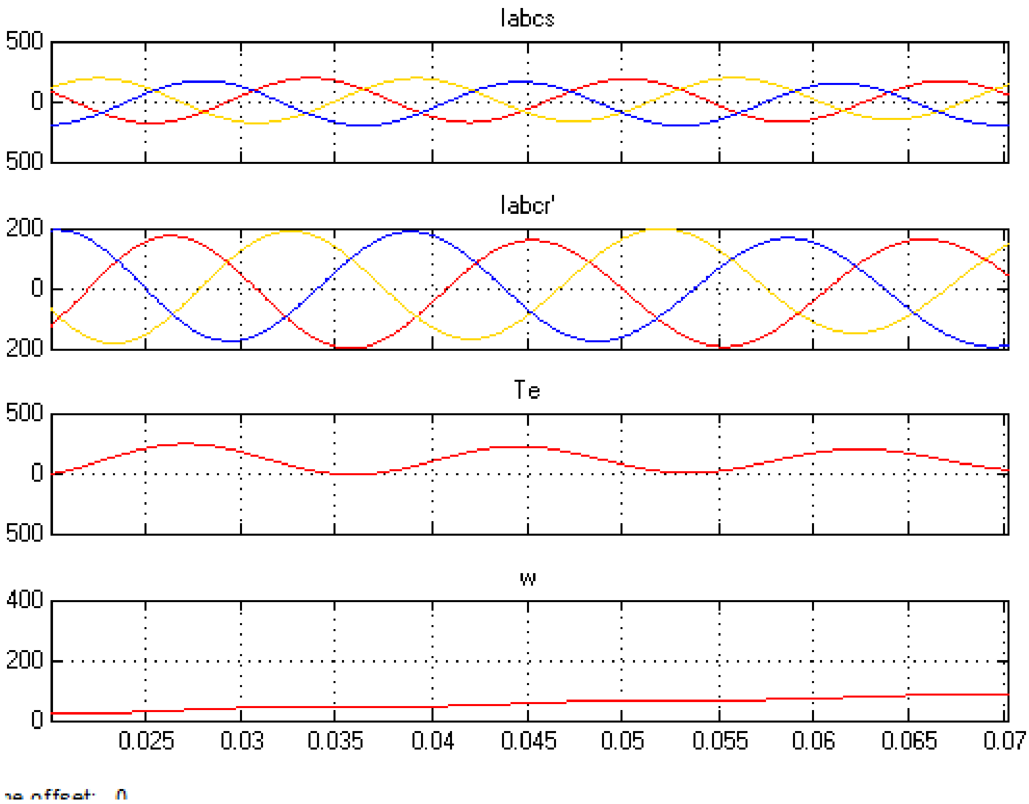

Figure 4.16. Line voltage.

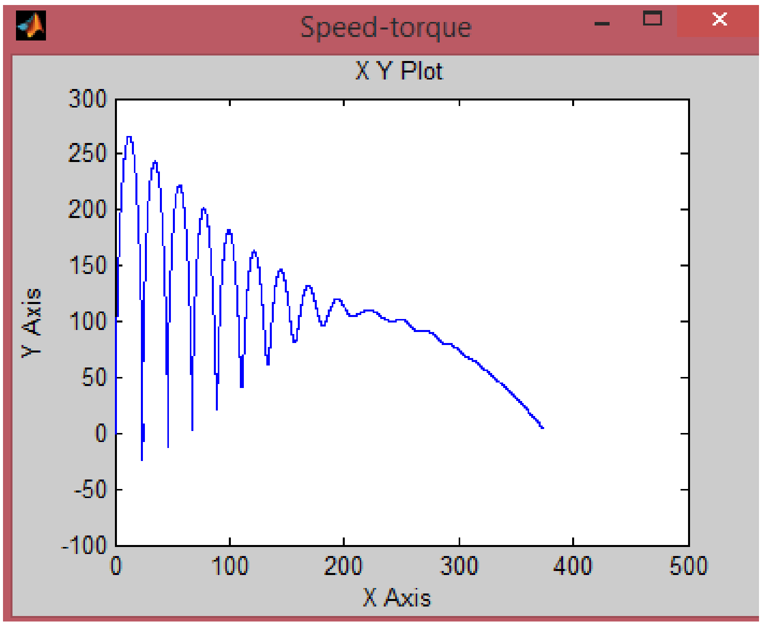

Figure 4.17: Transients torque.

4.8 HARMONICS

Harmonic is a kind of periodic movement where the restoring force is directly proportional to the displacement and acts in the inverse to that of displacement. Simple harmonic are as mathematical tools for oscillating spring etc.

Here is an example of what it looks like:

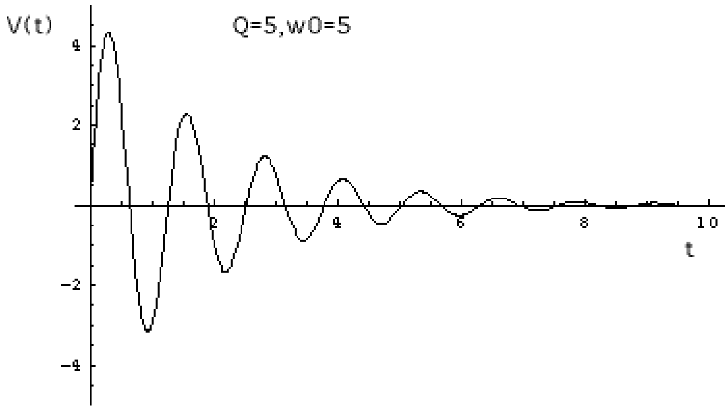

Figure 4.18. Simple harmonic.

