INTELLIGENT POWER QUALITY ASSESSMENT IN A PLANT DISTRIBUTION SYSTEM

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

Assoc. Prof. Dr Ravindra Nath Mukerjee
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2007

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Syairah binti Abdul Ghani

ABSTRACT

The objective of this project is to develop a power quality assessment procedure on a plant distribution system. This project focuses on identifying and differentiating features of two voltage sags waveforms caused by fault and large load starting respectively by using one of the digital signals processing technique, wavelet analysis. Power quality has become an important issue for electricity consumers at all levels of usage. It can be defined as the quality of voltage that results in proper operation of power quality sensitive equipment. It has very wide aspects and elements and will be discussed further in this report. Wavelets analysis is a windowing technique which can determine different frequency component of a signal with different resolutions. Wavelet analysis is very useful in analyzing non-stationary signals whose characteristics change with time. Then by using the Wavelet Toolbox, the two waveforms can be analyzed and differentiated.

ACKNOWLEDGEMENTS

Million of thanks are especially dedicated to my supervisor, Assoc. Prof. Dr Ravindra Nath Mukerjee for his support in completing this final year project. He is the one that has always given his helping hand throughout the project. He is also the one that always give the motivational support whenever the project faces obstacles and difficulties.

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INTRODUCTION

1.1 Background of Study

Intelligent power quality assessment procedure in a plant distribution system is a project which focuses on characterization of voltage sag waveforms. The characterization of the waveforms is obtained by using wavelet analysis.

1.2 Problem Statement

1.2.1 Problem Identification

Voltage sag is the most common power disturbance in industry. It is actually a brief reduction in voltage on AC power systems between half cycles to a few seconds. Voltage sags can be caused by many reasons such as starting a large load, loose or defective wiring, faults or short circuits. This may result in equipment failure and difficulty in plant operation, which leads to lost production; hence will increase the cost and affect the economical aspects of a company.

1.2.2 Significance of the Project

Since voltage sags may originate from various sources, a complete investigation has to be done in order to identify the cause when an event occurs. This is due to the different ways of overcoming the problem depending on the cause leading to voltage sag. From this project, wavelet analysis is utilized to differentiate the different type of voltage sag waveforms. Hence, the cause of the problem can be identified based on the features identified in the project. Using the features identified in this project, actual cause leading to a voltage dip can be determined online.

1.3 Objectives and Scope of the Study

The objective of the project is to identifying the features which differentiate one cause from the other, leading to voltage sag in order to recognize voltage sag event from its signature from a control room. This study focuses on differentiating the two waveforms of voltage sags that originate from large load starting and fault respectively. The actual data of large load starting event were recorded from Gas Processing Plant B, Petronas Gas Berhad, Paka, Terengganu. The signature for voltage sag due to fault were obtained from Star LRT Sentul Timur.

CHAPTER 2

LITERATURE REVIEW / THEORY

2.1 Power Quality

According to IEEE, the power quality problem can be defined in seven categories based on the waveforms which are:

- Transients
- Sags / Undervoltage
- Swells / Overvoltage
- Interruptions
- Waveform distortions
- Voltage fluctuations
- Frequency variations [2]

2.1.1 Transients

Transient are large, short duration voltage changes resulting from lightning strike or switching operations on the network. It will occur for less than one half cycle of the mains voltage. [1]

Transients can be divided again into two categories; impulsive transients and oscillatory transients. Impulsive transients are characterized by the rate of change of voltage or current magnitude as impulsive transients are generally events where currents and/or voltage are suddenly raising in positive or negative direction in fast, medium and slow speed. [2] Impulsive transients can be caused by lightning, poor grounding, fault clearing by the utility, or switching of inductive loads. People sometimes refer impulsive transients as power surge or spike.

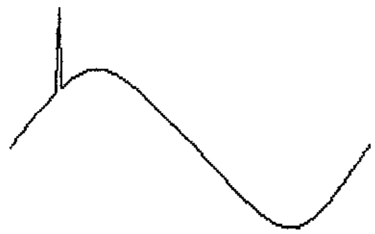

Figure 1 Impulsive Transients

Oscillatory transients on the other hand can be characterized by the frequency content and duration. It is a sudden change in the steady-state condition of a signal's voltage and/or current at both positive and negative signal limits oscillating at the natural system frequency and decay to zero within a cycle. [1] Oscillatory transients can originate from turning off an inductive or capacitive load such as capacitor banks or motors.

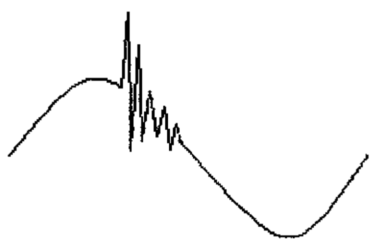

Figure 2 Oscillatory Transients

2.1.2 Sag/Undervoltage

Sags are reduction in the RMS voltage in the range of 10% to 90% of nominal voltage for duration more than half cycle to one minute. The possible causes that can lead to voltage sag are system fault, increase load demand, and translational event such as large motor starting. [3]

Voltage sags are the most common power disturbance and can disturb electronic equipment which lack sufficient internal energy storage. When large motor starts, it can draw up to six times or more its normal running current. This will surely caused the voltage drops within the circuit. Voltage sags may also originate from utility. When the utility attempted to clear the faults, it may cause voltage sag when it cleared more quickly or when the fault itself is a momentarily one.

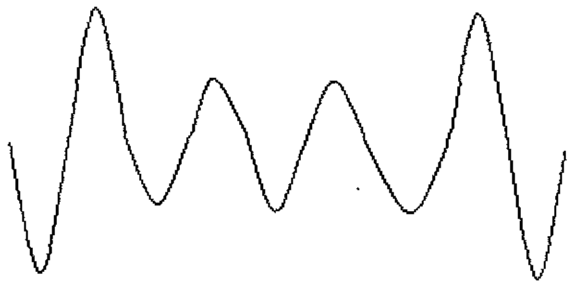

Figure 3 Voltage Sags

Undervoltage is an event resulted from the long term sags. It is a long term variation, which usually more than 1 minute and the voltage are less than 90% of the nominal voltage. Undervoltage maybe caused from the switching off of large loads or energization of large capacitor bank. It can create overheating in motors and lead to the failure of the nonlinear loads such as computer power supplies. [1]

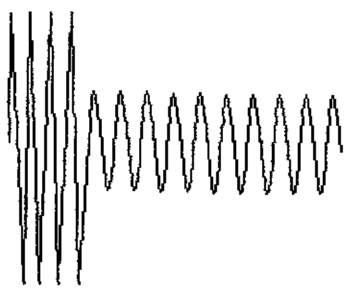

Figure 4 Undervoltage

2.1.3 Swell/Overvoltage

Swell is the reverse of the sags; an increment of RMS voltage more than 110% of nominal voltage for duration more than half main cycle and less than 1 minute. Swell can be originated from system faults, single-phase fault on a three-phase system, load switching, or capacitor switching. Swell can result to data errors, flickering of lights, degradation of electrical contacts, semiconductor damage in electronics and insulation degradation. [1]

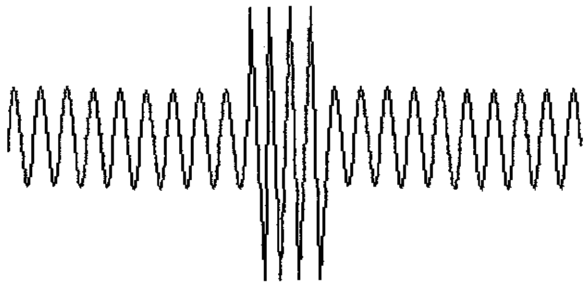

Figure 5 Swell

Just as the undervoltage, overvoltage is the long term version of the swell. The cause of this problem is mainly from the wrong tapping setting of the supply transformer, or the load reduction. This event will cause excess heat to the equipment

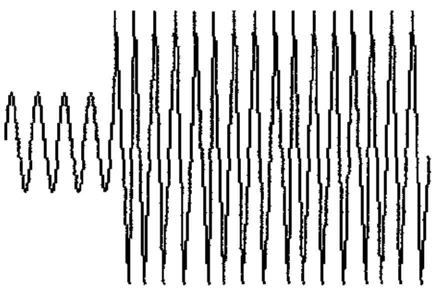

Figure 6 Overvoltage

2.1.4 Interruptions

Interruption is defined as the complete loss of supply voltage or load current depending on its duration. An interruption can be categorized as instantaneous, momentary, temporary, or sustained as described below: [1]

Table 1 Duration of Interruptions [2]

Instantaneous	0.5 to 30 cycles
Momentary	30 cycles to 2 seconds
Temporary	2 seconds to 2 minutes
Sustained	Greater than 2 minutes

There are many causes of interruption to occur and it can vary from place to place. The causes are lightning strikes, animals, trees, vehicle accidents, destructive weather, equipment failure or basic circuit breaker tripping. Interruptions can caused many losses to the industry and business. It will also caused lose of valuable data when information from the computer resulted from the corrupted data when the power suddenly loss.

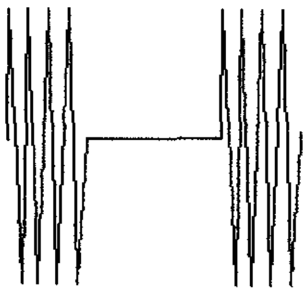

Figure 7   Interruption

2.1.5 Waveform Distortion

Waveform distortion can be divided into five types:

- DC Offset

Dc offset is usually due to failures of rectifiers within the many AC to DC conversion technologies. It also may originate from poor grounding. DC can traverse in the AC power system and add unwanted current to devices already operating at their rated level. The circulating DC current may result in overheating and saturation of transformers. The saturated transformers will lead to failure of full power delivery to the load and the instability in electronic load equipment. [1]

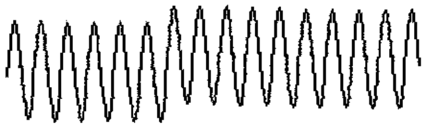

Figure 8   DC Offset

- Harmonics

Harmonics are additional frequencies presents in the mains voltage or current that are integral multiples of the main frequency. [2] As an example, 150 Hz is the third harmonics of a 50 Hz fundamental frequency; 3 x 50 = 150 Hz. The main cause for harmonics is nonlinear loads such as power electronic loads. Harmonics can cause many problems such as overheated transformers, neutral conductors and other electrical equipment and the tripping of circuit breakers, and loss of synchronization on timing circuits that are dependent upon a usual clean sine wave. [1]

Figure 9 Harmonics [1]

- Interharmonics

Interharmonics is the distorted voltage or current waveform containing periodic distortions of a sinusoidal nature that are not integer multiples of the fundamental supply frequency. This event originates from the faulty equipment, cycloconverters, induction motors and arcing devices. This event can lead to flicker of displays and incandescent lights and may cause heat to the equipment and communication interference.

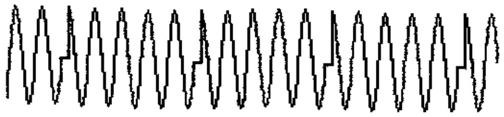

Figure 10 Interharmonics

- Notching

Notching is a result from the normal operation of 3-phase electronic switching devices such as AC to DC converters, variable speed drives, and light dimmers. The notching can result to system halts, data loss and data transmission problems. [1]

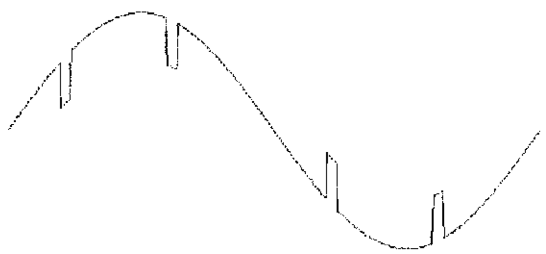

Figure 11 Notching [1]

- Noise

Noise is a disturbance with a broad frequency distribution up to about 200000Hz.[2] It can be generated by the power electronic devices, control circuits, arc welders, switching power supplies and so on. Poor grounding may also lead to noise problem. Noise can cause equipment malfunction, long term component failure and so on. [1]

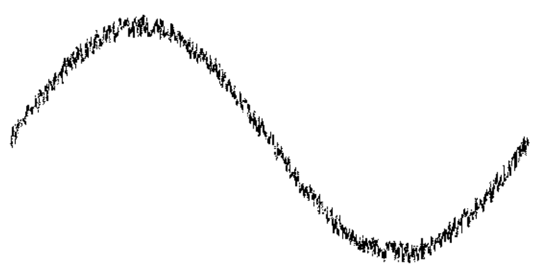

Figure 12 Noise [1]

2.1.6 Voltage Fluctuations

Voltage fluctuations is a systematic variation of the voltage waveform or a series of random voltage changes of small dimension, from 95% to 105% of nominal voltage at low frequency generally below 25Hz. [1] Voltage fluctuations can caused from any load that exhibits significant current variations. This event can lead to flickering of incandescent lamps.

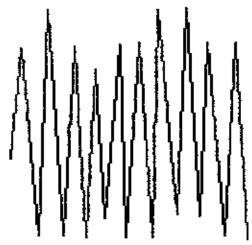

Figure 13 Voltage Fluctuations

2.1.7 Frequency Variations

Frequency variation is more common if the generator is heavily loaded, however it is rarely happening in the utility power systems. This may cause the motor to run faster or slower to match the frequency of the input power as the speed of rotation will depends on the frequency. This will lead the motor to heat and degradation through additional motor speed and current draw.

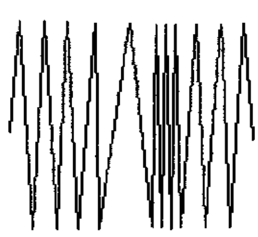

Figure 14 Frequency Variations

2.2 Wavelet Analysis

Wavelet analysis is a useful tool in analyzing non-stationary signals and utilizing a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals if more precise low frequency information would like to be obtained and shorter regions can be used if high frequency information is desired. [4]

2.2.1 *The Drawback of Fourier Analysis*

Fourier Transform is also one type of analyzing signals. Fourier Transform will actually break down a signal into constituent sinusoids of different frequencies. However, Fourier Transform has its own disadvantages and limitations where it can only reports the frequency that presents in the portion of the signal that is within the window. It cannot identify the times at which various frequency component occurs within a window. It is impossible to tell when a particular event took place when looking at the Fourier Transform. Fourier Transform can only be useful if the signal has the frequency content that stationary within a window. It fails to analyze non-stationary signal which the frequency content are unpredictable within a window. [5]

2.2.2 *Wavelet Basics*

Wavelet analysis can overcome the drawback of the Fourier Transform as it can analyze the signal with different resolutions by using the notion of function at different scales. Scales are inversely proportional to the frequency:

$$\text{Scale} = \alpha / \text{Frequency} \qquad [5]$$

Wavelet function localized both in frequency and time. There are wavelet families which each family has a characteristic shape and basic scale for each family covers a known and fixed interval of time. A wavelet family contains each component of the wavelet with consist of the father wavelet, mother wavelet and the other wavelet components which scaled and translated from the father or the mother wavelet itself. Father wavelet produces scaling function for the wavelet family whereas the mother wavelet produces the wavelet function. Both the father and mother wavelet has the scale equals to 1. There are many types of wavelet families exist such as Haar, Daubechies-6, Daubechies-16, Symlets, Coiflets and so on. All of the wavelet families are localized in time and they are nonzero only over a finite of time. [5]

(a) (b) (c)

Figure 15 Examples of Mother Wavelet (a)Meyer (b)Morlet (c)Mexican Hat

Wavelet transforms are classified into discrete wavelet transform (DWT) and continuous wavelet transform (CWT). CWT operate over every possible scale and translation whereas DWT use a specific subset of scale and translation values.

2.2.3 The Discrete Wavelet Transform (DWT)

The Discrete Wavelet Transform (DWT) provides the DWT coefficients $c_j[k]$ and $d_j[k]$ for the decomposition of the signal into its scaling function and wavelet function components. The scaling function coefficients $h_0[k]$ and wavelet function coefficient $h_1[k]$ maybe viewed as impulse response of a pair of filters. For all wavelet families, $h_0[k]$ behaves as the low pass filter and $h_1[k]$ behaves as a high pass filter. The filters divide the spectrum into two equal frequency bands. The low pass filter output contains the low frequency elements of the signal while the high pass output contains the high frequency component of the signal. [5]

In MATLAB, the output of the filter can be termed as approximation (A) and details (D). The approximations are the high-scale, low-frequency components of the signal. The details are the low-scale, high-frequency components. [4]

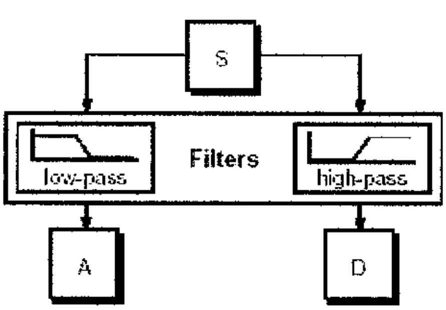

Figure 16 Wavelet Decomposition [4]

In wavelet analysis, the signal to be analyzed is divided into two parts by filtering it through the low pass and high pass filters as mentioned before. The high pass filter will picks up the small details whereas the low pass filter will picks up everything else. This process continues with the low pass portion of signals which in turn filtered by low and high pass filters. Further detail of the signal is uncovered at each step and the process of the subdividing the low frequency bands can continue as long as detail remains. [5] This is called multi-level decomposition. When the filtering only occurs once, then it is only level-1 decomposition and so on.

