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Early Detection and Localization of Thermal Faults from Acoustic Emission Measurement for TNB In-Service Power Transformers

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REFERENCES

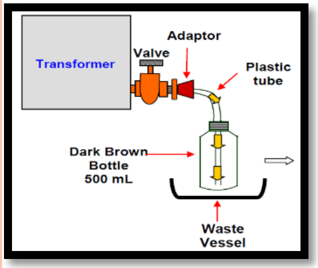
1. INTRODUCTION

- Faults in transformers can cause extensive damage and interruption of electricity supply resulting in large revenue losses.
- Diagnostic tests for in-service power transformer is important for early fault prediction and increase reliability of electricity supply.
- One of the diagnostic test is Acoustic Emission (AE) measurement. It is used to locate the acoustic emission activity inside the transformer.

Background of The Problem

- In TNBD, DGA test has been used to detect the presence of gases due to faults in a transformer.
- If DGA shows the presence of some fault related gases, the next step is usually to perform acoustic emission measurement.
- Currently, in TNB, the acoustic emission measurement is used to locate Partial Discharge activities based on AE descriptors range for PD.
- If PD location was detected, repair work will take place.
- However, if PD location was not detected, usually no further action was taken.

CURRENT PRACTICE (WITH PD DETECTED)



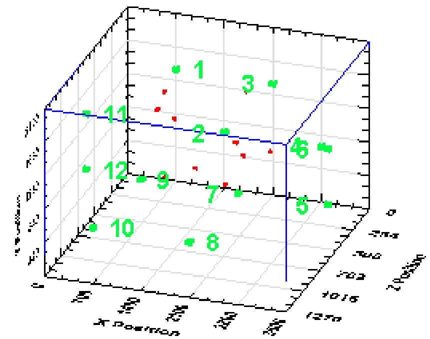
Oil sampling

DGA testing

AE Measurement

AE Descriptors Range
$40\ dB \le A \le 90\ dB$
$0 < E \le 500$
$10\ \mu s \le D \le 5000\ \mu s$

AE filtration & analysis



AE activities and location

Untank transformer

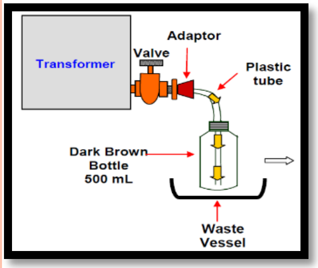
Locate fault based on AE location

Find the fault location

Repair Work

Transformer back into service

Current Practice (PD not detected)



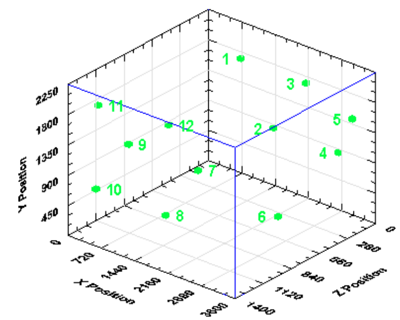
Oil sampling

DGA testing

AE Measurement

AE Descriptors Range
40 dB ≤ A ≤ 90 dB
0 < E ≤ 500
10 µs ≤ D ≤ 5000 µs

AE filtration & analysis

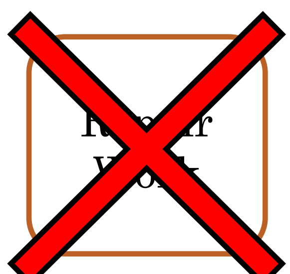


AE activities and location

Locate fault based on AE location

Untank transformer

Find the fault location



No action taken on the transformer

PROBLEM STATEMENT

- All acoustic emission activities during AE measurement will be recorded and filtered according to PD AE Descriptors range.
- In some cases, after AE measurement was performed, no PD activity could be recorded and located even though DGA test result has shown the occurrence of some fault related gases in the transformer oil.
- However, AE data not in the range of PD that was filtered during the analyzing process might indicate the occurrence of other faults.
- Hence, need to explore the range of AE Descriptors for other type of faults such as thermal fault.