Here is what I use for my simulation (designed by):

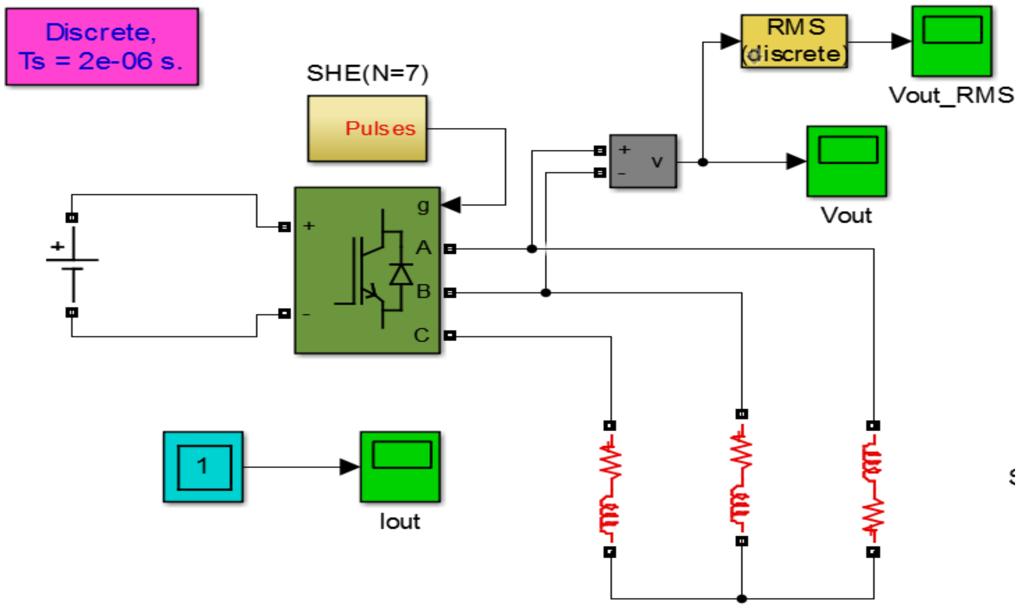

Figure 4.19. Simulink Circuit Harmonics

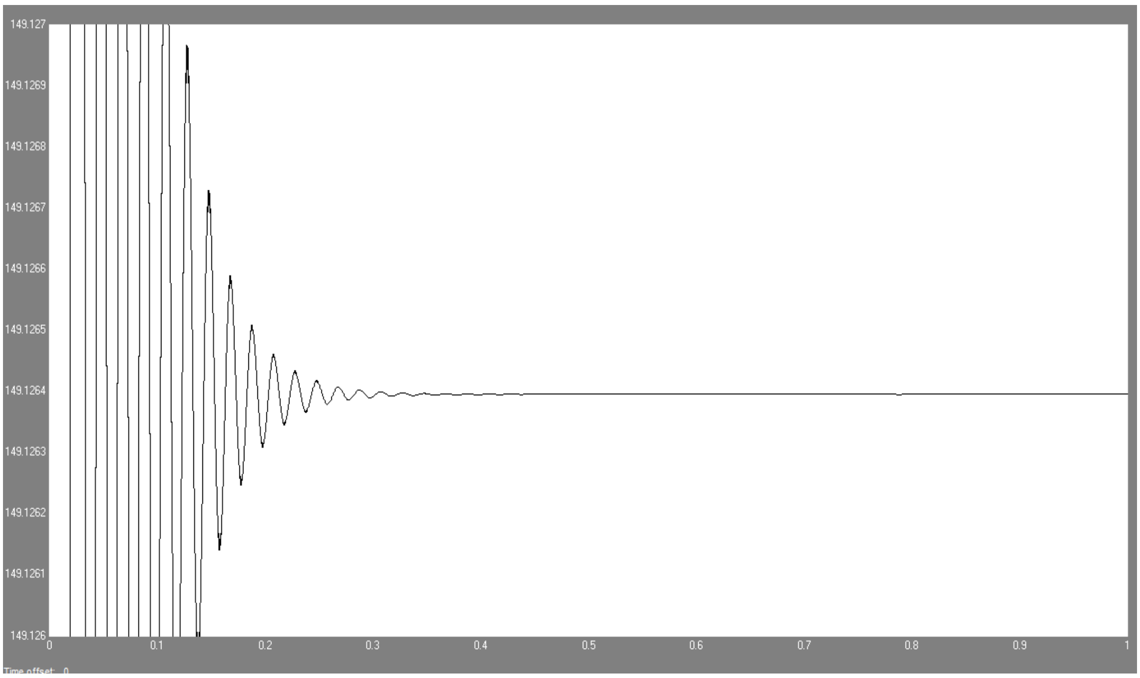

Figure 4.20. Output Waveform of the circuit the fig4.1

CHAPTER 5

WAVELET SIMULATION

5.1 INTRODUCTION

The WT is the representation of a signal as the addition of mini waves at diverse positions and duration. More precisely it is a signal representation as sum of mini waves at differ locations and differ scales. To represent the signal we use the wavelets coefficients. They are mainly 3 type groups of wavelets

1. . Continuous Wavelet Transform (CWT)
2. The Wavelet Series (WS)
3. Discrete Wavelet (DWT),

5.2 DISCRETE WAVELET TRANSFORM

DWT is used to obtain the representation of a signal in both frequency and time. It ıs an exceptionally tool for analyzing time series because of its properties to give a precise information of a signal in the frequency and time components. Contrary to Fourier analysis which is mostly based on stationary notion and which can’t give the information in both time and frequency, actual engineers in PQ need a tool which could surpass the FT. .That is where comes the DWT , suitable than FT. The objective of multiresolution is to create representation of a signal at different levels of resolution. Multiresolution is made out of 2 filters a low pass and a high pass filter at every single step. Multiresolution recognizes and analyzes problems , give early cautioning of PQ problems. Power quality issues are portrayed by:

5.2.1 How to choose a Mother Wavelet

Decision of examining mother wavelets assumes a noteworthy part in recognizing different sorts of force quality unsettling influences. Particularly when considering little scale signal disintegrations. For quick and short transient aggravations, Db4 and Db6 wavelets are mostly used, while for transient unsettling influences, Db8 and Db10 are especially favorable. Determination of a suitable mother wavelet for a wide range of PQ issues is vital, rather than making calculations to choose diverse proper wavelets for distinctive issues

The mother wavelet is limited both in time , wavers most quickly inside of a brief time of time., The breaking down wavelets turn out to be less confined in time and sway less because of the enlargement way of the wavelet change examination if the wavelet levels is higher. As an aftereffect of higher scale signal deterioration, quick and short transient aggravations is going to be identified at smaller levels, while moderate and long transient unsettling influences will be recognized at higher scales.