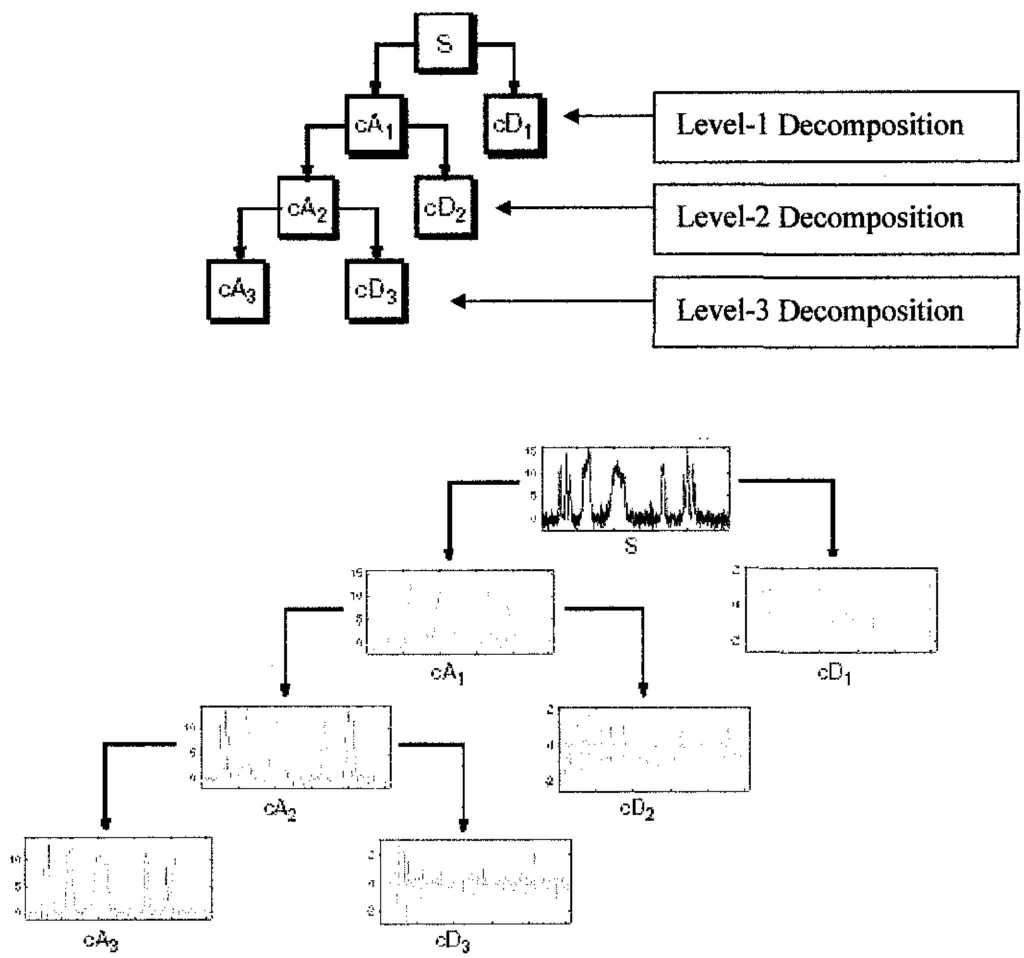

Figure 17   Multi-level Decomposition [4]

Filtering the low pass portion is to obtain the best frequency resolution at the lowest frequencies while accepting the poorer frequency resolution at higher frequencies. [5]

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 Procedure Identification

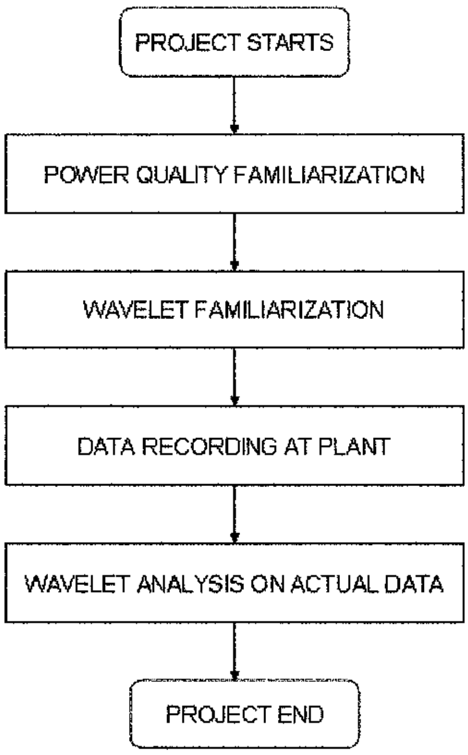

Figure 18 The Procedure Flow Chart

From the chart above, the project starts with a study on power quality as well as wavelet. The actual sag event then recorded at Gas Processing Plant B, Paka. Then, all the materials studied been applied in analyzing and classifying the waveforms captured at the plant as well as the data from Star LRT Sentul event.

3.2 Tools

3.2.1 Fluke 43BPower Quality Analyzer

The Fluke 43B Power Quality Analyzer performs the measurements to maintain power systems, troubleshoot power problems and diagnose equipment. By using this tool, a voltage sag scenario can be recorded as desired. This analyzer can measure both voltage and current and it also able to store memory up to 16 days. For the project, the recording has been done for 8 minutes only.

3.2.2 Wavelet Toolbox

The Wavelet Toolbox contains graphical tools and command line functions that can examine and explore characteristics of individual wavelet packets, perform wavelet packet analysis of one-dimensional and two-dimensional data and use wavelet packets to compress and remove noise from signals and images. [4] Since this project only involves in analyzing waveforms, only one-dimensional data analysis has been used. The analysis has been done by using the Discrete Wavelet Transform in the toolbox.

The analysis includes obtaining the amplitude ratio and the frequency at each level of analysis. The amplitude ratio has been done by finding the peak absolute value of both approximations and details for each level which can be obtained directly from the statistics option in the wavelet. The frequency of each level can be obtained by using command lines scal2frq.

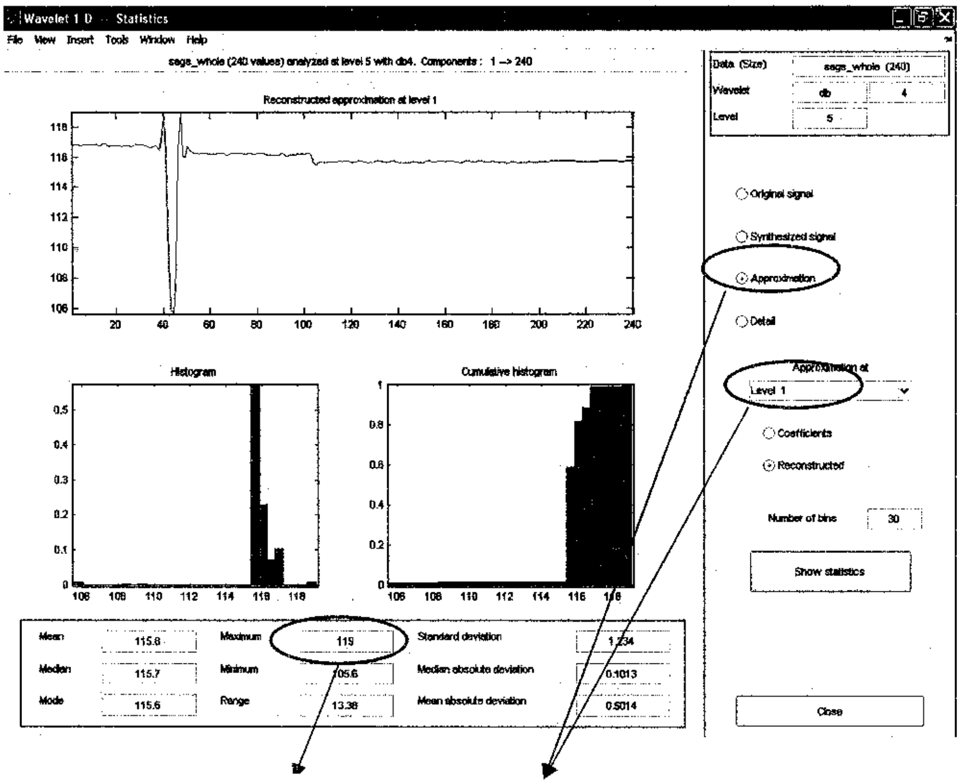

Figure 19 The Example of Statistic Options in Wavelet Toolbox

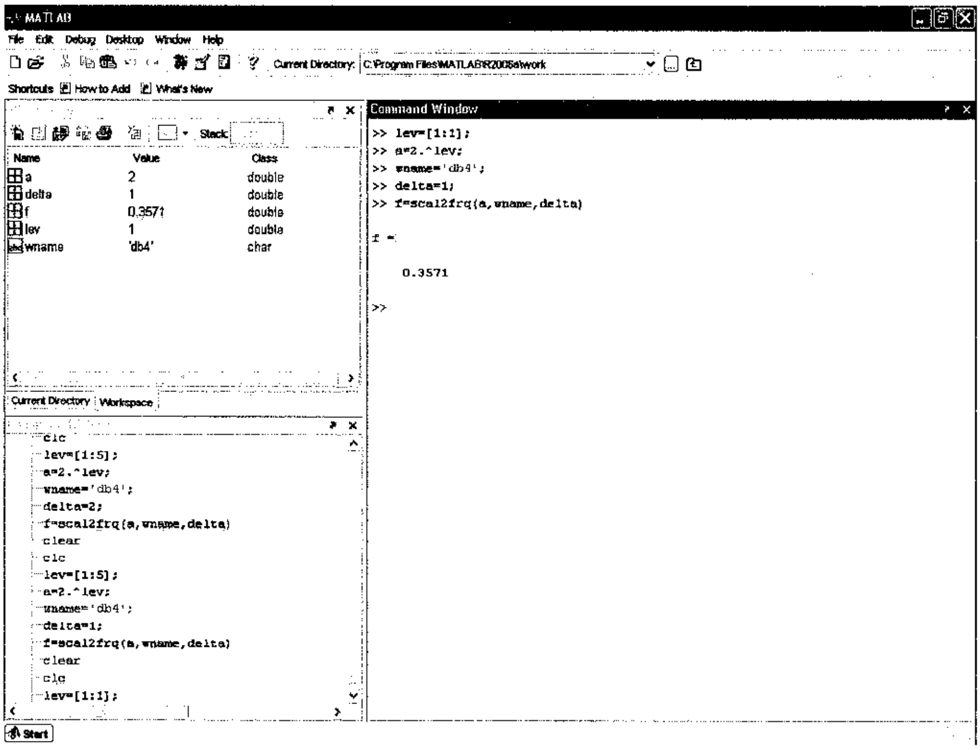

Figure 20 The Example of Obtaining Frequency using Command Line

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Findings

4.1.1 Data Recording at Plant

A trip to the plant, Gas Processing Plant B at Paka, Terengganu has been carried out during the last semester break. The purpose of this trip is to record and collect the data of voltage and current during large motor starting. The recording has been done successfully with the help and guidance from all the engineers and technicians.

The recording has been done by using Fluke 43B, Power Quality Analyzer at the 6.6KV busbar in one of the substation called GPP6 Process Substation. The motor involved in this recording is PM6-201E, motor for Amine Pump at Acid Gas Removal Unit (Unit 2). The work procedure and job safety analysis (JSA) for the recording can be referred at Appendix A and B respectively.

The work procedure is necessary in order to do any tasks in plant so that accidents can be avoided as there are high risks of any accidents to occur in plants. Proper work procedure ensures all the tasks carried out smoothly and all the safety measures are taken into account. The safety job analysis is essential so that any possibilities of accident to occur during the tasks have been analyzed first and the all precautionary measures are taken to avoid it. Both of the documents are needed together to apply for the cold work permit for the motor test runs.

The recorder has been set to record for 8 minutes. When the test run is scheduled, all the tools preparation has been set up in the substation with the help of technicians.

The results are as follows:

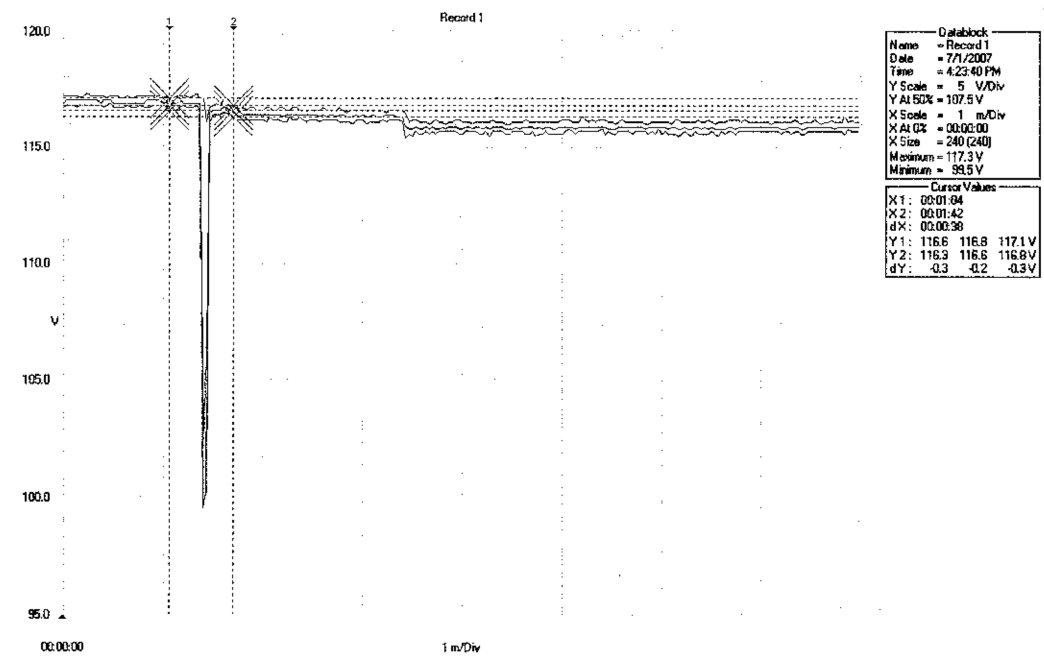

Figure 21 The Voltage Waveform

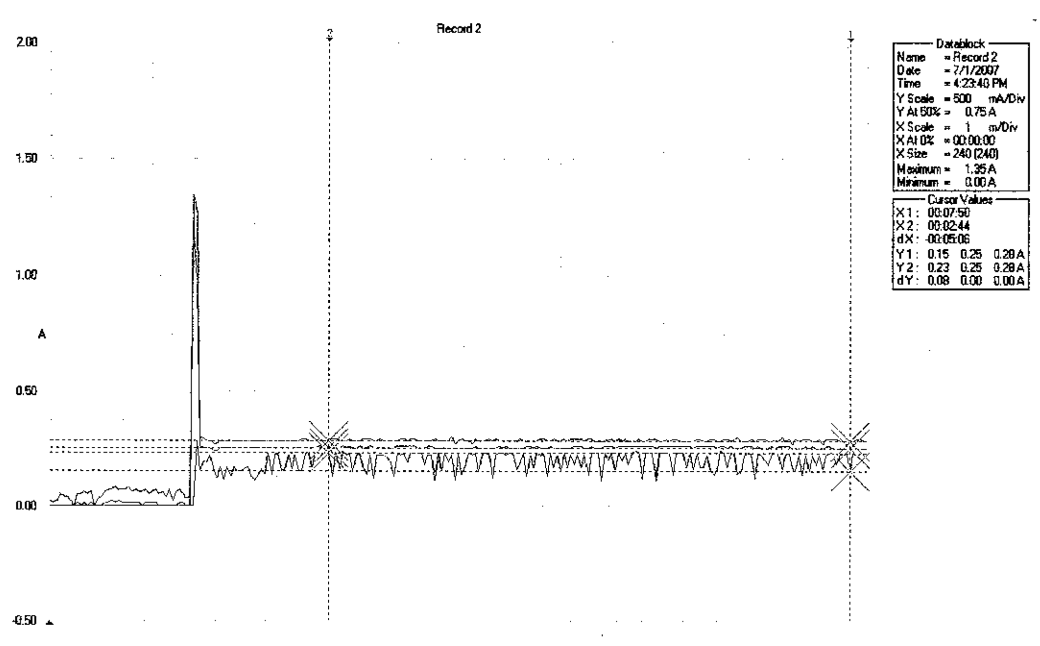

Figure 22 The Current Waveform

4.1.2 Wavelet Analysis on Actual Data

The wavelet analysis on the actual data has been carried out for the voltage recorded data. The aim for the analysis is to find the amplitude ratio and frequency component for all level of details and approximations. In order to find the amplitude for the signal, wavelet decomposition of level 5 using Daubechies 4 has been carried out. The analysis has been done to the overall signal, then to each part of the signal that is part of before, during and after the sag.

The results are as below:

Table 2 Result for amplitude ratio analysis for approximations

WAVEFORM TYPE	α_n	WHOLE	BEFORE	DURING	AFTER
Sag due to large load starting	n=1	0.9992	1.0000	1.0000	1.0000
	n=2	1.0000	1.0000	0.9479	1.0000
	n=3	0.9866	1.0000		0.9991
	n=4	0.9866	1.0000		0.9991
	n=5	0.9832	1.0000		0.9991
Sag due to fault	n=1	1.0000	1.0000	1.0000	1.0000
	n=2	0.9496		0.9266	0.9887
	n=3	0.9415		0.9211	0.9690
	n=4	0.9370		0.9220	
	n=5	0.9037			

Table 3 Result for amplitude ratio analysis for details

WAVEFORM TYPE	α_n	WHOLE	BEFORE	DURING	AFTER
Sag due to large load starting	n=1	1.0000	0.7529	0.1609	1.0000
	n=2	0.4280	1.0000	1.0000	0.6461
	n=3	0.6749	0.7312		0.7879
	n=4	0.1450	0.1315		0.7238
	n=5	0.1425	0.2464		0.2521
Sag due to fault	n=1	1.0000	1.0000	1.0000	1.0000
	n=2	0.3206		0.7607	0.3667
	n=3	0.3432		0.4722	0.1395
	n=4	0.3946		0.5786	
	n=5	0.4241			

Table 4 Result for frequency analysis

WAVEFORM TYPE	FREQUENCY			
	WHOLE	BEFORE	DURING	AFTER
Sag due to large load starting	0.1786	0.1786	0.1786	0.1786
	0.0893	0.0893	0.0893	0.0893
	0.0446	0.0446		0.0446
	0.0223	0.0223		0.0223
	0.0112	0.0112		0.0112
Sag due to fault	0.3571	0.3571	0.3571	0.3571
	0.1786		0.1786	0.1786
	0.0893		0.0893	0.0893
	0.0446		0.0446	
	0.0223			

4.2 Discussions

4.2.1 Data Recording at Plant

Figure 21 and 22 shows the result of the sag event recorded at plant. This recording was set to last for 8 minutes. From the figure, the characteristic of the current and voltage can be clearly seen. The voltage dropped abruptly the moment the motor was started. At the same time when the voltage dropped, the current started to increase. These are the waveforms of the sag event due to large load starting.