Research Objectives

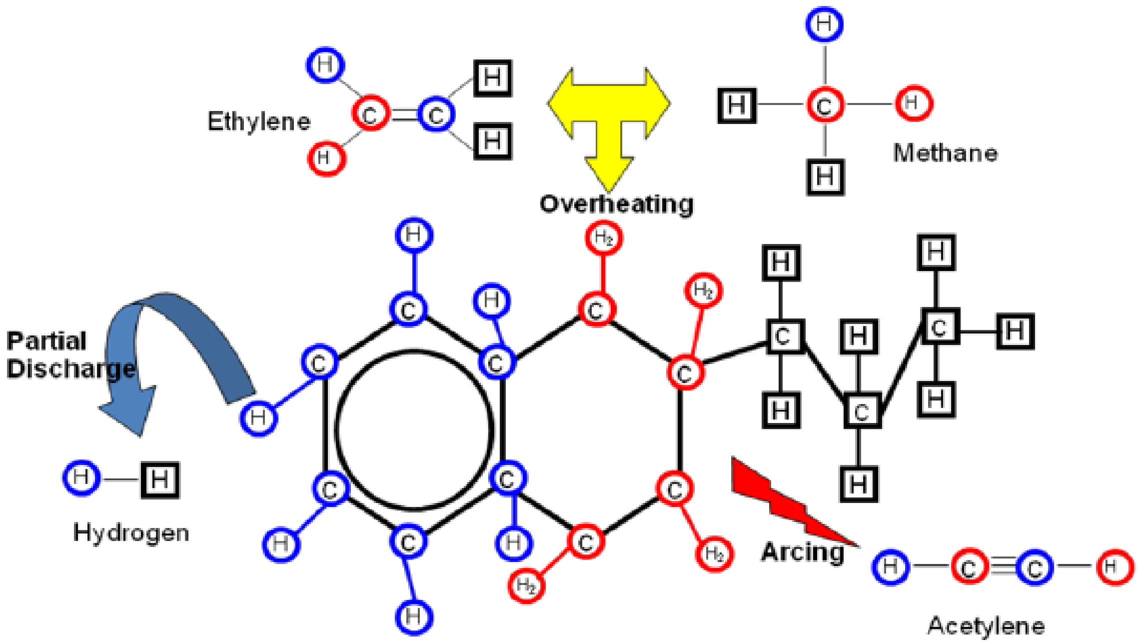
- To correlate between DGA test results and Acoustic Emission data
- To select the AE Descriptors for characterization of thermal faults
- To obtain the range of values of AE Descriptors for detection and localization of thermal faults

SCOPE OF RESEARCH

- Research were limited to :
  - 33/11 kV Transformer.
  - Partial discharge and thermal fault.
  - MTM 30 MVA transformer.
- Diagnostic testing methods were limited to DGA and Acoustic Emission measurement.
- Only IEC Ratio method was used to interpret the DGA results.

2. Literature Review

- **Dissolved Gas Analysis (DGA) [1,2]**
  - One of the most established technique and widely practiced by many utilities for transformer testing and diagnostics
  - Thermal and electrical fault caused deterioration and decomposition of solid/liquid insulation – release gases that dissolved in the oil.
  - Gases can be quantified by Dissolved Gases Analysis (DGA) technique to indicate the types of fault.



Hydrogen H2

Methane CH4

Ethane C2H5

Ethylene C2H4

Acetylene C2H2

2. Literature Review

- **Methods for DGA Interpretation [3,4]**
  - IEC Ratio
  - Doernenburg Ratio
  - Duval Triangle
  - Rogers ratio
  - Key gas Method

This research is only limited to IEC Ratio Method

IEC Ratio:

L	I	K	Diagnosis
0	0	0	Normal deterioration
0	1	0	Partial Discharge of low energy density
1	1	0	Partial discharge of high energy density
1-2	0	1-2	Discharge of low energy
1	0	2	Discharge of high energy
0	0	1	Thermal fault <150^{o}C
0	2	0	Thermal fault 150^{o}C - 300 ^{o}C
0	2	1	Thermal fault 300^{o}C - 700 ^{o}C
0	2	2	Thermal fault 700 ^{o}C

Gas Ratios	Ratio Codes
CH_4/H_2	I
C_2H_4/C_2H_6	K
C_2H_2/C_2H_4	L

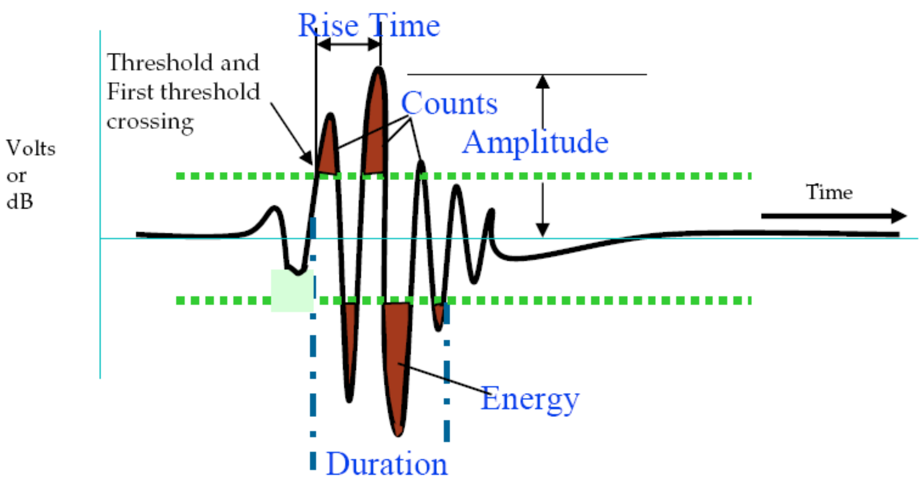
DGA Limitations [5]