5.3 APPLICATION RESULT

5.3.1 Notch

Using wavemenu;

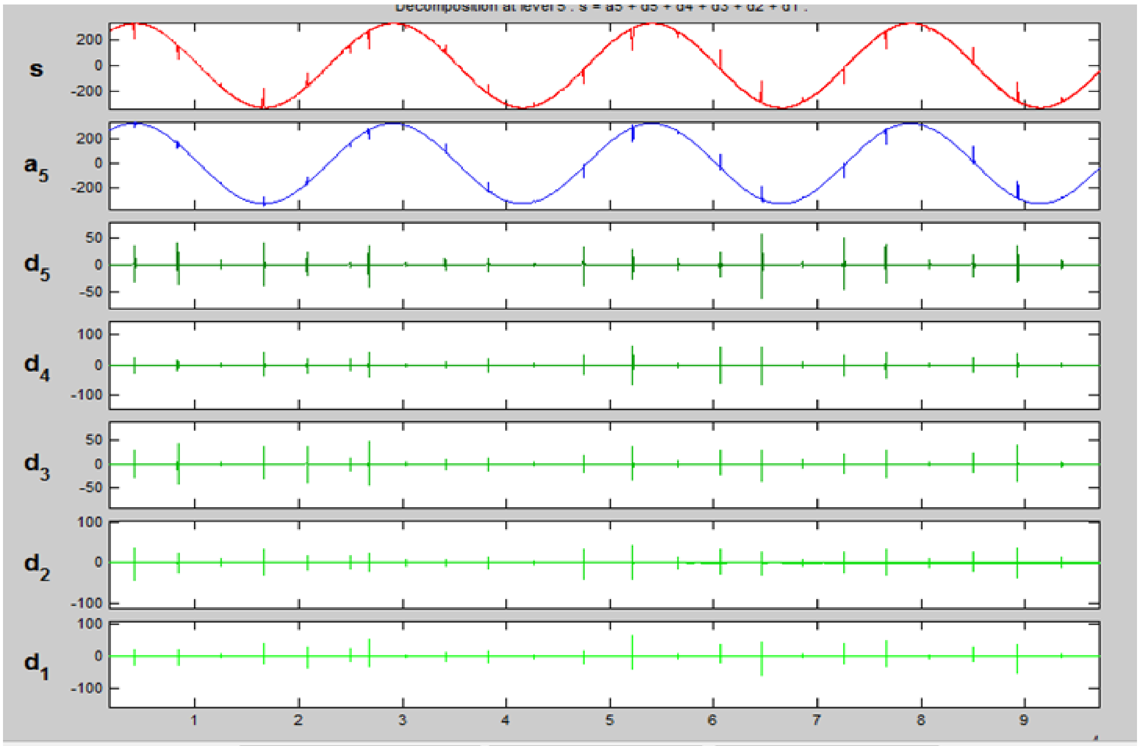

Figure 5.1. Signal Disturbances detection for periodic notch signal Daub4 scale 5.

The detail coefficients and the approximated coefficients can be seen on the fig above. Because we are dealing with frequency signal the WT for the detail coe shows the disturbances.

code: Using haar wavelets

```
s = notch(1:10);
l_s = length(s);
[cA1,cD1] = dwt(s,'db1');
B1 = upcoef('a',cB1,'db1',1,l_s);
C1 = upcoef('d',cC1,'db1',1,l_s);
```

```
subplot(1,2,2); plot(C1); title('Detail C1')
subplot(1,2,1); plot(B1);
 title('Approx B1')
B0 = idwt(cB1,cC1,'db1',l_s);
err = max(abs(s-B0));
[F,L] = wavedec(s,3,'db1');
cB3 = appcoef(F,L,'db1',3);
cB3 = detcoef(F,L,3);
cC2 = detcoef(F,L,2);
cC1 = detcoef(F,L,1);
B3 = wrcoef('a',F,L,'db1',3);
C1 = wrcoef('d',F,L,'db1',1);
C2 = wrcoef('d',F,L,'db1',2);
C3 = wrcoef('d',F,L,'db1',3);
subplot(2,2,2); plot(C1);
title('Detail C1')

subplot(2,2,1); plot(B3);
title('Approximation B3')

subplot(2,2,4); plot(D3);
title('Detail D3')
subplot(2,2,3); plot(D2);
title('Detail D2')

A0 = waverec(C,L,'db1');
err = max(abs(s-A0))
```