This value can be converted to the excel data by using Fluke 43B software. Then, this data can be converted to MATLAB file in order to do the analysis using the MATLAB Wavelet Toolbox.

4.2.2 Wavelet Analysis on Actual Data

Table 2 and table 3 shows the result of the wavelet analysis based on the amplitude ratio. Both of the waveform type results were shown at the same table. The amplitude ratio was calculated using the equation:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximations/details}}{\text{Highest peak absolute value among the levels}}$$

Where:

α_n = the amplitude ratio of level n

Table 4 shows the result for the frequency analysis. In order to find the frequency of waveforms, a command line function has been used; `scal2frq`. This function calculates the frequency based on the scales as the equation:

$$F_a = F_c / a\,\Delta \qquad [4]$$

Where:

F_a = pseudo-frequency corresponding to the scale, a

F_c = centre frequency of a wavelet in Hz

a = scale

Δ = sampling period

These amplitude ratio and frequency was calculated using both the whole waveform and also each segment of the sag signature; that is before, during and after the sag. The analysis has been done that way so that the analysis can be narrowed down thus the differences can be seen a lot more clearly. The details of the calculation can be referred at Appendix C.

There are differences of energy content in the sag signature. Both of the events are actually different in process although both resulted in voltage sag event. Hence, the energy contents of the signatures are bound to be different.

The differences are quite appreciable. By using these indices in real-time it is possible to debug the voltage sag signature to identify whether it is due to large load starting or fault. Identification of the cause will facilitate determination of the mitigation options.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This project is useful since power quality has become an important issue in industry these days. The features identified in the project which is amplitude ratio and frequency components enable discrimination of one voltage sag signature from the other, enabling detection of the cause that led to voltage sag. Using these differentiating features, formulation of a fuzzy logic based classification procedure is recommended as a future work.

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APPENDICES

APPENDIX A

WORK PROCEDURE FOR VOLTAGE SAG RECORDING

PETRONAS GAS	INTELLIGENT POWER QUALITY ASSESSMENT IN A PLANT DISTRIBUTION SYSTEM FINAL YEAR PROJECT	
	WORK PROCEDURE	

NO	WORK DESCRIPTION	ACTION	STATUS	REMARKS
1	Preparation of Permit To Work (PTW) and Job Safety Analysis (JSA)	Work Leader		
2	Preparation and inspection of tool/equipment	Work Leader & Electrical Inspector		
3	Inform HT Chargeman, Authorized Competent Person, and Operation Personnel	Work Leader		
4	Preparation at work area. Recording will start before motor starts so that the results before and after motor starts will be obtained.	Work Leader		6.6KV spare panel & SB6-DO3 (SB6-D01/DO2)
5	Work Step (refer to attachment for detail drawings): CURRENT MEASUREMENT 1. Identify the correct panel for the measurement 2. Clamp the Power Quality Analyzer at the respective cables 3. Make sure that all the checklist completed before start the recording 4. Recording is carried out for about 30 minutes	Work Leader		SB6-DO3 (SB6-D01/DO2) C11, C31 & C51 *(Attachment A)* *(Attachment B)*

	<u>VOLTAGE MEASUREMENT</u> 1. Identify the correct panel for the measurement 2. Do the connection at terminal block 3. Make sure that all the checklist completed before start the recording 4. Recording is carried out for about 30 minutes *Voltage and current reading are recorded simultaneously			6.6KV spare panel (SB6-D01/DO2) E11, E31 & E51 *(Attachment C)* *(Attachment D)*
5	Recording stops after 30 minutes	Work Leader		
6	Housekeeping at work area	Work Leader		
5	Completion and inform HT Chargeman, Authorized Competent Person, and Operation Personnel	Work Leader		
6	Close PTW	Work Leader		

Prepared by:

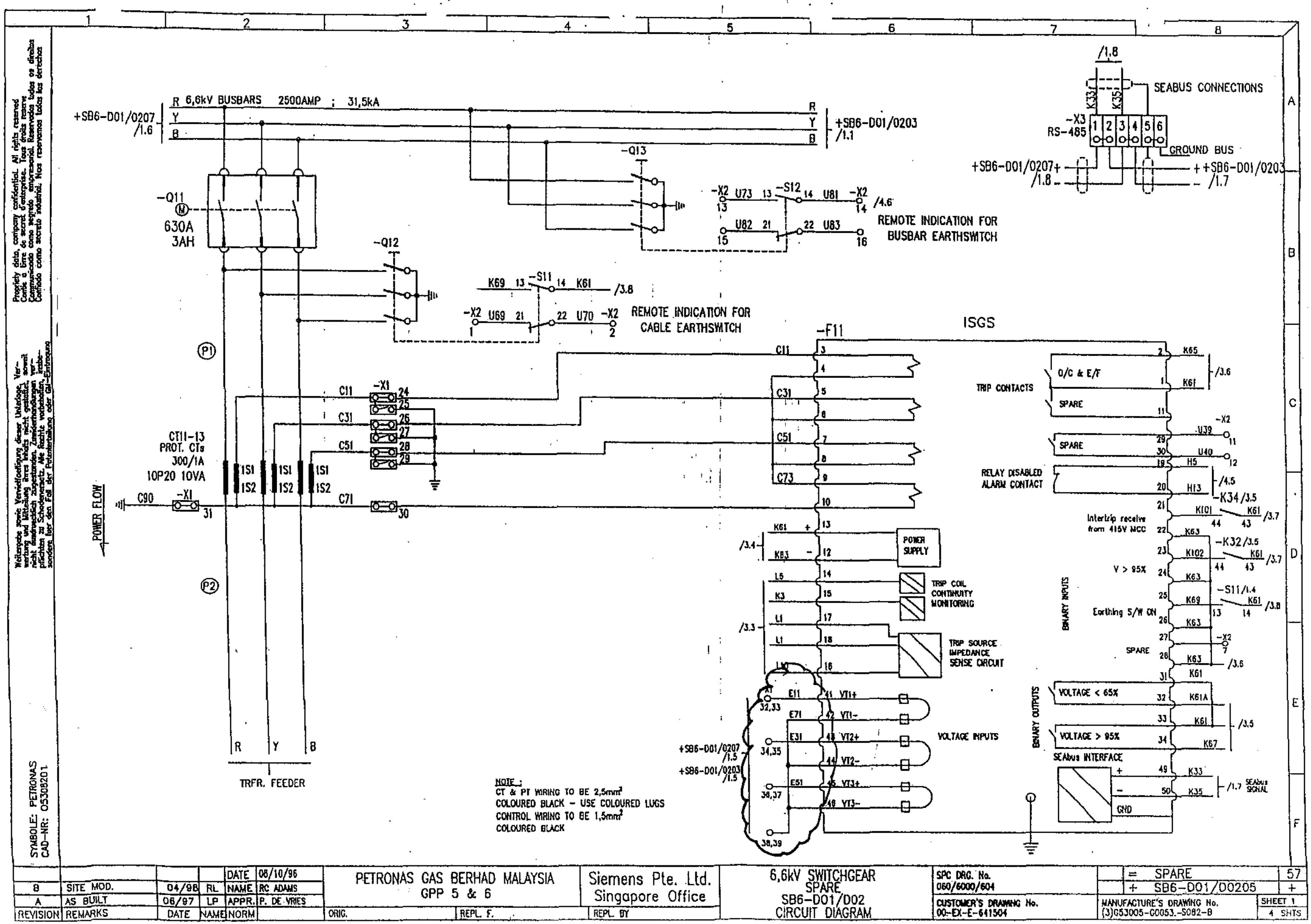
Syairah Abdul Ghani

Reviewed and approved by:

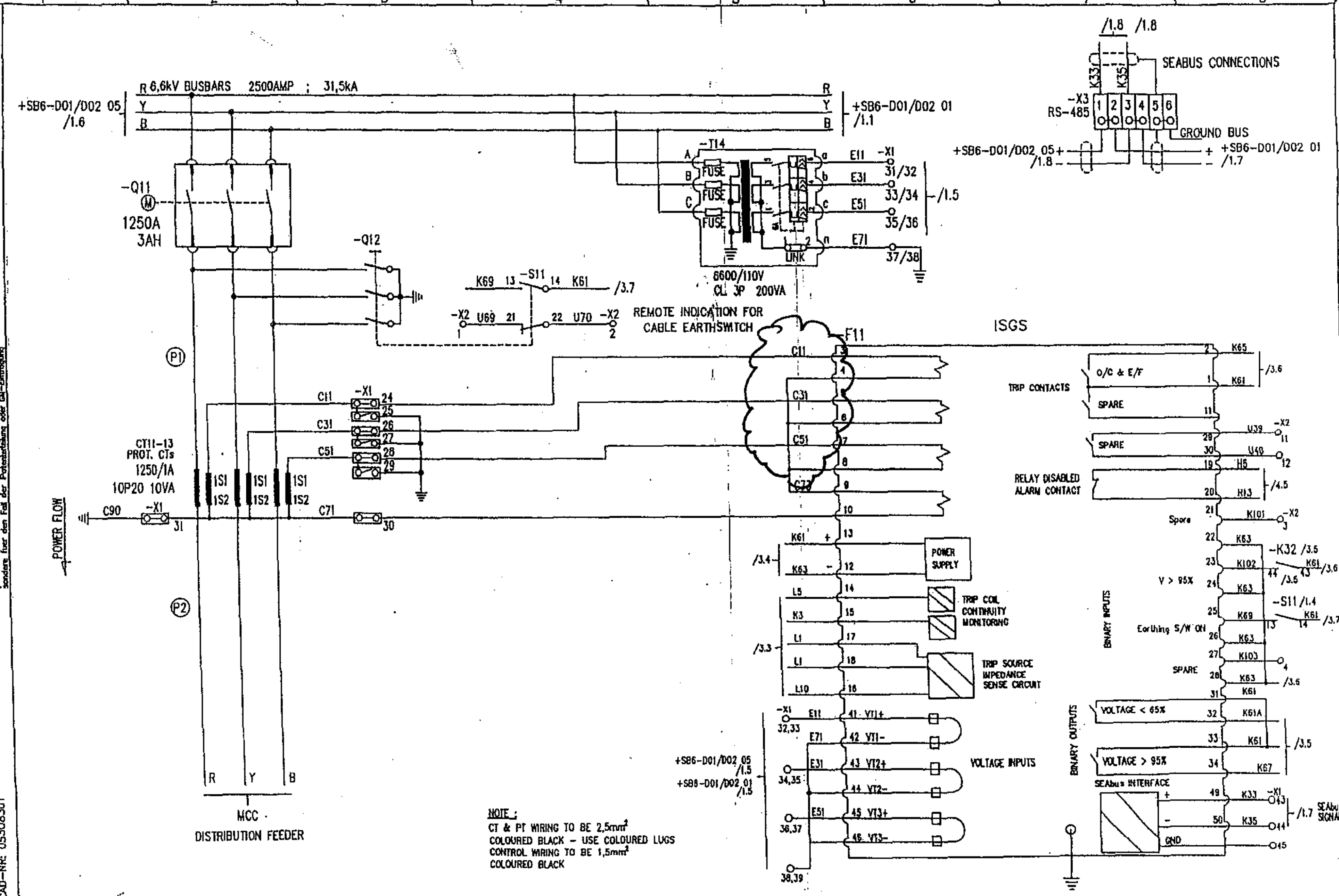
Mr Ag Zulkarenain Awangku Rajid

ATTACHMENT	DETAILS	REMARKS
A	6.6KV Switchgear SB6-DO3, SB6-DO1/DO2 Circuit Diagram Refer to Drawing 1	C11
B	Current Measurement Checklist Please make sure: 1. The clamp of the Power Quality Analyzer is properly clamped at the respective cables 2. Power Quality Analyzer is turned on	
C	6.6KV Switchgear Spare SB6-DO1/DO2 Circuit Diagram Refer to Drawing 2	E11 & E 31
D	Voltage Measurement Checklist Please make sure: 1. The probes of the Power Quality Analyzer is properly connected to the terminal 2. The terminal is properly tighten – no loose connection 3. Power Quality Analyzer is turned on	

ATTACHMENT C: DRAWING 2



ATTACHMENT A: DRAWING 1



REVISION	REMARKS	DATE	NAME	NORM
B	SITE MOD.	05/98	RL	NAME RC ADAMS
A	AS BUILT	06/97	LP	APPR. P. DE VRIES

DATE 08/10/96

PETRONAS GAS BERHAD MALAYSIA
GPP 5 & 6

Siemens Pte. Ltd.
Singapore Office

6,6kV SWITCHGEAR
SB6-D03
SB6-D01/D02
CIRCUIT DIAGRAM

SPC DRG. No. 060/6000/604

CUSTOMER'S DRAWING No.

= SB6-D03
+ SB6-D01/D0203

MANUFACTURE'S DRAWING No.

61
SHEET 1

SYMBOLE: PETRONAS
CAD-NR: 05308301

APPENDIX B

JOB SAFETY ANALYSIS

PETRONAS GAS	JOB SAFETY ANALYSIS (JSA)	JOB TITLE : VOLTAGE & CURRENT RECORDING AT 6.6KV BUSBAR PANEL DURING LARGE MOTOR STARTING	JSA NO :	PAGE : Page 1 of 1	NEW REVISED
		EQUIPMENT NO :	DATE :	14/06/07	REV. NO .
		SUPERVISOR : Mr Ag Zulkarenain Awangku Rajid	ANALYSIS BY :		
		DEPARTMENT :	REVIEWED B Mr Ag Zulkarenain Awangku Rajid		
NAME OF PERSON WHO DOES JOB :		COMPANY :	APPROVED BY :		
DESIGNATION :					

SEQUENCE OF BASIC JOB STEPS	POTENTIAL HAZARDS	PRECAUTIONARY MEASURES	ACTION BY:
Preparation at work area	All the tools and equipment needed are not properly arranged The tool used damaged	Make sure all the tools and equipment are neatly arranged Make sure the tool are in good condition (Test the tools and equipment prior to the installation)	
Identify the correct panel for the measurement (both for current and voltage measurement)	Wrong panel for measurement hence the result obtained will not be as desired	Confirm the panel tagging with drawings	
Clamp the Power Quality Analyzer at the respective cables for current measurement	Wrong cable clamped Hazardous position of clamp	Confirm the cable tagging with drawings Make sure the clamp position is safe (not too near with other components in the panel) Proper tagging/label to inform other personnel	
Do the connection at the terminal block for voltage measurement	Loose of connection Wrong terminal tagging for measurement	Make sure the terminals are tighten up Confirm the terminal and cable tagging with drawings Proper tagging/label to inform other personnel	
Housekeeping at work area after work completed	No injuries	General clean up on all working areas	

APPENDIX C

CALCULATION OF RESULTS

<u>Sags due to large load starting analysis</u>

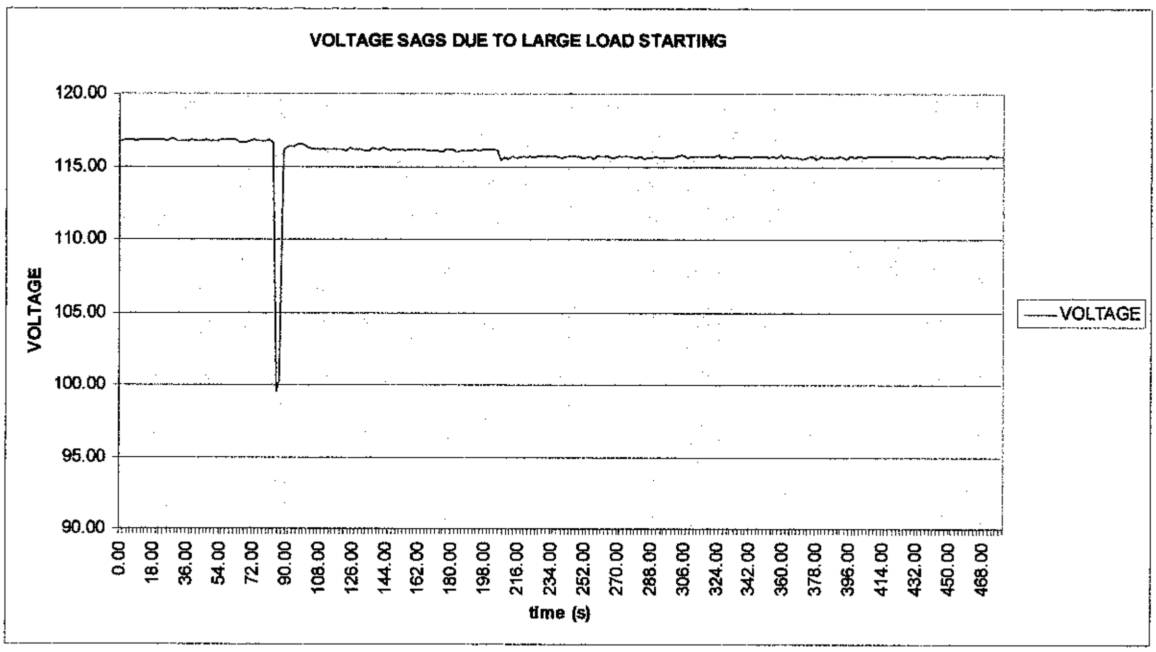
Original data: (already recorded in RMS value)