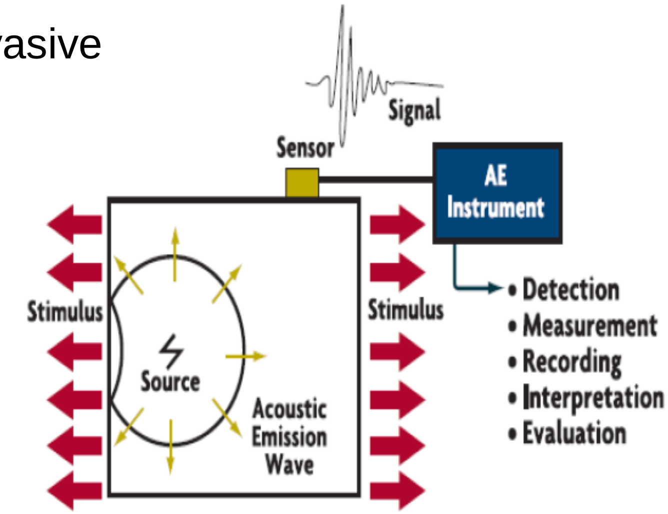
- Studies have shown that DGA cannot provide any information about the location or position of fault inside the transformer.

- DGA also does not provide any information about the severity of insulation damage.

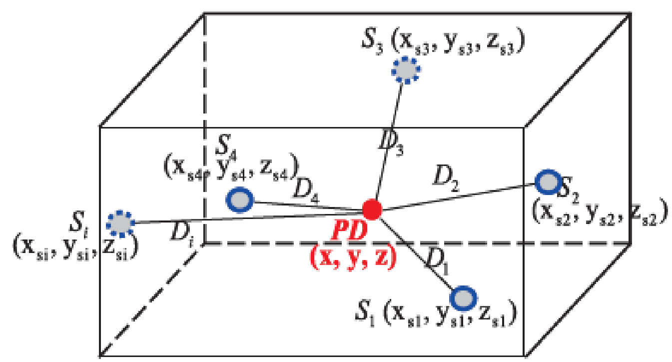
Acoustic Emission (AE) Signal and System [6,7]

- AE System can be applied on-line and non-invasive





Amplitude	Maximum peak of the burst AE in dB referred to sensor output
Duration	The time span that the burst AE is above the threshold
Energy	An integration of the area above the threshold



schematic view of a transformer tank with acoustic sensors

AE System for PD Detection

- The technique has been used to detect and locate PD but it is not yet established for other types of fault.
- The main advantage of using AE detection method is that it can locate the discharge occurrence.
- Three Parameters or Descriptors extracted from the AE signals emitted due to the occurrence of discharge have been used to analyze PD – Amplitude, Energy and Duration.

Range of Acoustic Emission Descriptors for PD [6]

AE Descriptors	Range
Amplitude	40 dB ≤ Amplitude ≤ 90 dB
Energy	0 < Energy ≤ 500
Duration	10 μs ≤ Duration ≤ 5000 μs