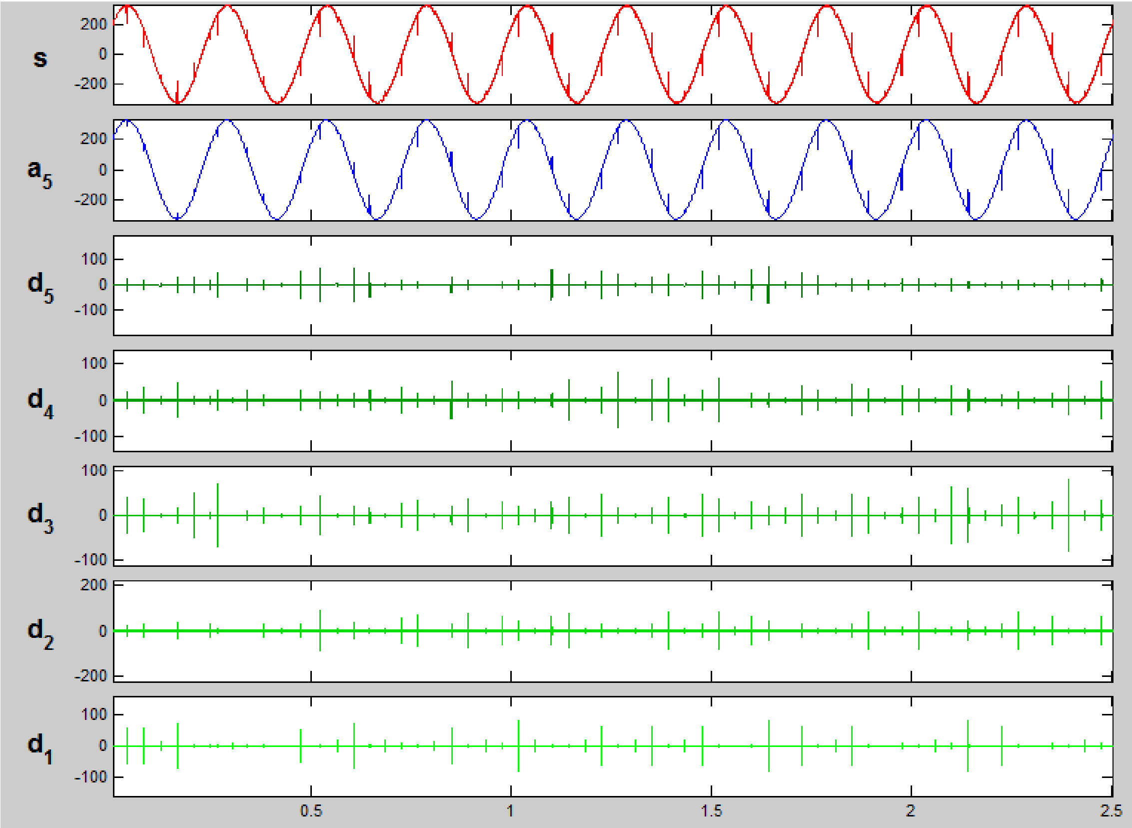

Figure 5.2. Disturbances detection for periodic notch signal haar level 5.

Comment is the same as the one above..

Note: When dealing with DWT,if one wants shows either slow or fast transients changes ,he should check the detail coe.And for other types of disturbances such Harmonics, just check the high level coefficients..

The error difference between the original signal and the approximated one is $8.5265*10^{-14}$.

Run the MATLAB code as prove.

5.3.2 Voltage Sag

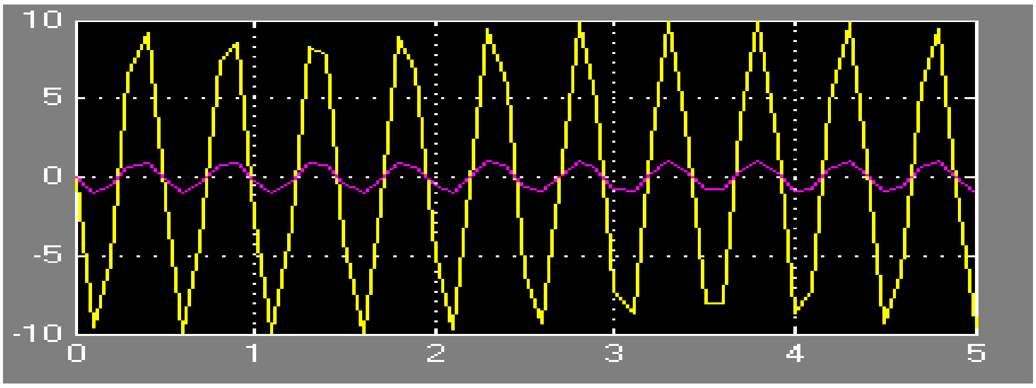

Figure 5.3. Normal voltage sag.

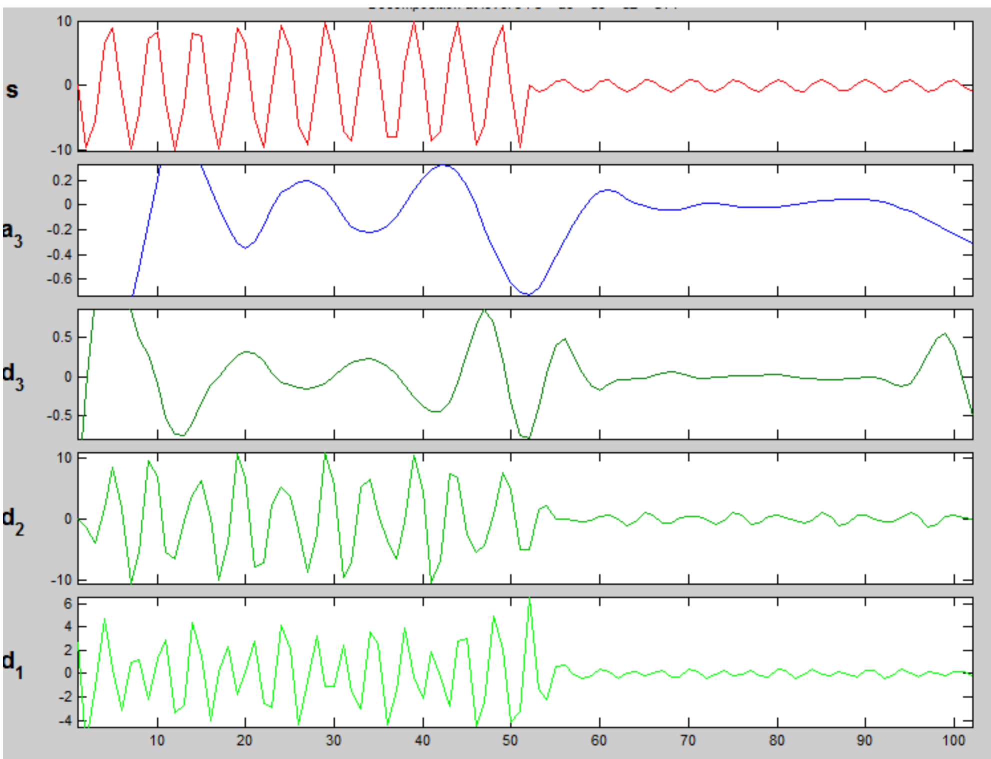

Figure 5.4. Voltage sag signal detectoiın.