TIME (s)	VOLTAGE (v)
0.00	116.70
2.00	116.80
4.00	116.80
6.00	116.80
8.00	116.70
10.00	116.80
12.00	116.80
14.00	116.80
16.00	116.80
18.00	116.80
20.00	116.80
22.00	116.80
24.00	116.70
26.00	116.80
28.00	116.90
30.00	116.70
32.00	116.70
34.00	116.70
36.00	116.70
38.00	116.80
40.00	116.70
42.00	116.70
44.00	116.70
46.00	116.80
48.00	116.70
50.00	116.70
52.00	116.70
54.00	116.80
56.00	116.80
58.00	116.80
60.00	116.80
62.00	116.80
64.00	116.60
66.00	116.60
68.00	116.60
70.00	116.70
72.00	116.80
74.00	116.70
76.00	116.70
78.00	116.70
80.00	116.80
82.00	116.60
84.00	99.50
86.00	100.20
88.00	116.10
90.00	116.40
92.00	116.40
94.00	116.40
96.00	116.50
98.00	116.50
100.00	116.40
102.00	116.30
104.00	116.20
106.00	116.20
108.00	116.20
110.00	116.20
112.00	116.20
114.00	116.20
116.00	116.20
118.00	116.20
120.00	116.20
122.00	116.10
124.00	116.30
126.00	116.20
128.00	116.20
130.00	116.20
132.00	116.10
134.00	116.10
136.00	116.30
138.00	116.20
140.00	116.20
142.00	116.30
144.00	116.20
146.00	116.10
148.00	116.20
150.00	116.20
152.00	116.20
154.00	116.10
156.00	116.20
158.00	116.20
160.00	116.20
162.00	116.20
164.00	116.20
166.00	116.10
168.00	116.10
170.00	116.10
172.00	116.10
174.00	116.00
176.00	116.20

178.00	116.20
180.00	116.20
182.00	116.00
184.00	116.10
186.00	116.10
188.00	116.10
190.00	116.10
192.00	116.20
194.00	116.10
196.00	116.20
198.00	116.20
200.00	116.20
202.00	116.20
204.00	116.10
206.00	115.40
208.00	115.60
210.00	115.50
212.00	115.70
214.00	115.60
216.00	115.60
218.00	115.70
220.00	115.60
222.00	115.70
224.00	115.60
226.00	115.70
228.00	115.70
230.00	115.70
232.00	115.70
234.00	115.70
236.00	115.70
238.00	115.60
240.00	115.60
242.00	115.70
244.00	115.70
246.00	115.70
248.00	115.70
250.00	115.60
252.00	115.60
254.00	115.70
256.00	115.50
258.00	115.70
260.00	115.70
262.00	115.70
264.00	115.70
266.00	115.60
268.00	115.60
270.00	115.70
272.00	115.70
274.00	115.70
276.00	115.70
278.00	115.60
280.00	115.60
282.00	115.70
284.00	115.50
286.00	115.60
288.00	115.60
290.00	115.70
292.00	115.60
294.00	115.60
296.00	115.60
298.00	115.60
300.00	115.60
302.00	115.70
304.00	115.80
306.00	115.70
308.00	115.60
310.00	115.70
312.00	115.70
314.00	115.70
316.00	115.70
318.00	115.70
320.00	115.70
322.00	115.70
324.00	115.80
326.00	115.60
328.00	115.70
330.00	115.60
332.00	115.60
334.00	115.70
336.00	115.70
338.00	115.70
340.00	115.70
342.00	115.60
344.00	115.70
346.00	115.70
348.00	115.70
350.00	115.70
352.00	115.60
354.00	115.70
356.00	115.60
358.00	115.80
360.00	115.60
362.00	115.70
364.00	115.60
366.00	115.60
368.00	115.60
370.00	115.50
372.00	115.60
374.00	115.70
376.00	115.60
378.00	115.50
380.00	115.70
382.00	115.60
384.00	115.60
386.00	115.60
388.00	115.60
390.00	115.70
392.00	115.60
394.00	115.50
396.00	115.70
398.00	115.60
400.00	115.70
402.00	115.70
404.00	115.60
406.00	115.70
408.00	115.70
410.00	115.70
412.00	115.70
414.00	115.70
416.00	115.70
418.00	115.70
420.00	115.70
422.00	115.70

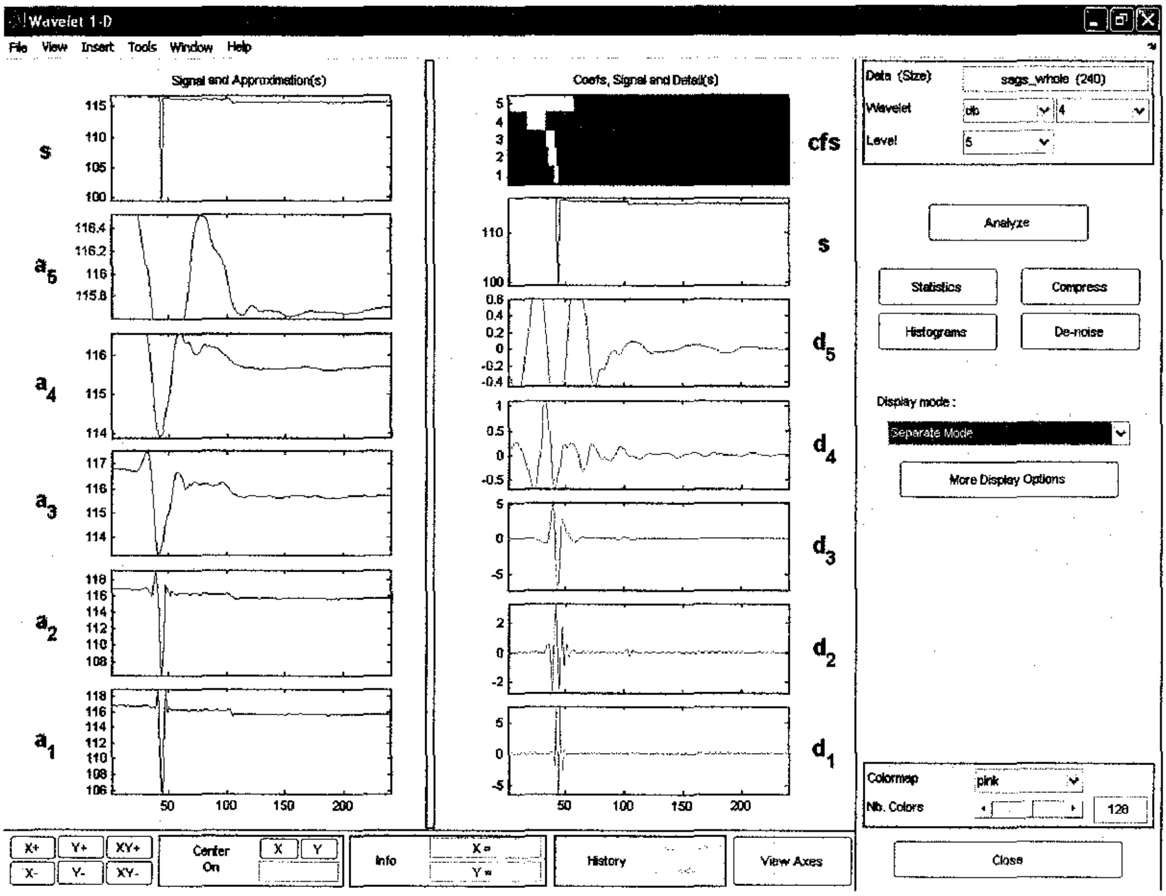
424.00	115.70	444.00	115.60	464.00	115.70
426.00	115.70	446.00	115.60	466.00	115.70
428.00	115.70	448.00	115.70	468.00	115.70
430.00	115.70	450.00	115.70	470.00	115.60
432.00	115.60	452.00	115.70	472.00	115.80
434.00	115.70	454.00	115.70	474.00	115.70
436.00	115.70	456.00	115.70	476.00	115.70
438.00	115.60	458.00	115.70	478.00	115.70
440.00	115.70	460.00	115.70		
442.00	115.70	462.00	115.70		

Plot:



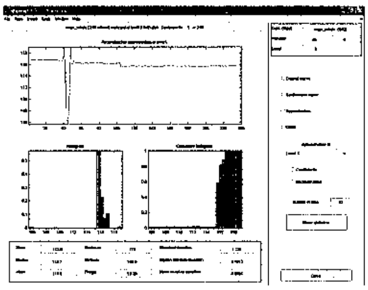
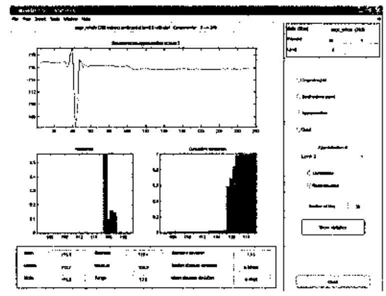
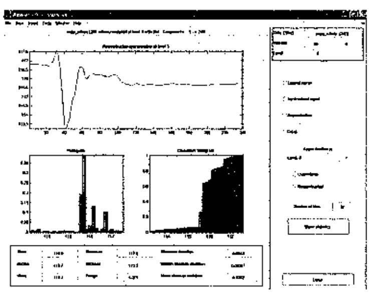
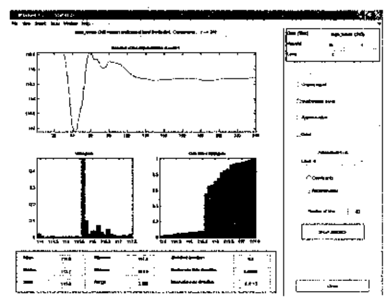
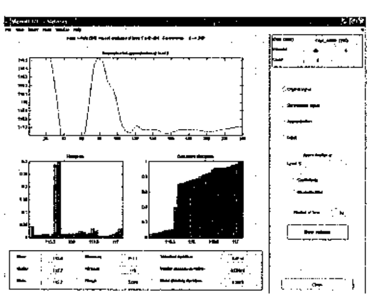
Wavelet Analysis:

Whole waveform analysis



- Amplitude ratio

For approximations:

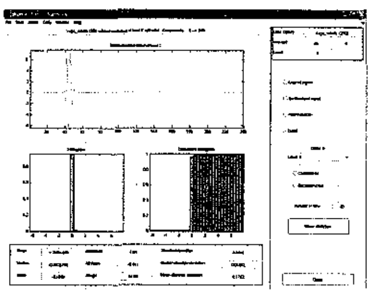
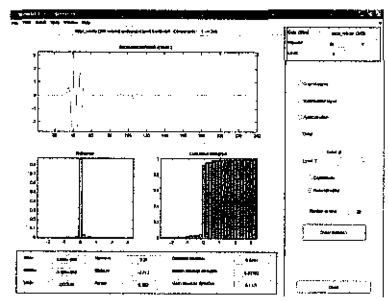
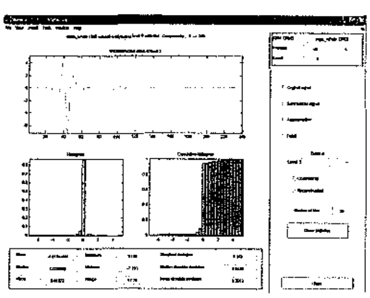
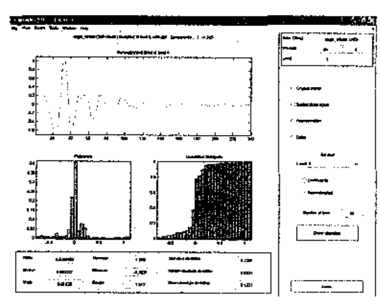
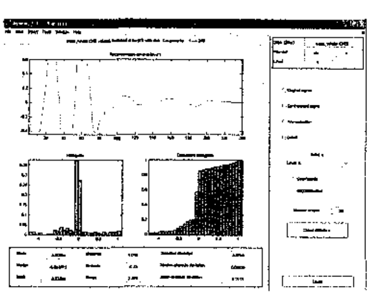
Level 1  Peak Absolute Value = 119	Level 2  Peak Absolute Value = 119.1
Level 3  Peak Absolute Value = 117.5	Level 4  Peak Absolute Value = 117.5
Level 5  Peak Absolute Value = 117.1	

Ratio for each level of approximations:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$$

α_n	**VALUES**
n=1	119/119.1 = 0.9992
n=2	119.1/119.1 = 1.0000
n=3	117.5/119.1 = 0.9866
n=4	117.5/119.1 = 0.9866
n=5	117.1/119.1 = 0.9832

For details:

Level 1  Peak Absolute Value = 7.64	Level 2  Peak Absolute Value = 3.27
Level 3  Peak Absolute Value = 5.156	Level 4  Peak Absolute Value = 1.108
Level 5  Peak Absolute Value = 1.089	

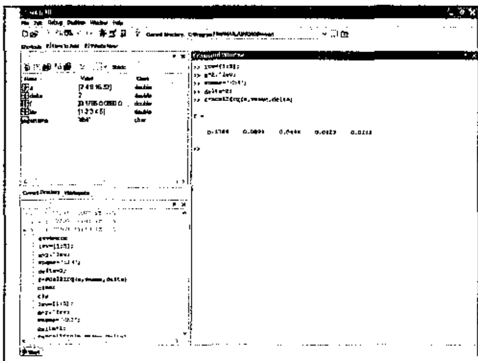
Ratio for each level of details:

α_n = <u>Peak absolute value of level n details</u>

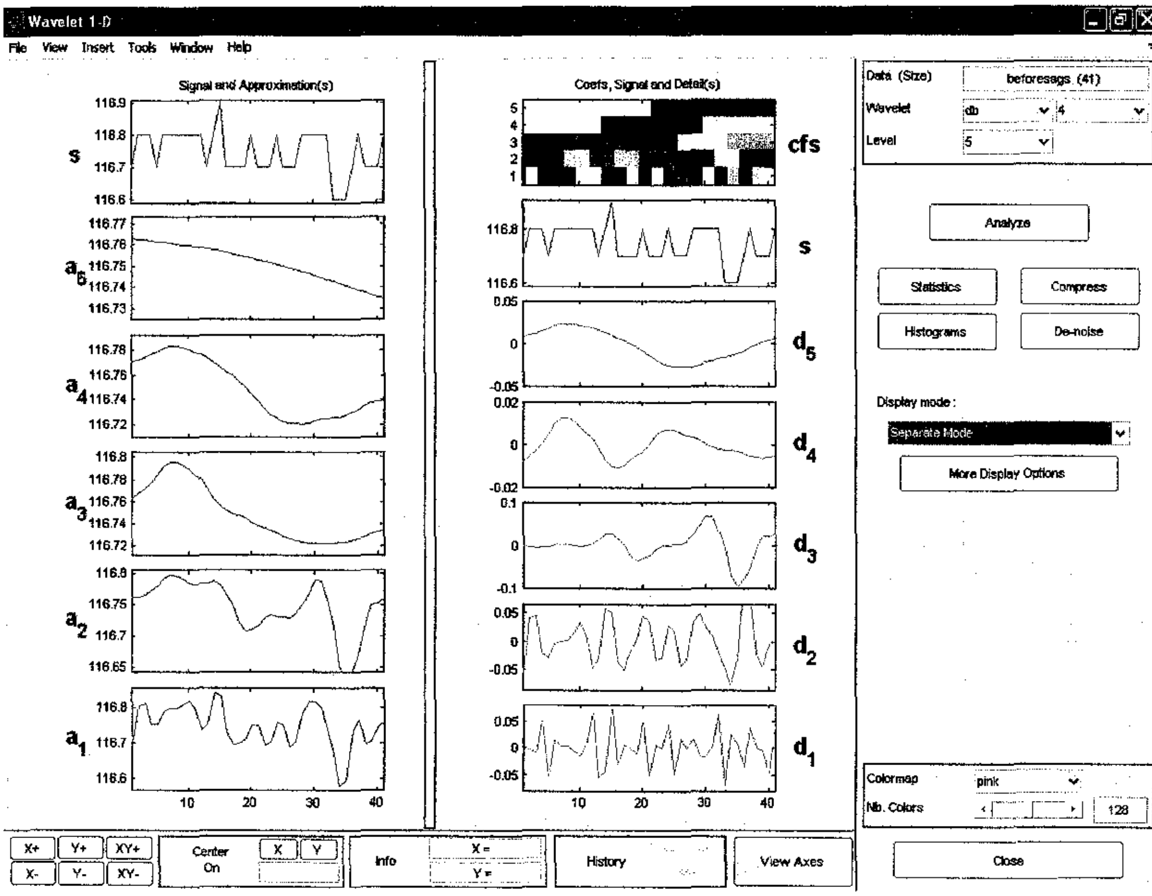
Highest peak absolute value among the levels

α_n	VALUES
n=1	7.64/7.64 = 1.0000
n=2	3.27/7.64 = 0.4280
n=3	5.156/7.64 = 0.6749
n=4	1.108/7.64 = 0.1450
n=5	1.089/7.64 = 0.1425

- Frequency

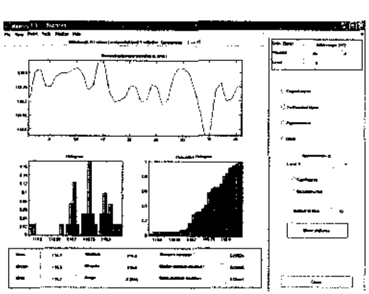
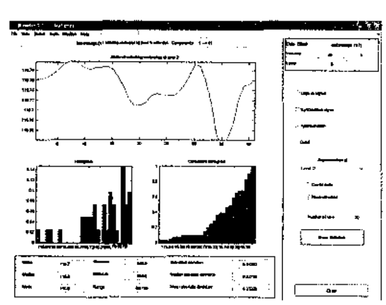
	Result: f = 0.1786 0.0893 0.0446 0.0223 0.0112