No range for Thermal faults

Research Gap

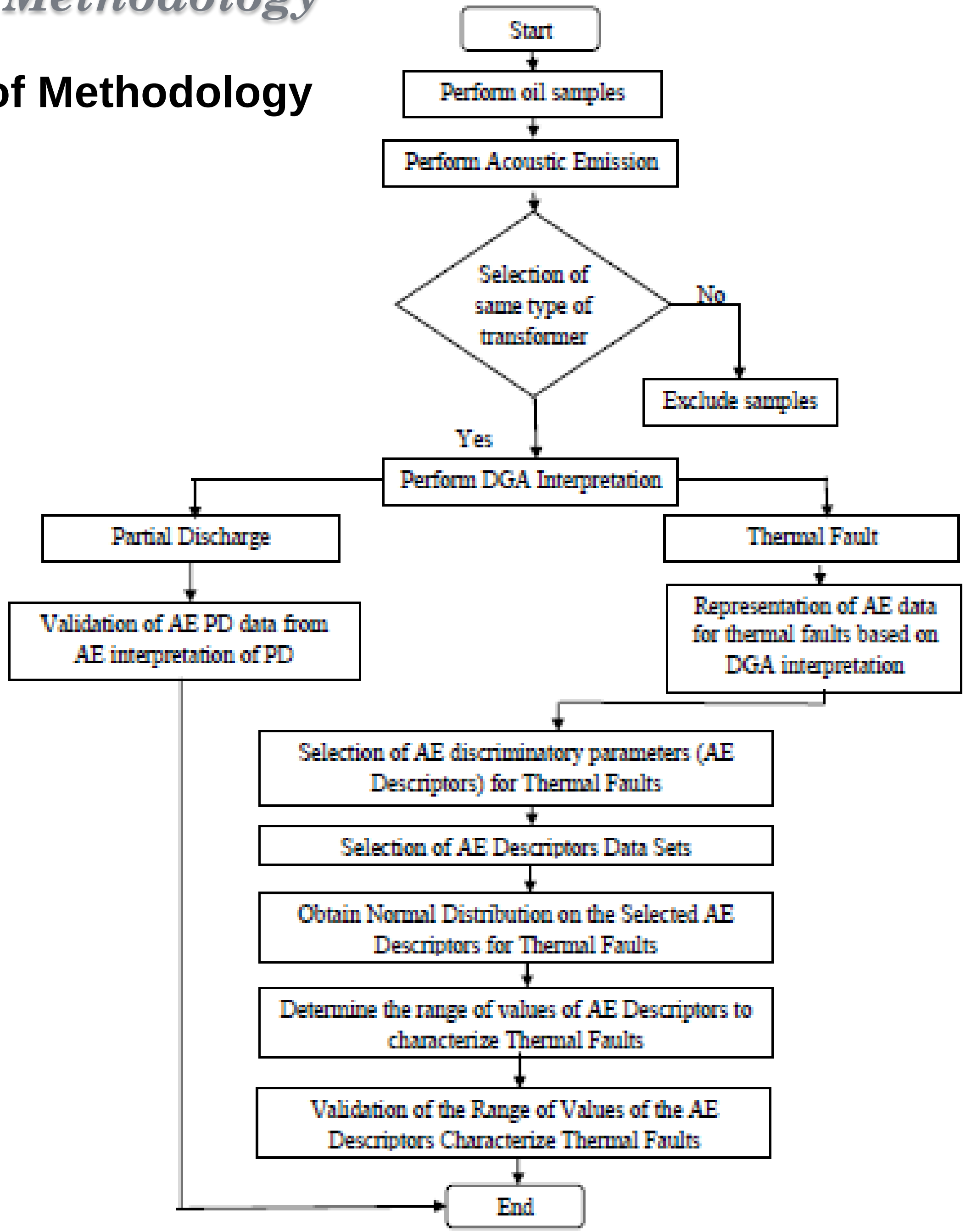
- **Acoustic Emission for Heat Detection [8]**
  - Arturo Nunez and Samual J. Ternowchek in their studies have mentioned that, although PD can be detected by using AE measurement, **not much work have been done for localized heating**.
  - Based on their studies, AE signal was detectable when the localized temperature reaches about 120^{0}C and it increases with temperature.
  - This shows that data obtained from the **acoustic emission has its own characteristics that can be further studied.**

- **Acoustic Emission Characterization [9]**
  - Studies made by G. Santos Filho, L.Zaghetto and O.Pereira shows that the **characteristic of acoustic emission** such as repetition rate, duration, energy can **give an indication of the cause of emission.**