5.3.3 Harmonics

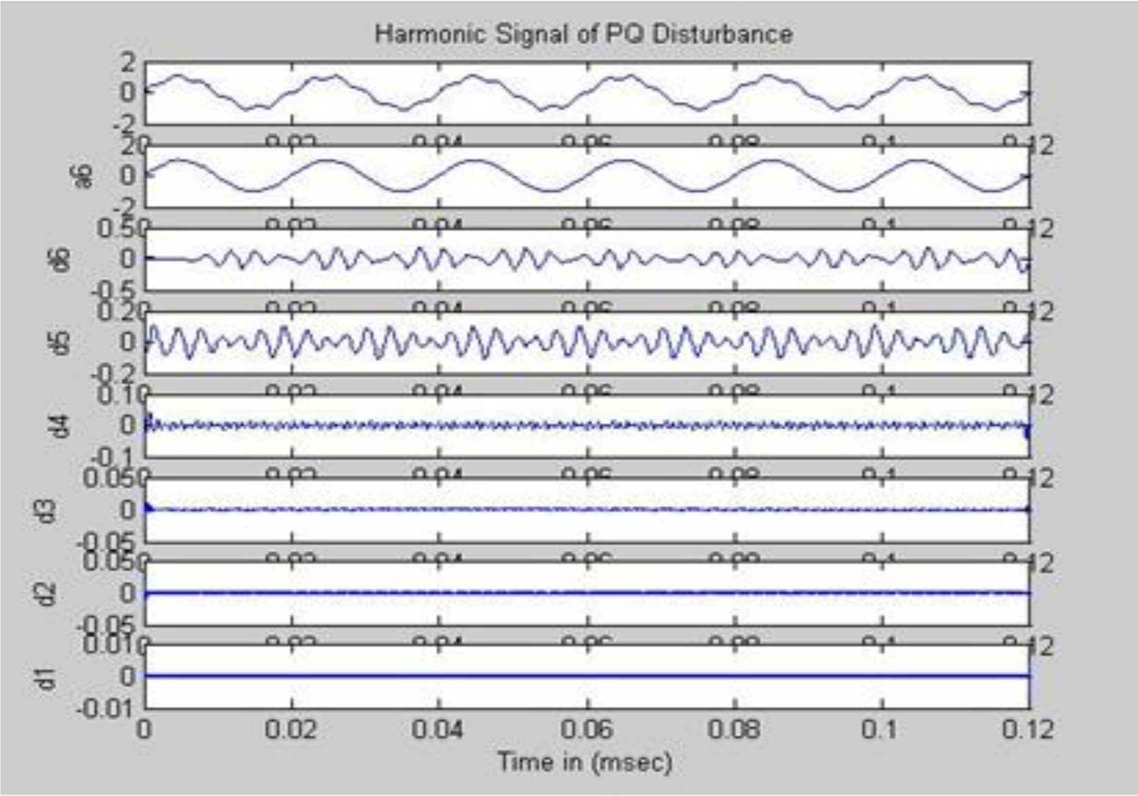

Figure 5.5. Signal showing Harmonic disturbances detection.

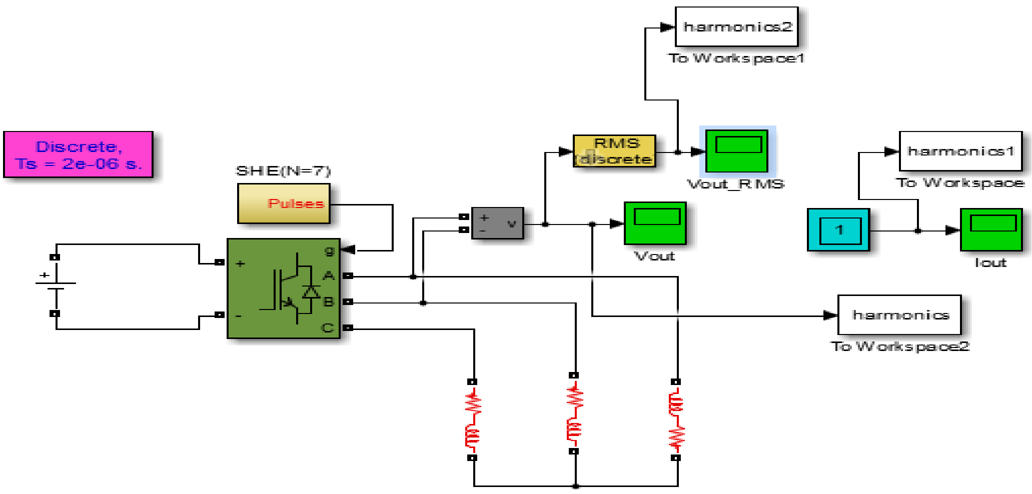

Figure 5.6. Harmonic Circuit

5.3.4 Noise

This example represents the electrical consumption measured 3 days. It is an interesting case because of the noise introduced ther is disturbance in the monitoring equipment..

It proves how good Wavelet analysis can denoise a signal.