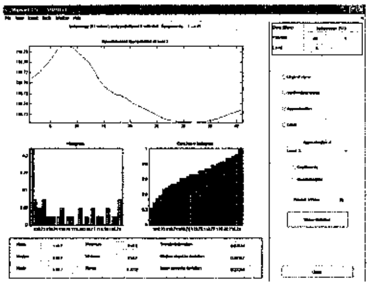
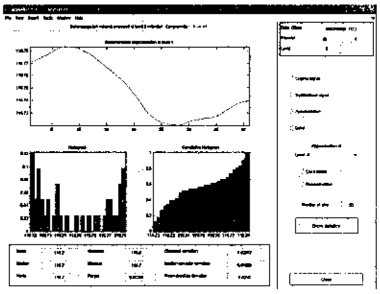
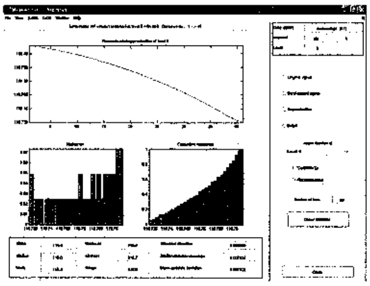
Before sag analysis



- Amplitude ratio

For approximations:

Level 1	Level 2
 Peak Absolute Value = 116.8	 Peak Absolute Value = 116.8

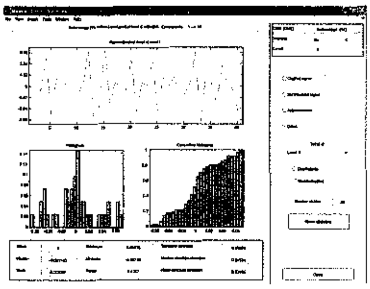
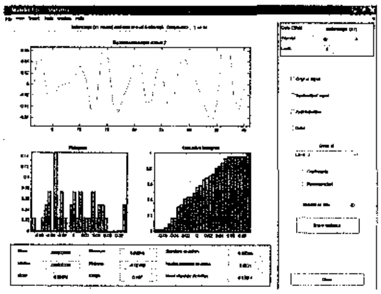
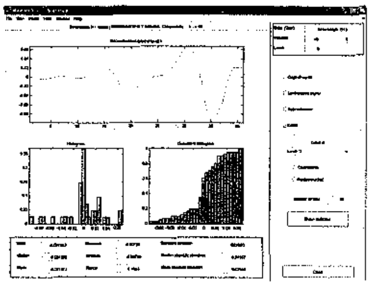
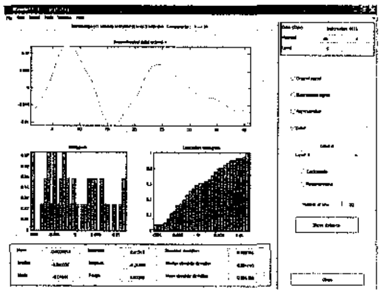
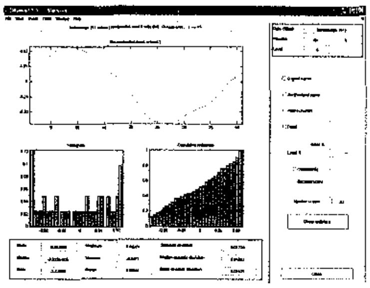
Level 3	Level 4
 Peak Absolute Value = 116.8	 Peak Absolute Value = 116.8
Level 5  Peak Absolute Value = 116.8	

Ratio for each level of approximations:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	116.8/116.8 = 1.0000
n=2	116.8/116.8 = 1.0000
n=3	116.8/116.8 = 1.0000
n=4	116.8/116.8 = 1.0000
n=5	116.8/116.8 = 1.0000

For details:

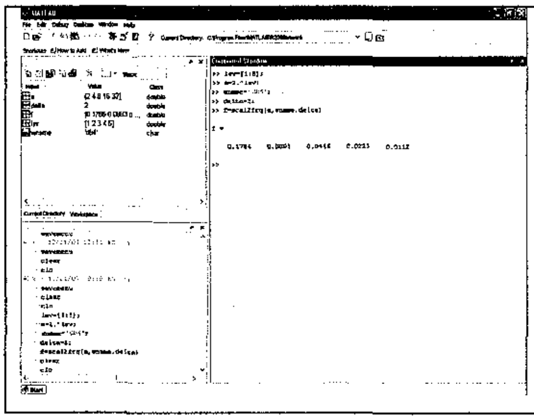
Level 1  Peak Absolute Value = 0.06939	Level 2  Peak Absolute Value = 0.09216
Level 3  Peak Absolute Value = 0.06739	Level 4  Peak Absolute Value = 0.01212
Level 5  Peak Absolute Value = 0.02271	

Ratio for each level of details:

$$\alpha_n = \frac{\text{Peak absolute value of level n details}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	0.06939/0.09216 = 0.7529
n=2	0.09216/0.09216 = 1.0000
n=3	0.06739/0.09216 = 0.7312
n=4	0.01212/0.09216 = 0.1315
n=5	0.02271/0.09216 = 0.2464

- Frequency

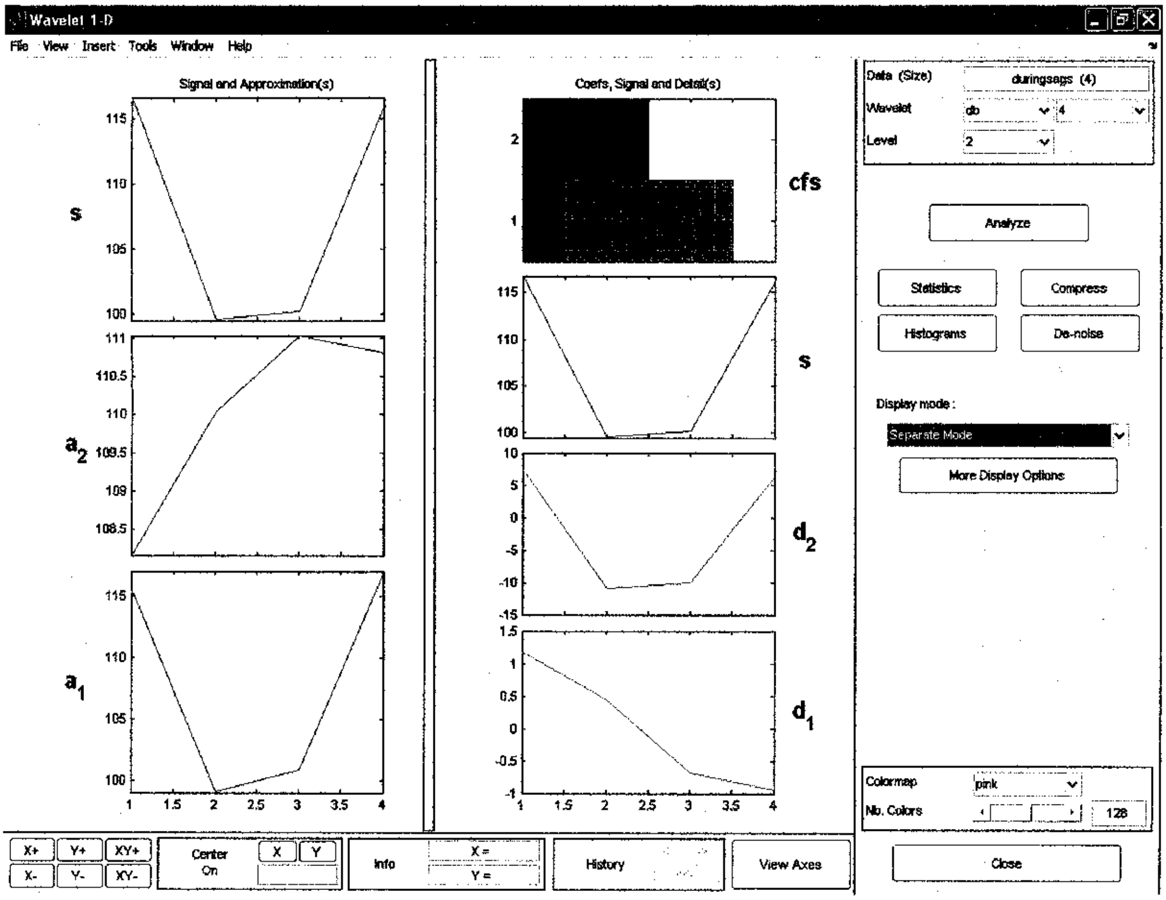


Result:

f =

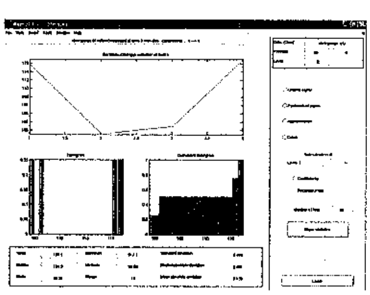
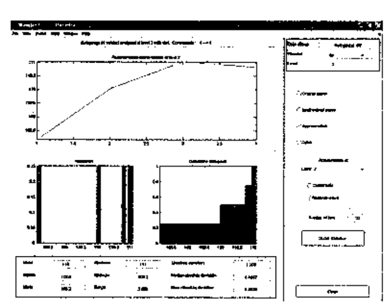
0.1786 0.0893 0.0446 0.0223 0.0112

During sag analysis



- Amplitude ratio

For approximations:

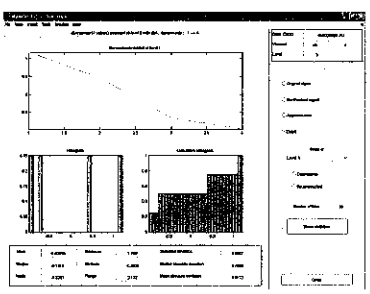
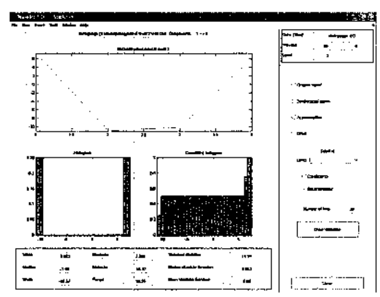
Level 1	Level 2
	
Peak Absolute Value = 117.1	Peak Absolute Value = 111

Ratio for each level of approximations:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	117.1/117.1 = 1.0000
n=2	111/117.1 = 0.9479

For details:

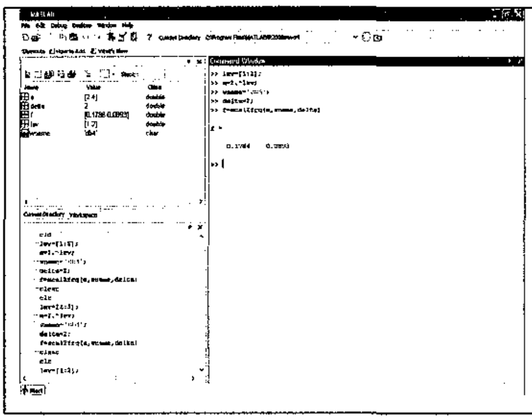
Level 1	Level 2
	
Peak Absolute Value = 1.169	Peak Absolute Value = 7.265

Ratio for each level of details:

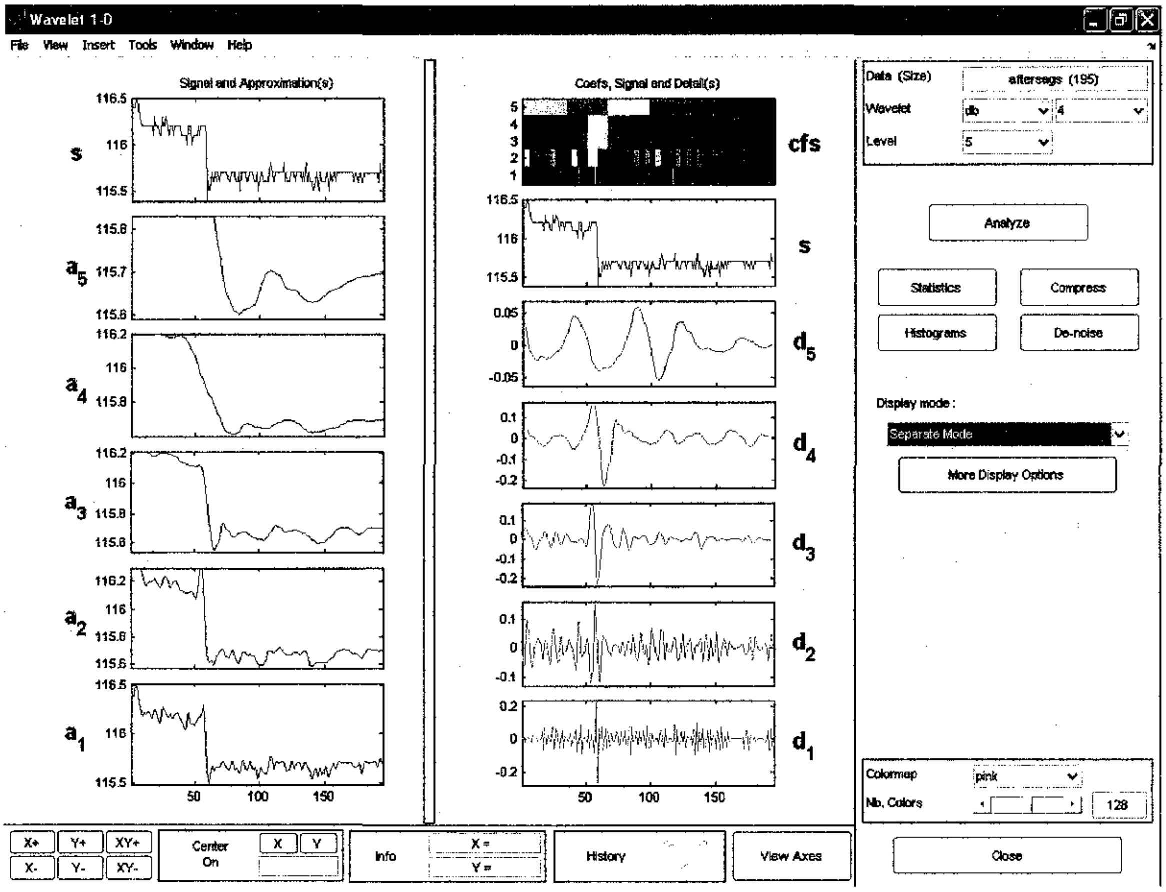
$$\alpha_n = \frac{\text{Peak absolute value of level n details}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	1.169/7.265 = 0.1609
n=2	7.265/7.265 = 1.0000

- Frequency

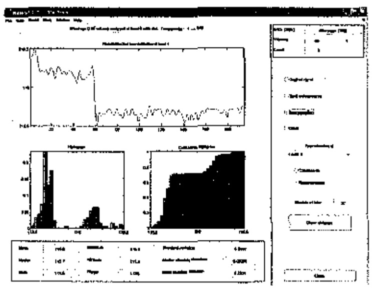
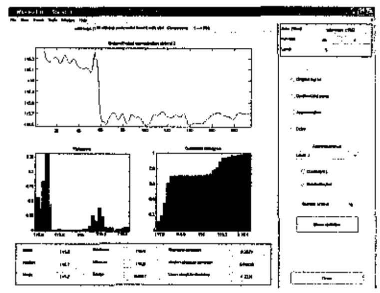
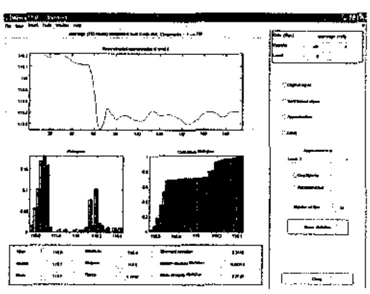
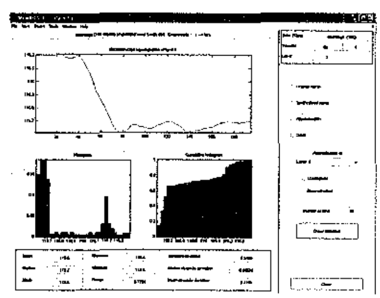
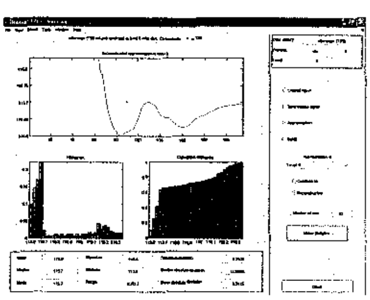
	Result: f = 0.1786 0.0893

After sag analysis



- Amplitude ratio

For approximations:

Level 1  Peak Absolute Value = 116.5	Level 2  Peak Absolute Value = 116.5
Level 3  Peak Absolute Value = 116.4	Level 4  Peak Absolute Value = 116.4
Level 5  Peak Absolute Value = 116.4	

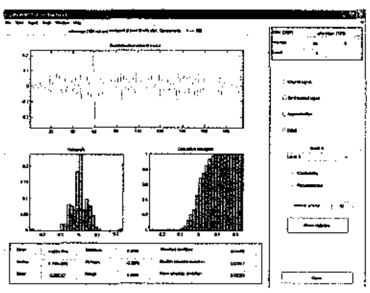
Ratio for each level of approximations:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	116.5/116.5 = 1.0000
n=2	116.5/116.5 = 1.0000
n=3	116.4/116.5 = 0.9991
n=4	116.4/116.5 = 0.9991
n=5	116.4/116.5 = 0.9991