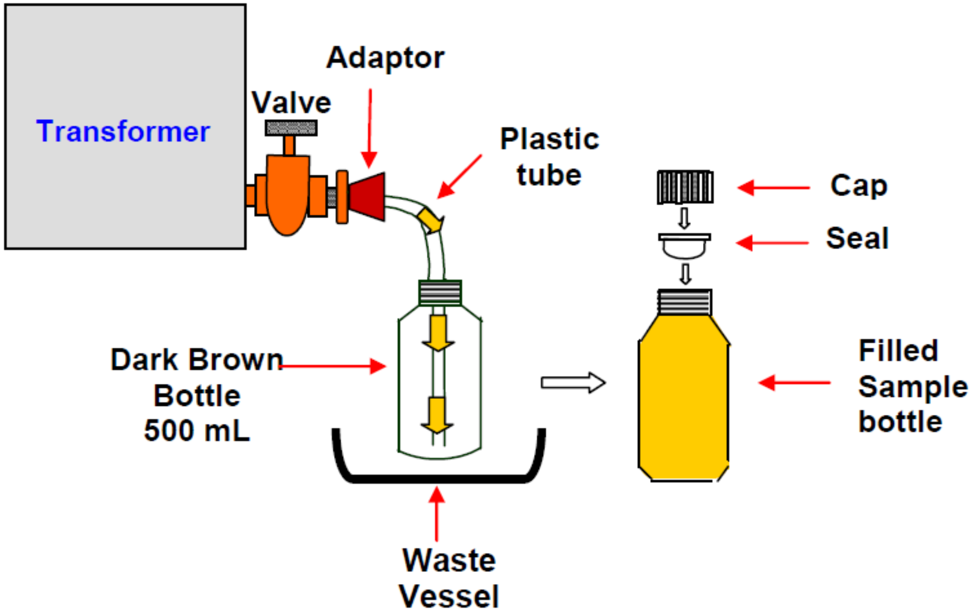
Need to explore the characteristics of AE for thermal fault

3. *Research Methodology*

- **Flowchart of Methodology**

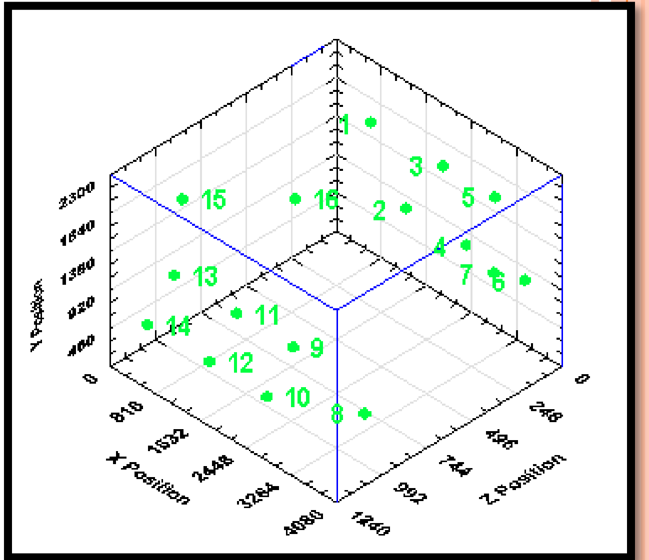


- **Perform Oil Sample [2]**