Matlab Code:

Original noise waveform

First of the code: application of Haar wavelet

```
load leleccum;
s = leleccum(1:3920);
l_s = length(s);
[cA1,cD1] = dwt(s,'db1');
D1 = upcoef('d',cD1,'db1',1,l_s);
A1 = upcoef('a',cA1,'db1',1,l_s);
subplot(1,2,2); plot(D1); title('Detail D1')
subplot(1,2,1); plot(A1); title('Approximation A1')
err = max(abs(s-A0))

A0 = idwt(cA1,cD1,'db1',l_s);
```

Matlab answer:

```
noisedenoise


err =


   2.2737e-13
```

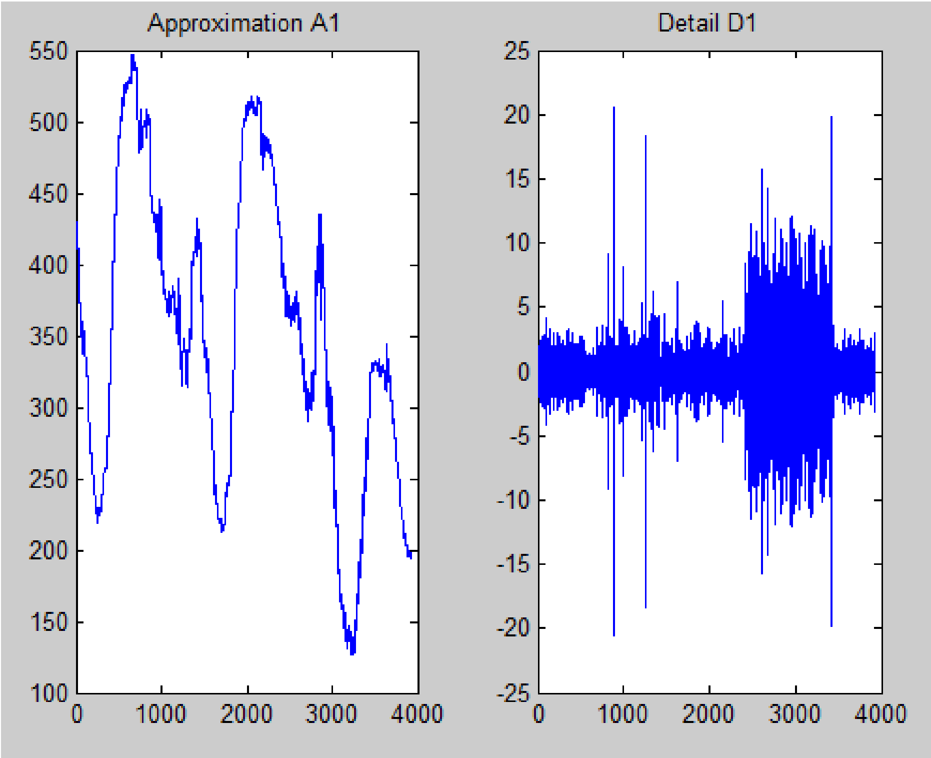

Figure 5.7. 1D analysis of the noise (Haar level 1).

Multl level Decom

[C,L] = wavedec(s,3,'db1');

Extraction of 3,2,1 level approx coeff from C

[cD1,cD2,cD3] = detcoef(C,L,[1,2,3]);

cA3 = appcoef(C,L,'db1',3);

Reconstruct Level 3 approximation and the Level 1, 2, and 3 details.

A3 = wrcoef('a',C,L,'db1',3);

D2 = wrcoef('d',C,L,'db1',2);
D3 = wrcoef('d',C,L,'db1',3);
D1 = wrcoef('d',C,L,'db1',1);

Now results of a multilevel decomposition

plot(A3);

```
subplot(2,2,1);
plot(D1); title('Detail D1') subplot(2,2,3);
plot(D3); title('Detail D3')
title('Approximation A3') subplot(2,2,2);
plot(D2); title('Detail D2') subplot(2,2,4);
```

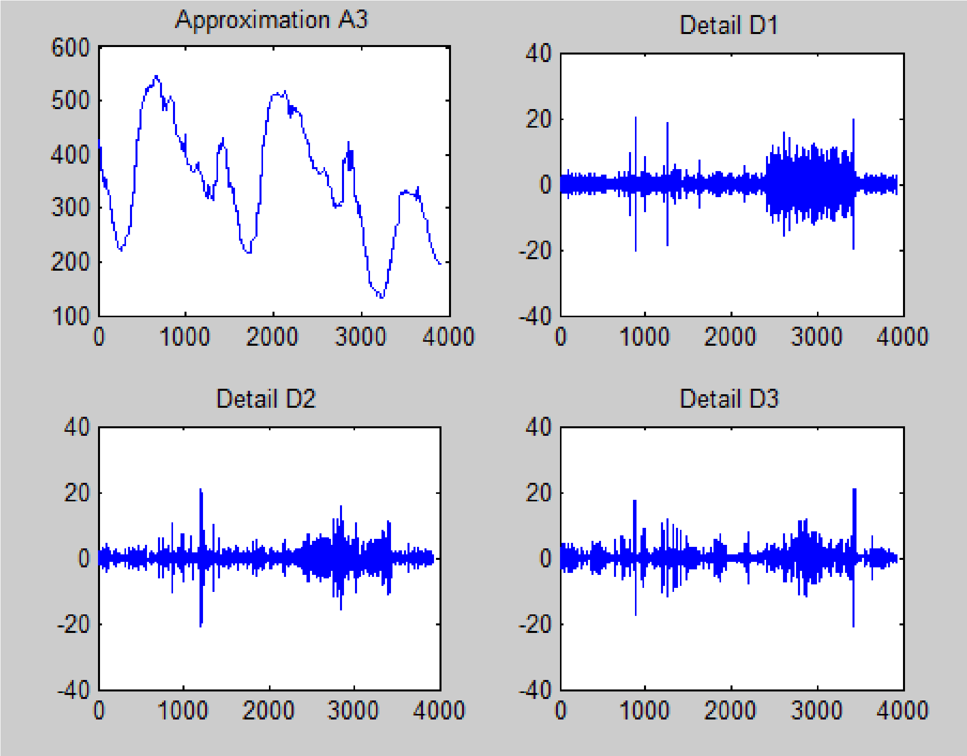

Figure 5.8. 1D analysis with Haar (3 level).