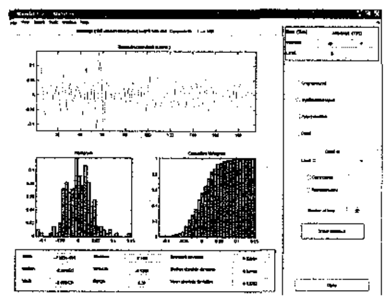
For details:

Level 1



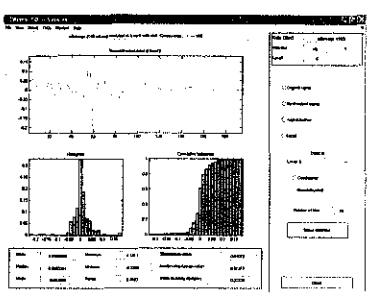
Peak Absolute Value = 0.2306

Level 2



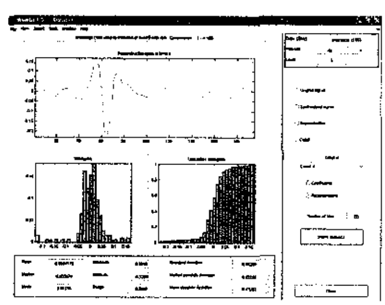
Peak Absolute Value = 0.149

Level 3



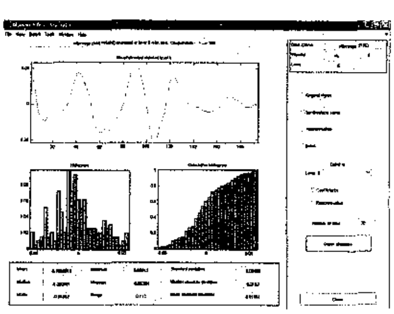
Peak Absolute Value = 0.1817

Level 4



Peak Absolute Value = 0.1669

Level 5



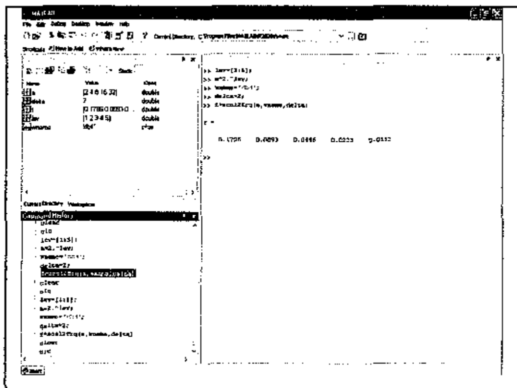
Peak Absolute Value = 0.05813

Ratio for each level of details:

$$\alpha_n = \frac{\text{Peak absolute value of level n details}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	0.2306/0.2306 = 1.0000
n=2	0.149/0.2306 = 0.6461
n=3	0.1817/0.2306 = 0.7879
n=4	0.1669/0.2306 = 0.7238
n=5	0.05813/0.2306 = 0.2521

- Frequency



Result:

f =

0.1786 0.0893 0.0446 0.0223 0.0112

Sags due to fault

Original data:

(Phase data)

TIME (s)	VOLTAGE (V)
1	88.384
2	87.53
3	86.065
4	84.356
5	83.745
6	81.548
7	79.351
8	77.519
9	75.078
10	72.514
11	69.951
12	67.387
13	64.823
14	61.771
15	58.231
16	55.423
17	51.883
18	47.61
19	43.46
20	39.553
21	35.647
22	30.764
23	26.613
24	22.34
25	17.945
26	13.551
27	8.912
28	4.761
29	-0.244
30	-4.395
31	-8.79
32	-12.94
33	-17.335
34	-22.218
35	-25.88
36	-29.787
37	-33.816
38	-37.966
39	-42.117
40	-45.535
41	-49.197
42	-53.348
43	-56.4
44	-60.062
45	-62.748
46	-66.41
47	-68.73
48	-71.782
49	-74.467
50	-76.909
51	-79.717
52	-81.182
53	-83.745
54	-85.454
55	-87.164
56	-88.14
57	-89.239
58	-90.46
59	-91.192
60	-91.192
61	-91.68
62	-90.948
63	-90.215
64	-89.605
65	-88.628
66	-87.652
67	-86.309
68	-85.21
69	-83.501
70	-82.158
71	-79.961
72	-77.397
73	-75.566
74	-73.125
75	-70.439
76	-66.41
77	-65.067
78	-61.893
79	-58.719
80	-55.423
81	-51.273
82	-47.854
83	-43.582
84	-38.821
85	-34.67
86	-30.642
87	-26.491
88	-20.997
89	-18.434
90	-13.551
91	-9.156
92	-4.273
93	-0.488
94	4.273
95	9.278
96	14.283
97	17.823
98	21.73
99	25.758
100	30.275

101	34.426
102	38.088
103	42.483
104	46.878
105	49.93
106	54.08
107	56.888
108	60.184
109	62.626
110	65.922
111	68.852
112	71.782
113	74.59
114	76.909
115	78.984
116	80.083
117	79.961
118	78.74
119	75.81
120	73.003
121	70.439
122	70.317
123	70.073
124	70.927
125	69.951
126	70.439
127	70.073
128	70.195
129	69.584
130	67.753
131	66.654
132	64.945
133	63.358
134	61.893
135	61.649
136	61.527
137	61.405
138	61.405
139	60.917
140	60.062
141	58.353
142	56.034
143	52.738
144	50.784
145	47.61
146	45.535
147	42.605
148	39.675
149	36.623
150	32.473
151	26.247
152	20.021
153	12.452
154	5.249
155	-0.977
156	-6.226
157	-10.255
158	-13.184
159	-16.358
160	-19.166
161	-22.096
162	-25.026
163	-27.59
164	-30.275
165	-33.327
166	-36.501
167	-39.553
168	-42.117
169	-43.338
170	-44.314
171	-44.558
172	-44.925
173	-45.779
174	-47.488
175	-49.686
176	-52.249
177	-53.958
178	-56.522
179	-57.499
180	-57.743
181	-58.231
182	-59.33
183	-60.428
184	-61.771
185	-62.748
186	-64.457
187	-64.823
188	-64.335
189	-64.579
190	-63.847
191	-63.603
192	-62.138
193	-61.527
194	-60.551
195	-59.33
196	-57.743
197	-55.667
198	-54.935
199	-53.714
200	-52.127
201	-50.906
202	-49.319
203	-47.61
204	-44.803
205	-42.483
206	-40.896
207	-38.088
208	-35.647
209	-33.693
210	-31.496
211	-28.566
212	-25.514
213	-22.34
214	-20.021
215	-16.236
216	-12.94
217	-10.01
218	-8.057
219	-3.906
220	-0.488
221	2.808
222	6.226
223	9.522

224	13.429	265	50.662	306	-51.273
225	15.748	266	49.075	307	-52.982
226	18.434	267	46.756	308	-54.447
227	21.486	268	44.803	309	-55.912
228	24.416	269	42.483	310	-56.766
229	27.467	270	40.53	311	-57.743
230	30.153	271	38.21	312	-58.597
231	32.473	272	35.647	313	-60.062
232	35.891	273	33.083	314	-59.696
233	37.112	274	30.275	315	-60.062
234	39.553	275	27.834	316	-60.551
235	41.262	276	24.538	317	-60.306
236	43.338	277	21.974	318	-59.818
237	45.291	278	19.288	319	-59.208
238	46.756	279	16.114	320	-59.086
239	48.465	280	13.306	321	-57.377
240	49.441	281	10.743	322	-57.377
241	51.517	282	7.569	323	-56.4
242	53.104	283	4.761	324	-55.179
243	53.958	284	1.953	325	-53.836
244	55.057	285	-0.977	326	-52.249
245	56.156	286	-4.029	327	-51.029
246	56.156	287	-6.714	328	-49.564
247	57.865	288	-10.377	329	-47.732
248	59.086	289	-12.94	330	-45.901
249	59.818	290	-15.748	331	-44.558
250	60.428	291	-17.945	332	-42.239
251	60.551	292	-21.119	333	-39.919
252	61.283	293	-23.683	334	-37.356
253	61.405	294	-26.003	335	-35.403
254	60.795	295	-28.688	336	-34.06
255	60.306	296	-31.252	337	-31.984
256	60.917	297	-33.816	338	-30.153
257	60.428	298	-35.647	339	-28.81
258	60.673	299	-38.332	340	-26.979
259	58.475	300	-40.774	341	-24.782
260	57.987	301	-42.361	342	-22.462
261	56.644	302	-44.68	343	-20.387
262	55.057	303	-45.535	344	-18.312
263	53.958	304	-48.465	345	-14.771
264	52.86	305	-49.686	346	-11.475

347	-9.644	388	67.509	429	-54.447
348	-6.592	389	66.899	430	-57.499
349	-3.906	390	65.8	431	-60.673
350	-1.099	391	64.945	432	-62.504
351	1.221	392	63.603	433	-65.312
352	5.005	393	62.626	434	-67.387
353	8.545	394	60.428	435	-69.706
354	11.597	395	58.841	436	-72.27
355	14.649	396	56.4	437	-75.322
356	17.823	397	53.958	438	-77.275
357	21.119	398	52.005	439	-78.984
358	24.66	399	49.93	440	-81.304
359	28.2	400	49.197	441	-82.769
360	31.008	401	48.221	442	-82.769
361	34.182	402	46.634	443	-83.99
362	36.867	403	43.826	444	-83.99
363	39.553	404	41.629	445	-84.234
364	41.629	405	37.966	446	-84.722
365	44.314	406	34.304	447	-84.722
366	46.756	407	30.031	448	-84.6
367	49.319	408	25.88	449	-83.379
368	51.761	409	21.608	450	-82.402
369	54.691	410	17.457	451	-81.548
370	56.888	411	13.795	452	-80.693
371	59.33	412	10.377	453	-79.595
372	60.306	413	6.958	454	-78.374
373	61.771	414	2.808	455	-76.787
374	62.87	415	-1.465	456	-75.078
375	63.725	416	-5.493	457	-73.735
376	65.067	417	-9.766	458	-71.171
377	66.166	418	-14.283	459	-69.218
378	67.631	419	-18.312	460	-66.41
379	68.73	420	-22.829	461	-64.091
380	69.462	421	-27.59	462	-61.161
381	69.828	422	-30.153	463	-57.987
382	70.561	423	-33.816	464	-54.691
383	70.683	424	-36.623	465	-51.517
384	70.317	425	-40.53	466	-47.732
385	70.073	426	-43.338	467	-43.093
386	69.096	427	-47.122	468	-39.431
387	68.364	428	-51.151	469	-35.769

470	-31.74	511	85.21	552	-42.849
471	-27.467	512	84.6	553	-46.878
472	-22.829	513	83.623	554	-50.784
473	-18.8	514	82.891	555	-54.325
474	-15.138	515	81.548	556	-57.254
475	-11.231	516	80.571	557	-60.917
476	-6.836	517	79.228	558	-62.87
477	-2.93	518	77.764	559	-66.532
478	1.831	519	76.543	560	-70.195
479	6.104	520	74.101	561	-71.904
480	10.377	521	72.27	562	-73.857
481	14.161	522	70.561	563	-76.665
482	18.8	523	67.143	564	-78.862
483	23.073	524	65.8	565	-80.693
484	27.345	525	62.748	566	-83.501
485	31.13	526	59.574	567	-84.356
486	36.135	527	56.156	568	-85.21
487	38.943	528	52.738	569	-86.797
488	42.361	529	48.953	570	-87.652
489	45.901	530	45.535	571	-87.652
490	49.564	531	41.873	572	-87.408
491	51.517	532	38.088	573	-87.896
492	56.888	533	33.327	574	-87.774
493	59.696	534	29.177	575	-87.286
494	62.626	535	25.026	576	-86.187
495	64.823	536	20.753	577	-85.821
496	67.387	537	16.969	578	-84.722
497	70.195	538	12.818	579	-83.257
498	72.392	539	9.156	580	-82.402
499	74.834	540	4.883	581	-80.938
500	76.665	541	0.732	582	-79.228
501	78.374	542	-2.197	583	-77.275
502	80.205	543	-7.203	584	-75.2
503	82.158	544	-11.109	585	-73.735
504	83.379	545	-16.236	586	-71.049
505	84.112	546	-20.021	587	-68.852
506	84.844	547	-23.927	588	-66.166
507	85.332	548	-27.834	589	-63.358
508	85.699	549	-31.984	590	-60.428
509	85.943	550	-36.135	591	-57.01
510	85.454	551	-39.553	592	-53.226

593	-50.174
594	-46.267
595	-42.361
596	-37.966
597	-33.816
598	-29.299
599	-25.27
600	-20.875
601	-17.213
602	-12.696
603	-8.301
604	-4.273
605	-0.122
606	4.273
607	8.79
608	12.696
609	17.213
610	21.608
611	26.491
612	30.031
613	33.571
614	37.6
615	41.873
616	45.047
617	49.686
618	52.738
619	56.278
620	58.841
621	62.138
622	65.434
623	69.096
624	70.561
625	73.369
626	76.054
627	78.13
628	80.327
629	82.402
630	83.867
631	85.088
632	86.187
633	87.164
634	88.384
635	88.995
636	88.751
637	88.262
638	89.117
639	87.774
640	87.164
641	86.065
642	84.722
643	83.623
644	82.647
645	80.693
646	79.473
647	78.008
648	75.81
649	74.223
650	71.66
651	69.34
652	66.41
653	63.847
654	60.795
655	57.499
656	53.592
657	49.686
658	46.39
659	41.995
660	38.21
661	33.571
662	29.543
663	25.27
664	20.875
665	16.847
666	12.818
667	7.935
668	3.296
669	-1.587
670	-5.005
671	-9.522
672	-14.039
673	-18.434
674	-22.462
675	-25.88
676	-30.275
677	-34.182
678	-38.699
679	-42.483
680	-46.023
681	-49.564
682	-53.348
683	-56.888
684	-60.184
685	-63.236
686	-66.288
687	-69.218
688	-71.904
689	-74.834
690	-76.909
691	-79.473
692	-81.304
693	-83.257
694	-84.6
695	-86.553
696	-87.652
697	-88.995
698	-89.483
699	-90.093
700	-90.093
701	-90.582
702	-89.605
703	-88.751
704	-88.262
705	-87.286
706	-86.187
707	-84.844
708	-83.867
709	-82.402
710	-80.449
711	-79.228
712	-76.299
713	-74.712
714	-72.026
715	-69.462

716	-66.777
717	-63.847
718	-59.94
719	-56.766
720	-53.104
721	-49.319
722	-44.925
723	-41.384
724	-37.112
725	-32.106
726	-27.956
727	-23.805
728	-19.41
729	-15.016
730	-10.621
731	-6.714
732	-2.564
733	1.709
734	6.47
735	10.255
736	14.649
737	18.8
738	23.439
739	27.956
740	31.984
741	36.135
742	40.408
743	44.314
744	47.854
745	52.249
746	55.179
747	57.377
748	62.138
749	64.701
750	67.753
751	70.439
752	73.491
753	75.688
754	78.496
755	80.571
756	82.402

757	84.478
758	85.699
759	87.53
760	88.628
761	89.117
762	90.582
763	90.093
764	90.215
765	91.07
766	89.849
767	89.239
768	88.14
769	86.675
770	86.187
771	84.966
772	83.745
773	80.938
774	80.449
775	78.13
776	76.177
777	74.223
778	72.758
779	68.608
780	65.678
781	63.48
782	59.818
783	56.4
784	52.982
785	48.953
786	45.169
787	40.774
788	36.867
789	32.351
790	28.322
791	23.683
792	20.021
793	15.504
794	10.865
795	6.348
796	2.075
797	-2.442

798	-6.592
799	-11.475
800	-15.504
801	-20.387
802	-24.171
803	-27.956
804	-32.229
805	-36.745
806	-40.408
807	-44.314
808	-48.343
809	-51.639
810	-55.79
811	-59.452
812	-62.26
813	-64.945
814	-67.387
815	-71.171
816	-74.345
817	-76.909
818	-79.106
819	-81.06
820	-83.257
821	-85.21
822	-86.919
823	-88.751
824	-89.361
825	-90.704
826	-91.436
827	-92.535
828	-91.436
829	-90.826
830	-90.582
831	-89.971
832	-89.605
833	-88.384
834	-87.164
835	-85.821
836	-83.135
837	-82.28
838	-80.693

839	-78.984	880	75.078	921	14.039
840	-76.421	881	77.397	922	10.01
841	-74.223	882	79.106	923	5.371
842	-71.904	883	81.548	924	0.855
843	-68.974	884	83.257	925	-3.54
844	-66.044	885	85.577	926	-7.447
845	-62.87	886	86.919	927	-12.208
846	-59.452	887	87.652	928	-16.358
847	-56.156	888	89.605	929	-21.242
848	-51.517	889	90.215	930	-25.27
849	-48.709	890	90.826	931	-29.299
850	-44.436	891	90.948	932	-33.938
851	-39.431	892	91.436	933	-37.844
852	-35.403	893	90.826	934	-41.873
853	-31.496	894	90.215	935	-45.535
854	-26.247	895	89.849	936	-49.564
855	-22.096	896	89.361	937	-53.47
856	-17.945	897	87.774	938	-57.132
857	-13.673	898	86.919	939	-60.306
858	-9.034	899	85.332	940	-64.213
859	-4.883	900	84.356	941	-67.387
860	0	901	82.402	942	-69.096
861	4.029	902	80.205	943	-72.636
862	8.423	903	78.008	944	-75.078
863	12.696	904	76.421	945	-78.252
864	18.19	905	73.613	946	-80.449
865	22.34	906	71.293	947	-82.402
866	25.636	907	67.143	948	-84.6
867	30.153	908	65.922	949	-86.675
868	34.67	909	63.847	950	-88.384
869	38.577	910	59.574	951	-89.361
870	42.361	911	55.912	952	-90.582
871	46.145	912	52.371	953	-91.436
872	50.296	913	48.343	954	-91.925
873	53.836	914	44.314	955	-92.169
874	57.621	915	40.164	956	-92.047
875	59.33	916	35.28	957	-91.925
876	63.969	917	31.496	958	-91.68
877	66.532	918	27.223	959	-91.07
878	69.584	919	22.951	960	-89.849
879	71.904	920	19.166	961	-88.628