3. Research Methodology

Perform Acoustic Emission (AE) Measurement [6]



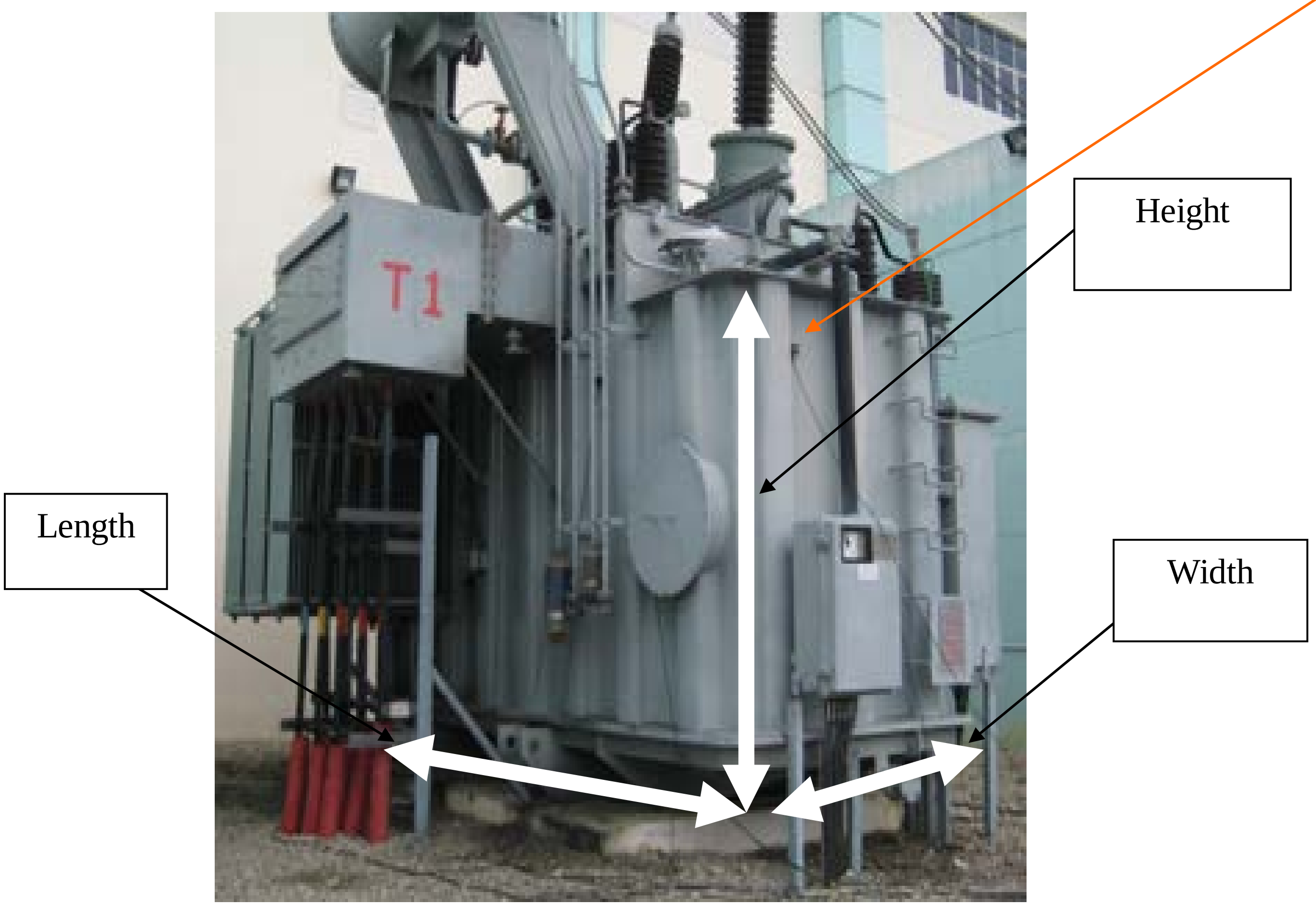
- Measure the dimension of TX (width, length, height)
- Locate the sensors on TX body.
- Record the sensors location/coordinate.