Now Reconstruction of the origin signal from 3 level decomp.

```
err = max(abs(s-A0))

A0 = waverec(C,L,'db1');

err =4.5475e-13
```

To use wavelets for noise removal, you will to identify the components which contain the noise, then reconstruct without those components the original signal. We note that in our previous case, that successive approximations reduce more and more the noise (because after each level high frequency components are filtered out). as shown on the figure the 3 level approx is more clearer compared to the original signal comparison between original and approximation signal

```
axis off subplot(2,1,2);
title('Level 3 Approximation');
plot(A3);
subplot(2,1,1);
title('Original');
plot(s);

axis off
```

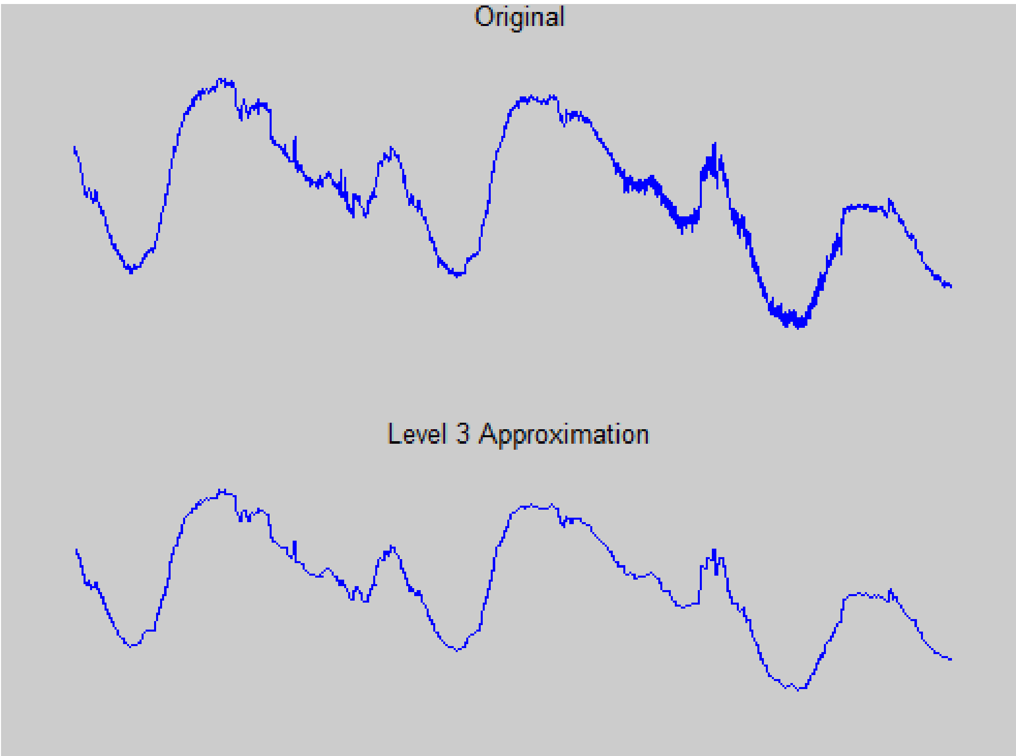

Figure 5.9. Comparison between the Approximated and the Original signals after denoisation

See close they look.

Now we are going to do the same thing using Wavemenu.

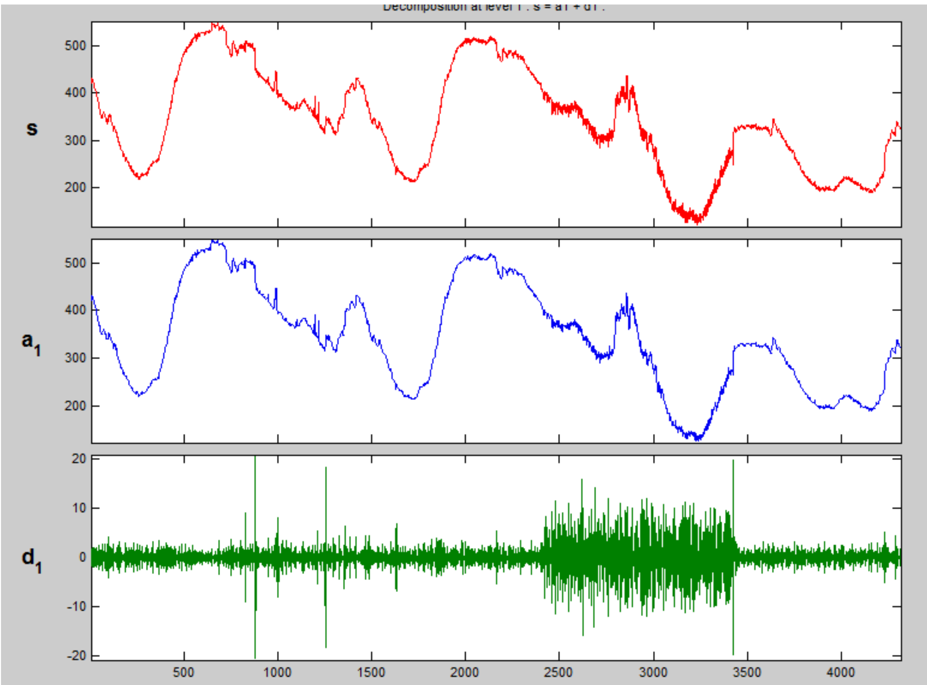

Figure 5.10. Lelecum analysis with Haar level 1.