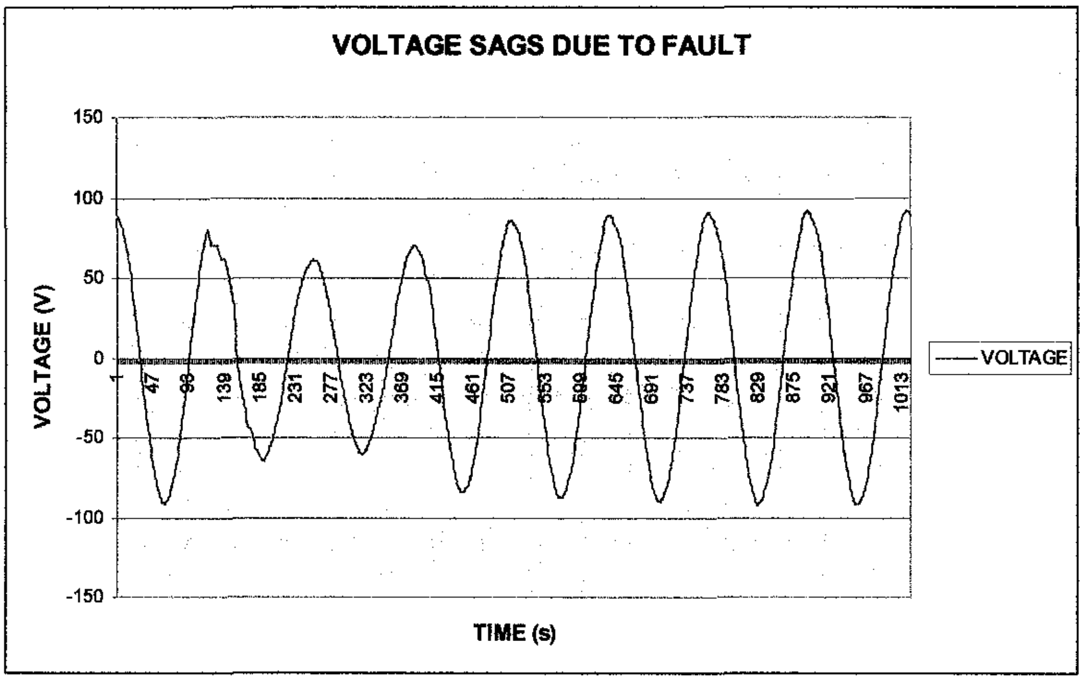
962	-88.018
963	-86.187
964	-84.722
965	-83.013
966	-81.06
967	-78.984
968	-77.397
969	-74.59
970	-72.148
971	-68.608
972	-65.922
973	-62.748
974	-59.574
975	-55.667
976	-52.249
977	-48.465
978	-43.948
979	-39.553
980	-34.914
981	-31.008
982	-26.491
983	-22.096
984	-17.945
985	-13.551
986	-8.668
987	-4.151
988	-0.366
989	4.395
990	9.034
991	13.795
992	17.701
993	22.584
994	26.735
995	32.106
996	35.158
997	39.431
998	43.704
999	48.343
1000	51.395
1001	54.691
1002	58.475

1003	61.893
1004	65.067
1005	67.509
1006	70.561
1007	73.491
1008	75.322
1009	78.252
1010	80.693
1011	82.647
1012	84.356
1013	86.675
1014	88.14
1015	89.605
1016	90.215
1017	90.704
1018	91.802
1019	92.169
1020	92.169
1021	91.436
1022	91.192
1023	90.46
1024	88.995

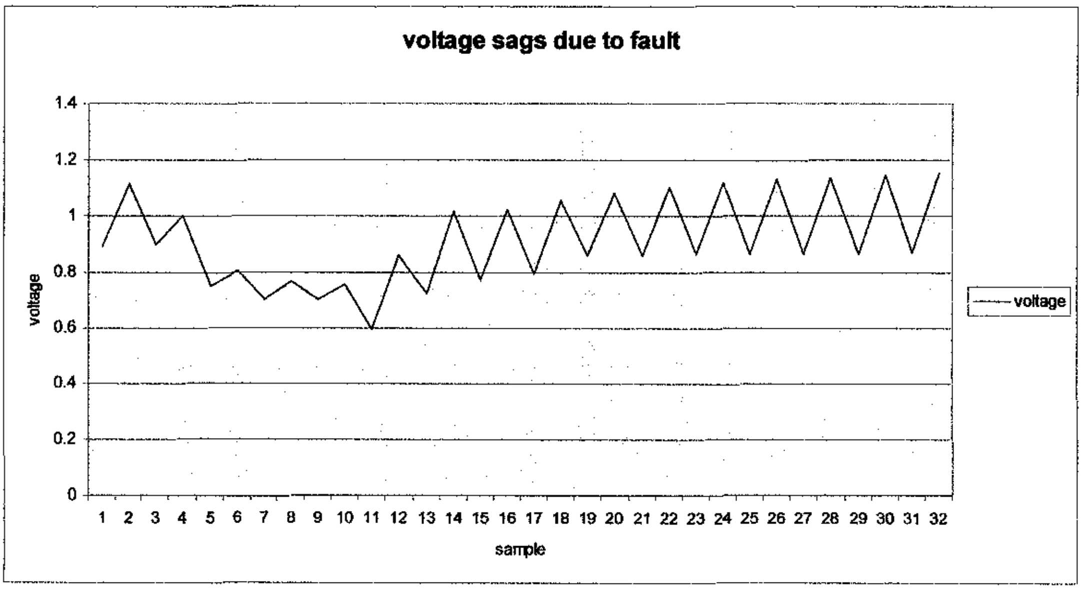
(RMS data)

SAMPLE	VOLTAGE (V)
1	0.89337
2	1.115206
3	0.895284
4	0.99767
5	0.752208
6	0.806516
7	0.703378
8	0.764938
9	0.703252
10	0.757076
11	0.594659
12	0.861931
13	0.725085
14	1.016431
15	0.775597
16	1.022585
17	0.792094
18	1.052274
19	0.859348
20	1.080928
21	0.862052
22	1.104236
23	0.864259
24	1.117027
25	0.864004
26	1.128211
27	0.866498
28	1.134642
29	0.864184
30	1.14787
31	0.870611

Plot:



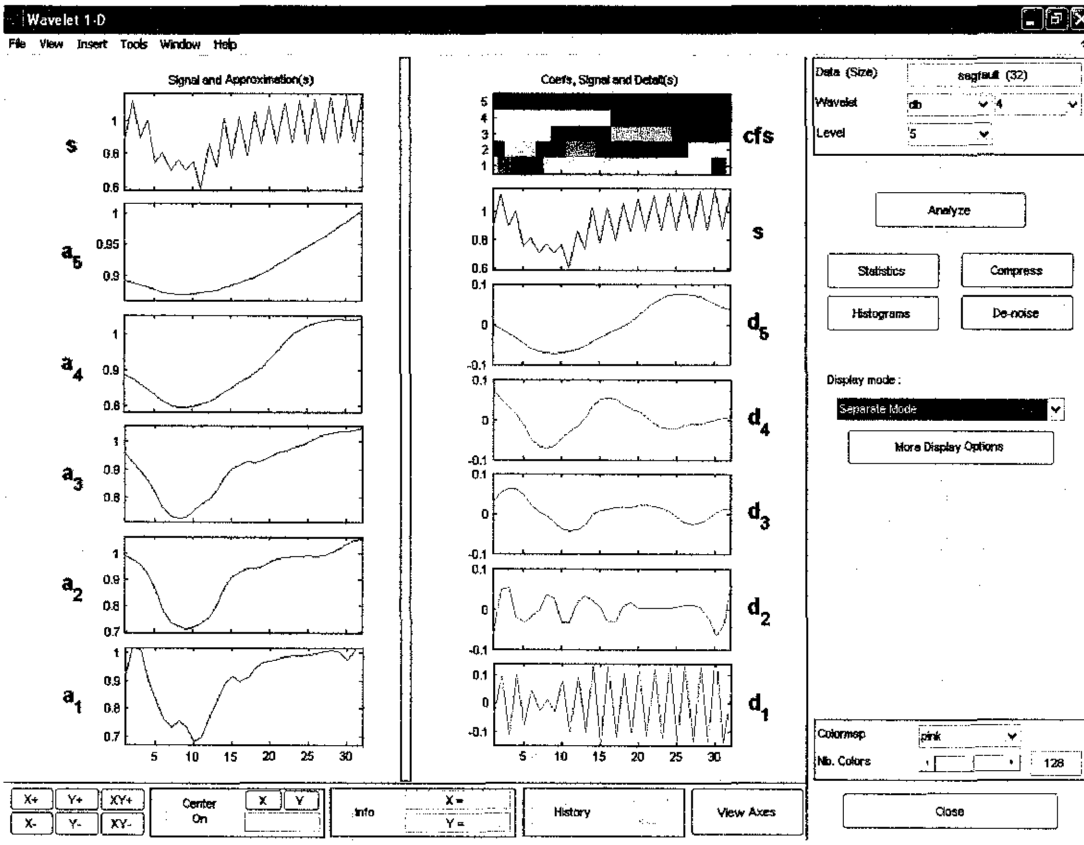
Waveform for instantaneous values



Waveform for RMS values

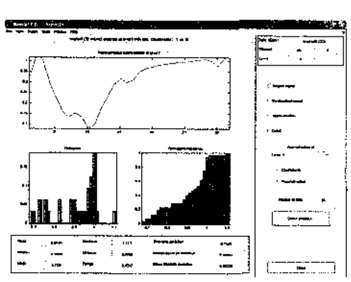
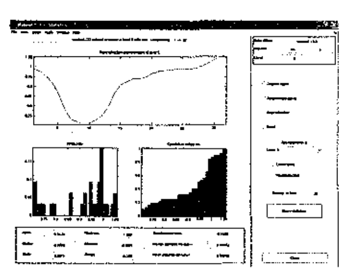
Wavelet Analysis:

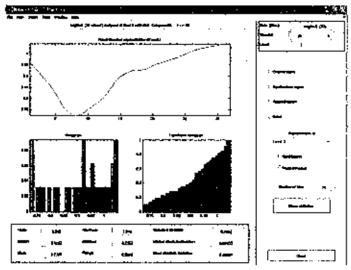
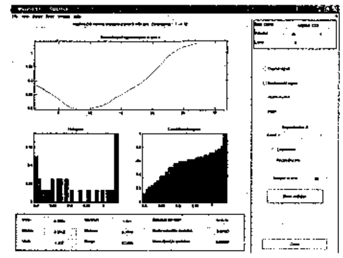
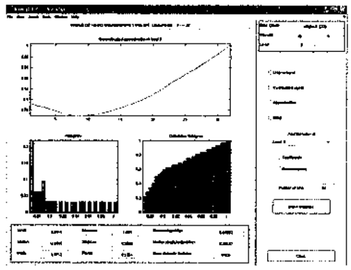
__Whole waveform analysis__



- Amplitude ratio

For approximations:

Level 1	Level 2
 Peak Absolute Value = 1.111	 Peak Absolute Value = 1.055

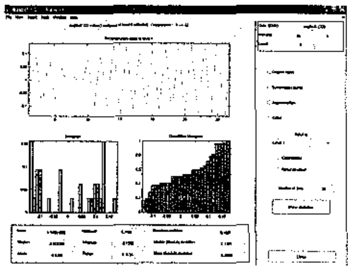
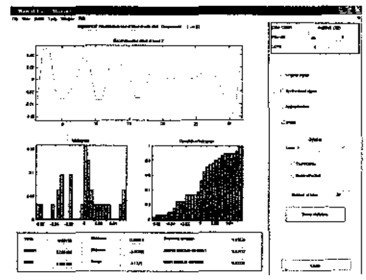
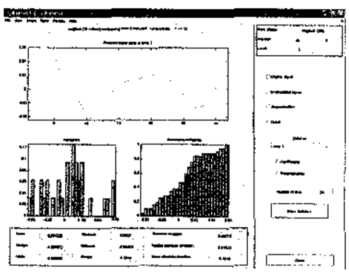
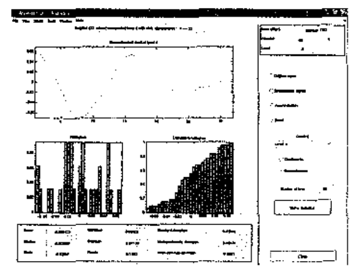
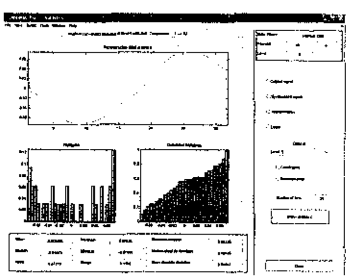
Level 3  Peak Absolute Value = 1.046	Level 4  Peak Absolute Value = 1.041
Level 5  Peak Absolute Value = 1.004	

Ratio for each level of approximations:

$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$

α_n	VALUES
n=1	1.111/1.111 = 1.0000
n=2	1.055/1.111 = 0.9496
n=3	1.046/1.111 = 0.9415
n=4	1.041/1.111 = 0.9370
n=5	1.004/1.111 = 0.9037

For details:

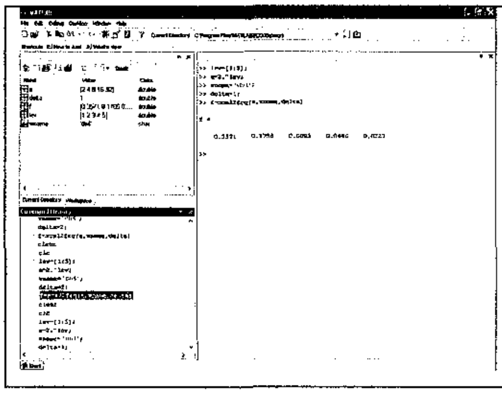
Level 1  Peak Absolute Value = 0.1751	Level 2  Peak Absolute Value = 0.05613
Level 3  Peak Absolute Value = 0.0601	Level 4  Peak Absolute Value = 0.06909
Level 5  Peak Absolute Value = 0.07426	

Ratio for each level of details:

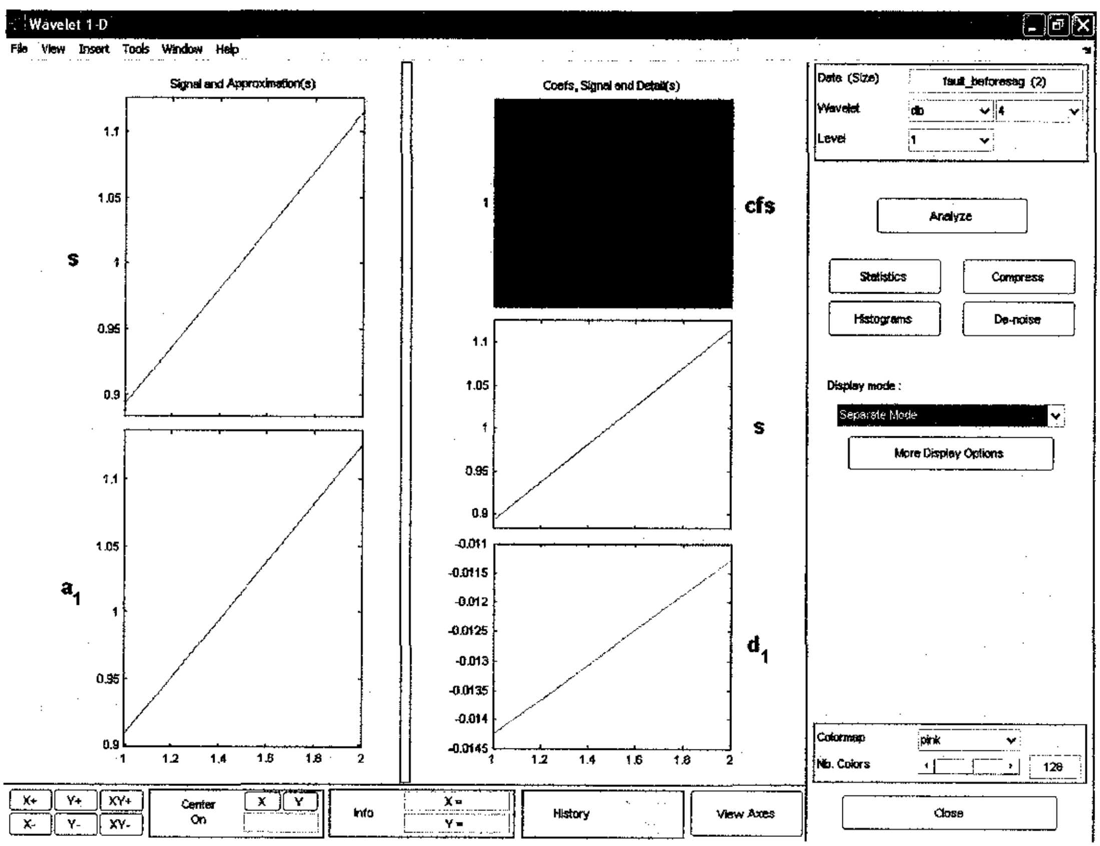
$$\alpha_n = \frac{\text{Peak absolute value of level n details}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	0.1751/0.1751 = 1.0000
n=2	0.05613/0.1751 = 0.3206
n=3	0.0601/0.1751 = 0.3432
n=4	0.06909/0.1751 = 0.3946
n=5	0.07426/0.1751 = 0.4241