- Key in TX dimension in the AE system.
- Key in the sensors location/coordinate
- Perform sensors performance check

- Run the system for 24 hours.
- Record the AE activity.

AE Sensor: RS15I-AST

Power Transformer with the AE Sensors



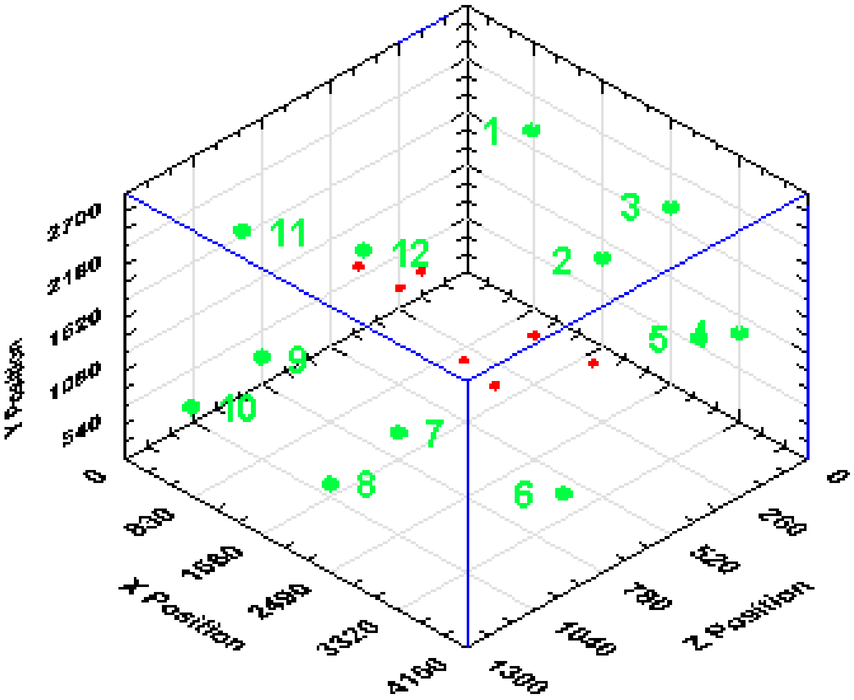
Sensors Location

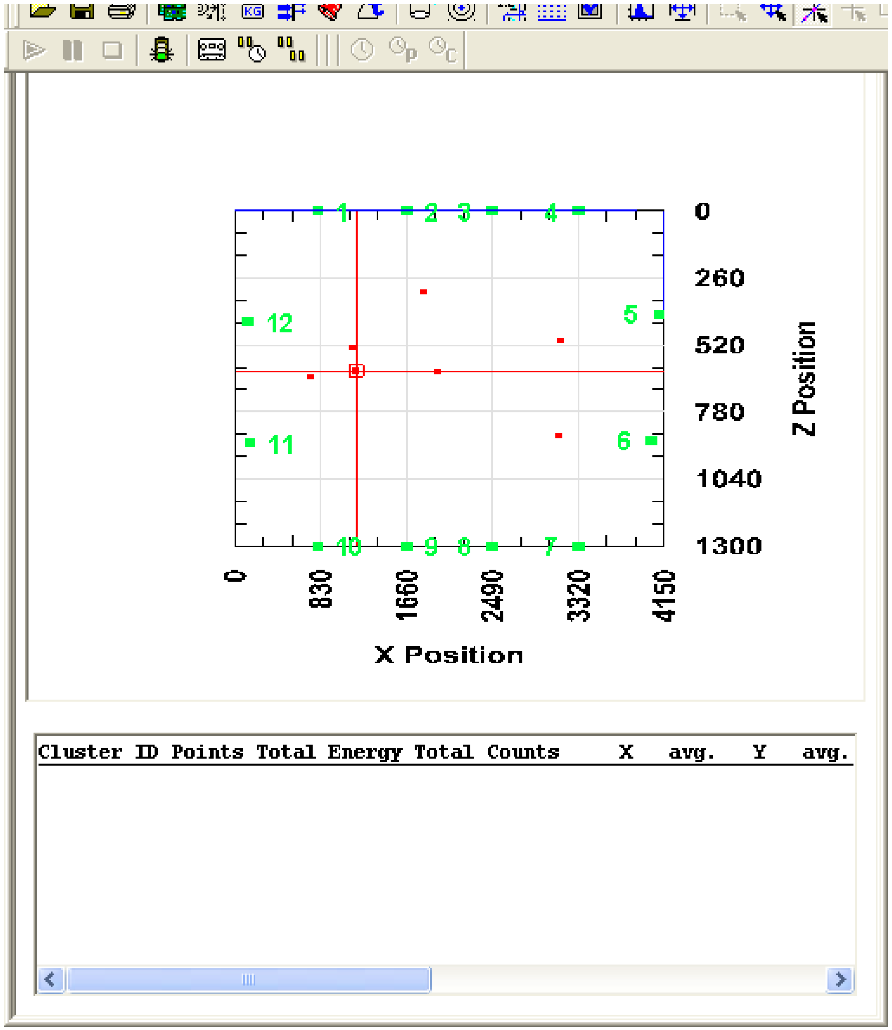
Sensor	X(mm)	Y(mm)	Z(mm)
1	830	1800	0
2	1660	900	0
3	2490	1800	0
4	3320	900	0
5	4000	1800	430
6	4000	900	860
7	3320	1800	1140
8	2490	900	1140
9	1660	1800	1140
10	830	900	1140
11	0	1800	860
12	0	900	430

X = Length, Y = Height, Z = Width

3D VIEW WITH AE ACTIVITIES

- From AE system visualization software





x = 1172 mm, y = 1282 mm, z = 620 mm

Energy	43.875
Duration	2563.625 µs
Amplitude	50.5 dB

3. Research Methodology

Selection of Transformers

- Transformers from various manufacturers were installed in the system.
- Different transformers have their own dimensions according to the manufacturer.
- Different in dimensions will lead to different sensors location/coordinate.
- **Therefore, only transformers from MTM were used in this research.**

a) MTM

b) Xian

c) Pauwels

3. Research Methodology

- **Perform DGA Interpretation**
  - IEC Ratio Method was used to interpret DGA Results
  - DGA results were categorized into two categories :
    - Partial Discharge
    - Thermal Fault