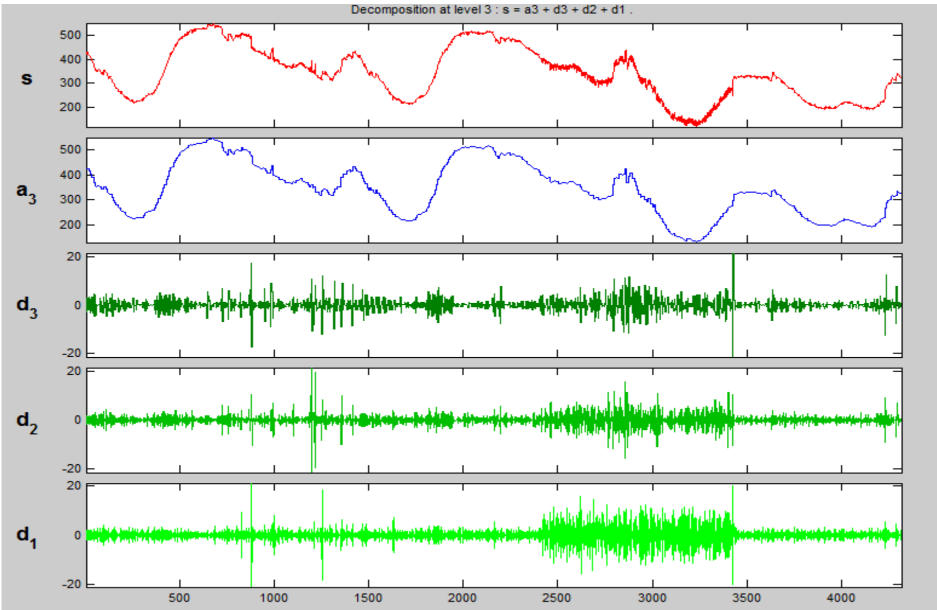

Figure 5.11. Lelecum analyse with Haar level 3.

Comment: Noise really reduced at 3 level.

5.3.5 Transient:

DWT point of interest coefficients at low scales demonstrates high and quick drifter's aggravations. As music are moderate and nonstop aggravations subsequently those are identified at high scales. From dauch5 and dauch6 we can see, these unsettling influences aren't numerous numbers of basic parts.

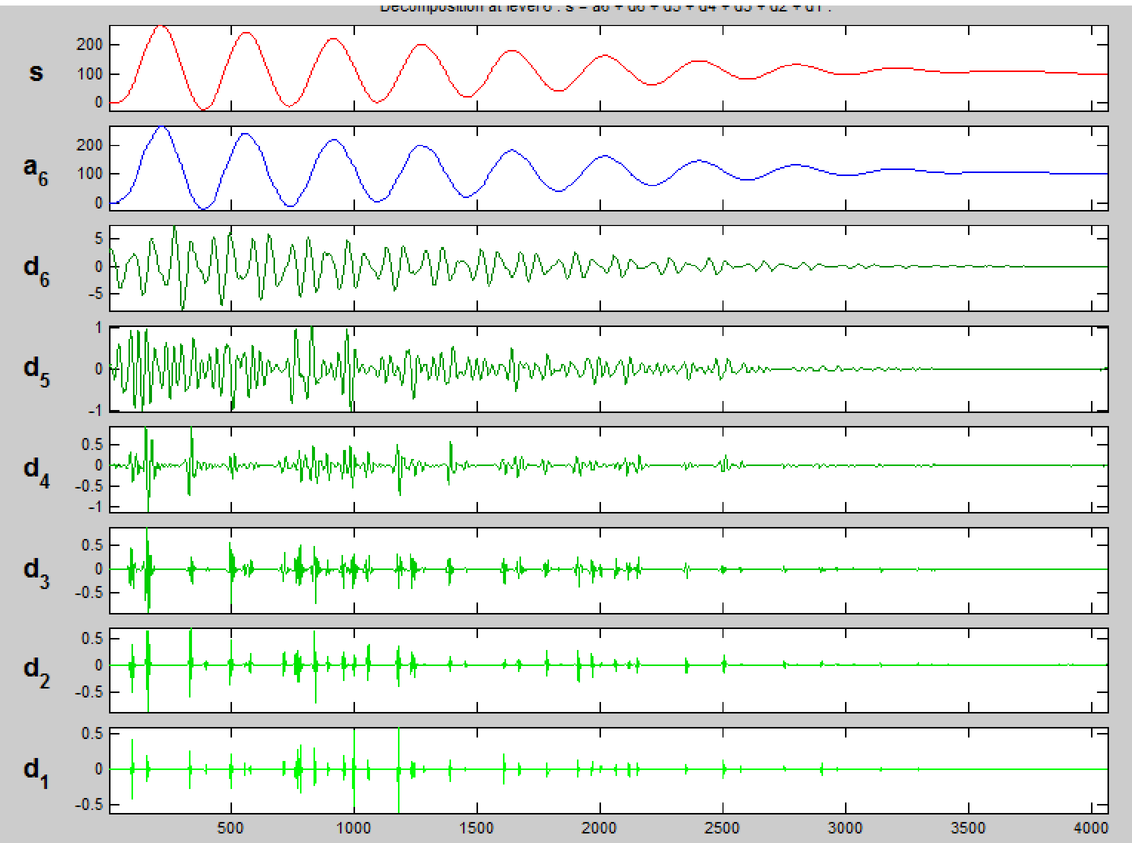

Figure 5.12. Transient analysis with db4 level 6.

CHAPTER 6

CONCLUSION

This thesis is about wavelet and its application in power electrical field There have been many discussions on to analyze the different waveform distortion type of PQ disturbances. First the selection of the mother wavelet and the calculation of the weight are the essential part in wavelets analysis. The wavelet is a good to way to detect disturbances in PQ and it is nice mathematical means. When we need time and frequency information, wavelet is the key.

CHAPTER 7

FUTURE WORK

There are a lot to be done with wavelets. It is a great tool in areas such as approximation theory, signal processing and specially Harmonic analysis. More over the filtering capacity of wavelets is really an interesting subject on its own. But also the usage of wavelet in information technology (image processing computer graphics, signal processing). Its application in filtering is yet to be fully explored.

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