- Frequency

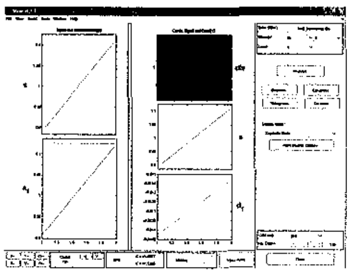
	Result: f= 0.3571 0.1786 0.0893 0.0446 0.0223

Before sag analysis



- Amplitude ratio

For approximations:

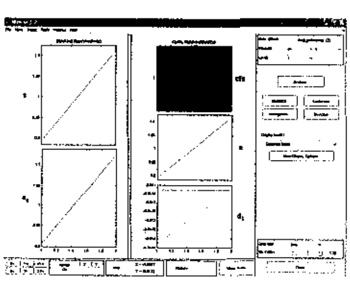
Level 1  Peak Absolute Value = 1.1255	

Ratio for each level of approximations:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$$

α_n	**VALUES**
n=1	1.1255/1.1255 = 1.0000

For details:

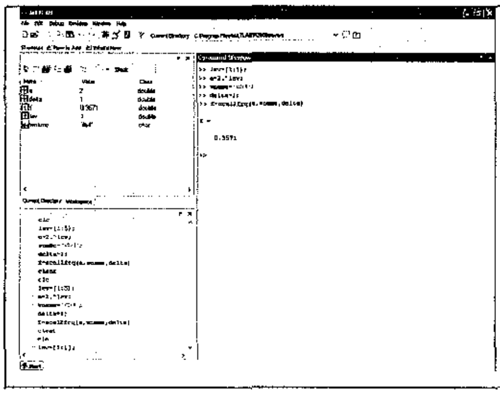
Level 1  Peak Absolute Value = 0.0133	

Ratio for each level of details:

$$\alpha_n = \frac{\text{Peak absolute value of level n details}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	0.0133/0.0133 = 1.0000

- Frequency

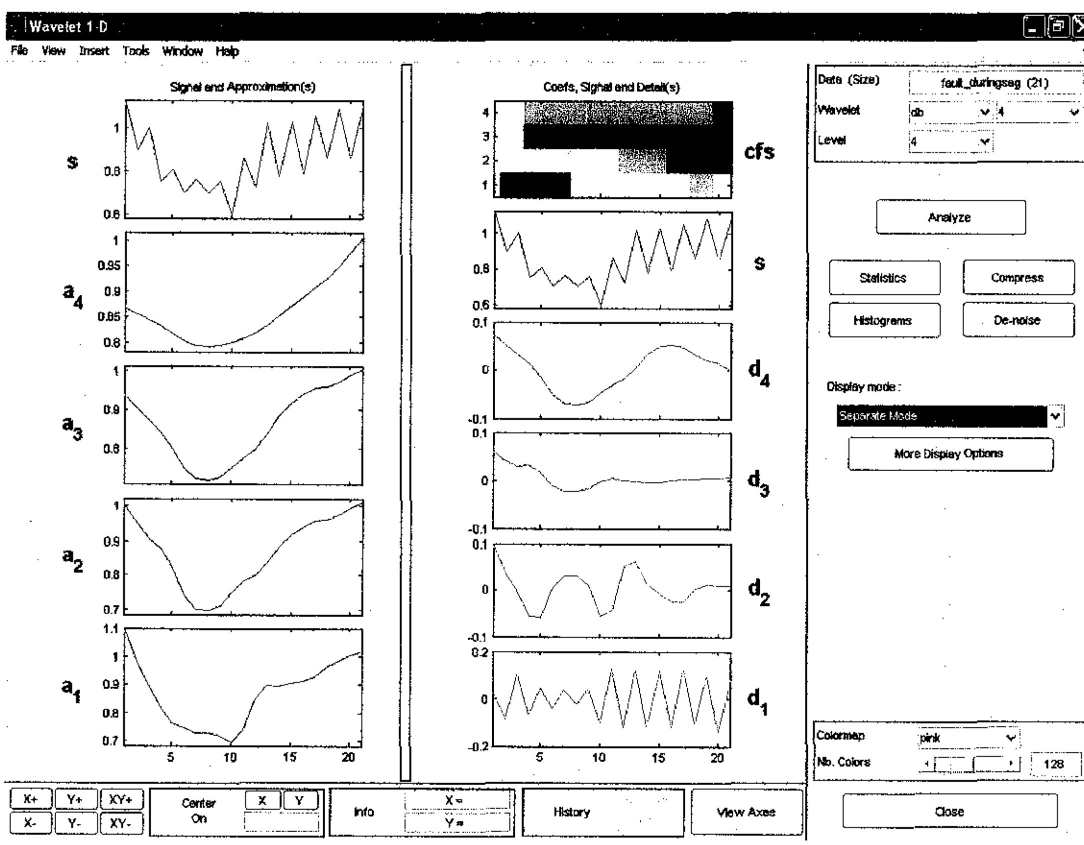


Result:

f =

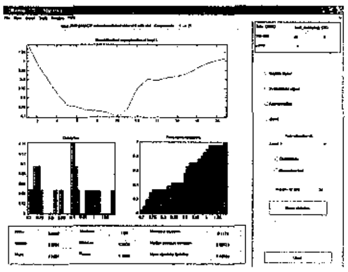
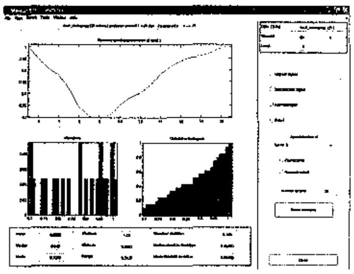
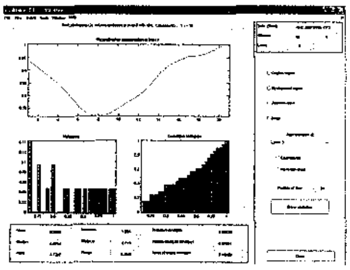
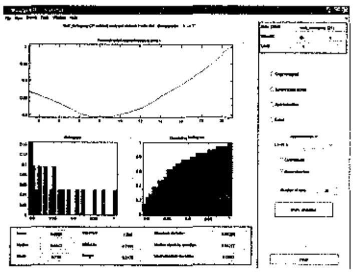
0.3571

During sag analysis



- Amplitude ratio

For approximations:

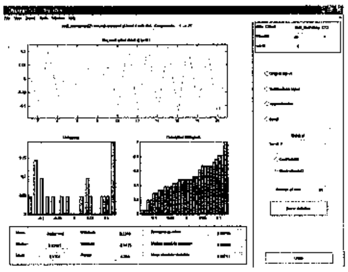
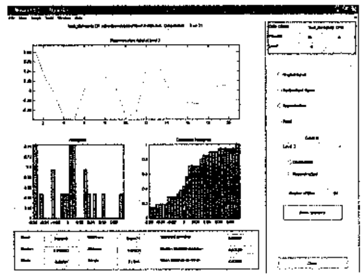
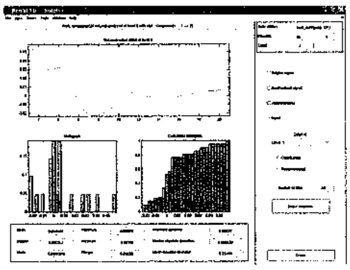
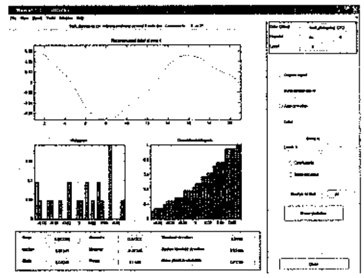
Level 1	Level 2
 Peak Absolute Value = 1.09	 Peak Absolute Value = 1.01
Level 3  Peak Absolute Value = 1.004	Level 4  Peak Absolute Value = 1.005

Ratio for each level of approximations:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	1.09/1.09 = 1.0000
n=2	1.01/1.09 = 0.9266
n=3	1.004/1.09 =0.9211
n=4	1.005/1.09 = 0.9220

For details:

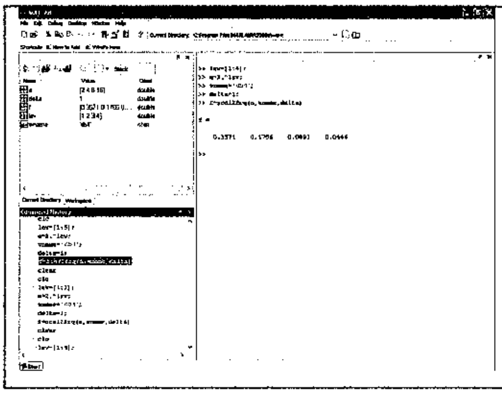
Level 1  Peak Absolute Value = 0.1245	Level 2  Peak Absolute Value = 0.09471
Level 3  Peak Absolute Value = 0.05879	Level 4  Peak Absolute Value = 0.07203

Ratio for each level of details:

$$\alpha_n = \frac{\text{Peak absolute value of level n details}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	0.1245/0.1245 = 1.0000
n=2	0.09471/0.1245 = 0.7607
n=3	0.05879/0.1245 = 0.4722
n=4	0.07203/0.1245 = 0.5786

- Frequency

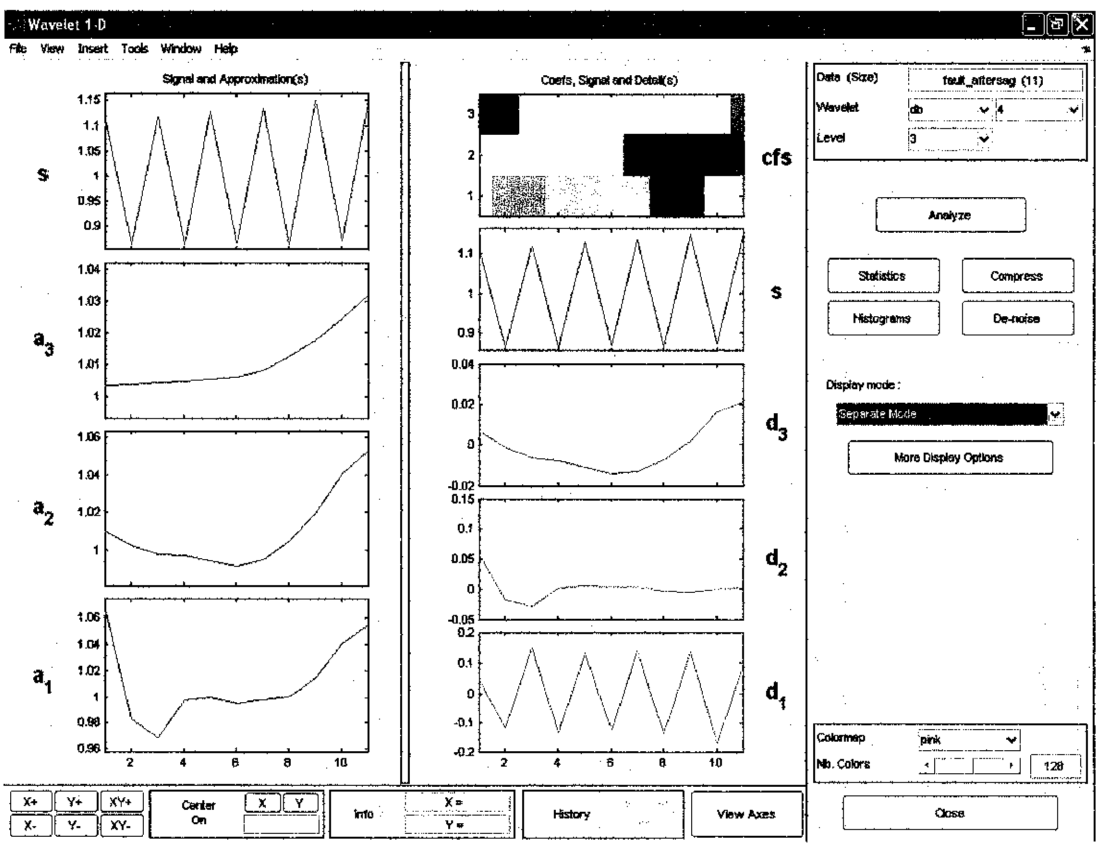


Result:

f =

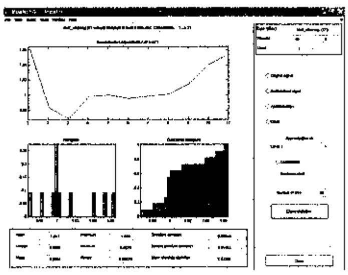
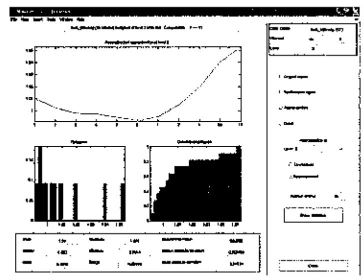
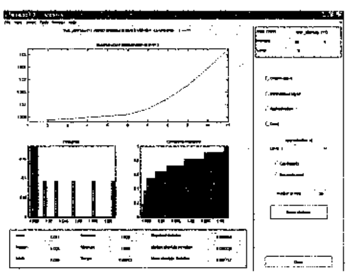
0.3571   0.1786   0.0893   0.0446

After sag analysis



- Amplitude ratio

For approximations:

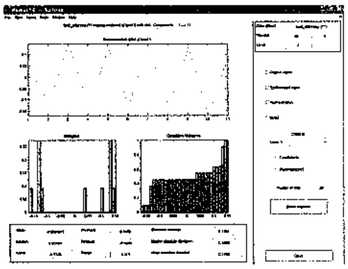
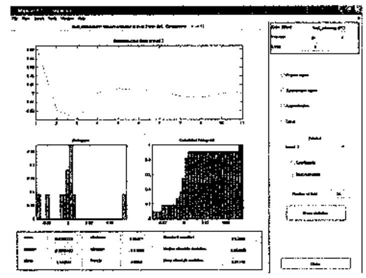
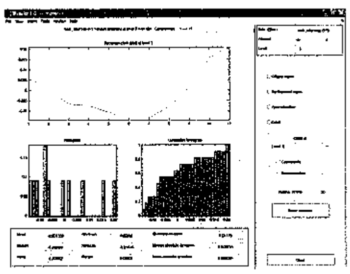
Level 1  Peak Absolute Value = 1.065	Level 2  Peak Absolute Value = 1.053
Level 3  Peak Absolute Value = 1.032	

Ratio for each level of approximations:

$$\alpha_n = \frac{\text{Peak absolute value of level n approximation}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	1.065/1.065 = 1.0000
n=2	1.053/1.065 = 0.9887
n=3	1.032/1.065 = 0.9690

For details:

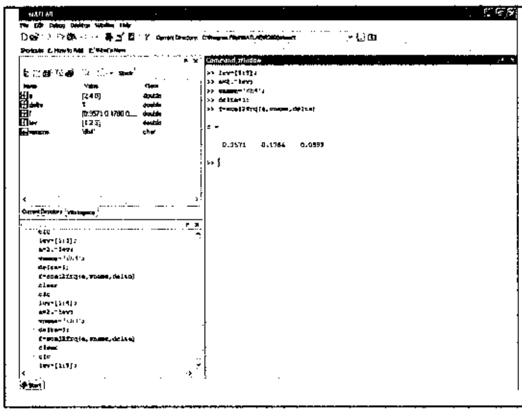
Level 1  Peak Absolute Value = 0.1492	Level 2  Peak Absolute Value = 0.05471
Level 3  Peak Absolute Value = 0.02081	

Ratio for each level of details:

$$\alpha_n = \frac{\text{Peak absolute value of level n details}}{\text{Highest peak absolute value among the levels}}$$

α_n	VALUES
n=1	0.1492/0.1492 = 1.0000
n=2	0.05471/0.1492 = 0.3667
n=3	0.02081/0.1492 = 0.1395

- Frequency



Result:

f =

0.3571 0.1786 0.0893

<u>Summary</u>

- Amplitude ratio

Approximations:

WAVEFORM TYPE	a_n	WHOLE	BEFORE	DURING	AFTER
Sag due to large load starting	n=1	0.9992	1.0000	1.0000	1.0000
	n=2	1.0000	1.0000	0.9479	1.0000
	n=3	0.9866	1.0000		0.9991
	n=4	0.9866	1.0000		0.9991
	n=5	0.9832	1.0000		0.9991
Sag due to fault	n=1	1.0000	1.0000	1.0000	1.0000
	n=2	0.9496		0.9266	0.9887
	n=3	0.9415		0.9211	0.9690
	n=4	0.9370		0.9220	
	n=5	0.9037			

Details:

WAVEFORM TYPE	α_n	WHOLE	BEFORE	DURING	AFTER
Sag due to large load starting	n=1	1.0000	0.7529	0.1609	1.0000
	n=2	0.4280	1.0000	1.0000	0.6461
	n=3	0.6749	0.7312		0.7879
	n=4	0.1450	0.1315		0.7238
	n=5	0.1425	0.2464		0.2521
Sag due to fault	n=1	1.0000	1.0000	1.0000	1.0000
	n=2	0.3206		0.7607	0.3667
	n=3	0.3432		0.4722	0.1395
	n=4	0.3946		0.5786	
	n=5	0.4241			

- Frequency

WAVEFORM TYPE	FREQUENCY			
	WHOLE	BEFORE	DURING	AFTER
Sag due to large load starting	0.1786	0.1786	0.1786	0.1786
	0.0893	0.0893	0.0893	0.0893
	0.0446	0.0446		0.0446
	0.0223	0.0223		0.0223
	0.0112	0.0112		0.0112
Sag due to fault	0.3571	0.3571	0.3571	0.3571
	0.1786		0.1786	0.1786
	0.0893		0.0893	0.0893
	0.0446		0.0446	
	0.0223			