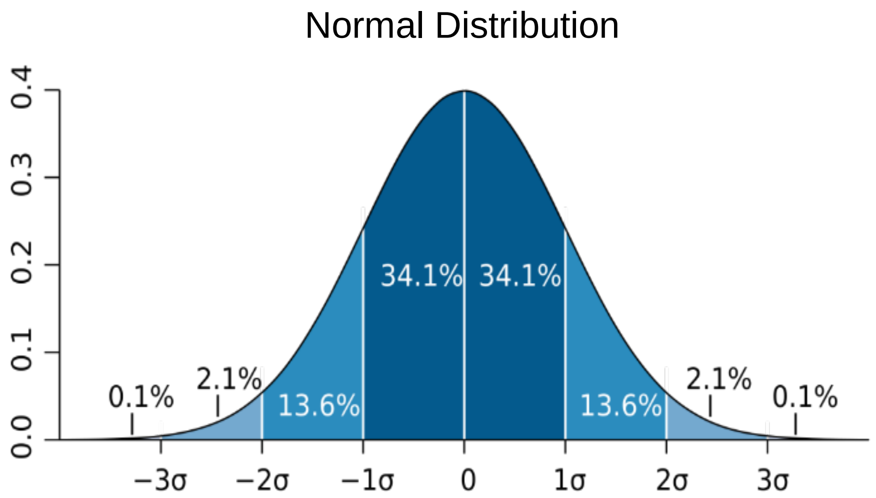
3. Research Methodology

Analysis of AE Data

- Analyze AE data from two categories:
  - Partial Discharge (Sample A)
  - Thermal Fault (Sample B)
- Select the AE Descriptors:
  - Amplitude
  - Duration
  - Energy
- Study and compare the pattern of the AE Descriptors for each sample with the AE PD range:

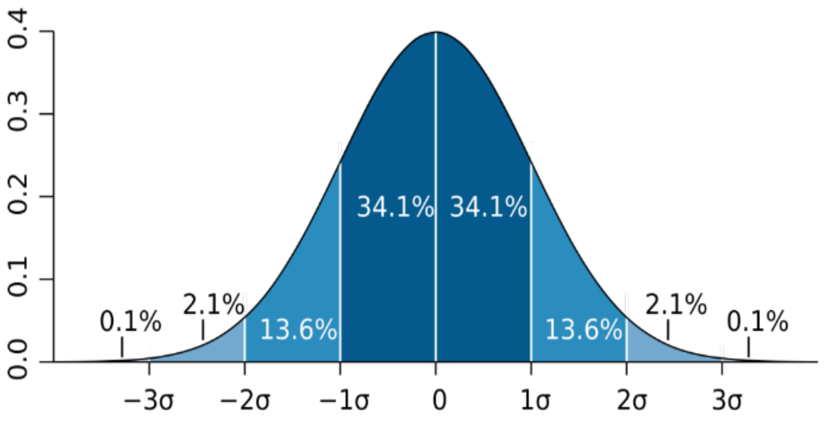
AE Descriptors	**Range for PD**
Amplitude	40 dB ≤ Amplitude ≤ 90 dB
Energy	0 < Energy ≤ 500
Duration	10 µs ≤ Duration ≤ 5000 µs

Characterization of AE Descriptors for Thermal faults Using Statistical Analysis



- ***Obtain Normal Distribution on the Selected AE Descriptors***
  - Perform Normal Distribution on each sample of the AE data set due to thermal fault
  - Data outside the ±1σ (standard deviation) of the mean will be considered as outliers and removed
  - Only the remaining data will be used for the next process

3. Research Methodology



- ***Determine the range of values of the AE Descriptors for Thermal Fault***
  - The remaining data (after removing the outliers) from each sample was **combined** into one table
  - The range of values for thermal fault is determined from the upper and lower limits of the normal distribution based on ±1σ (standard deviation)

- ***Validation of the Thermal Fault AE Descriptors range***
  - Determine the upper and lower limits of the AE Descriptors for each sample **separately** based on t - distribution
  - Compare with Thermal fault AE range - upper and lower limits obtained earlier

4. Results and Analysis

List of Selected Transformers

No	Location	Manufacturer
1	PPU Damansara Intan T2	MTM
2	PPU Seligie T1	Xian
3	PPU Bandar Sunway T1	Lioyang
4	PPU Bandar Sultan Sulaiman T1	Lioyang
5	PPU Bandar Sultan Sulaiman T2	Lioyang
6	PPU Strong Crest T2	Xian
7	PPU Seafield T2	Puwels
8	PPU Bukit Kemuning T1	MTM
9	PPU Bayu Perdana T2	Takaoka
10	PPU Lion Town T1	Puwels
11	PPU Olak Lempit T1	Electro
12	PPU Morib T1	Xian
13	PPU Lumut T2	MTM
14	PPU Bemban T2	MTM
15	PPU Bukit Merah T1	MTM
16	PPU Bukit Mewah T2	Electro
17	PPU Kubu Gajah T1	Puwels
18	PPU Lekir T1	MTM
19	PPU Lekir T2	MTM
20	PPU Meru Raya T1	MTM
21	PPU Simpang Pulai T1	Electro
22	PPU TLDM T1	Takaoka
23	PPU TLDM T2	Takaoka
24	PPU Semanggar T1	Electro

Sample		PPU
A (PD)	A1	Damansara Intan T2
	A2	Bemban T2
	A3	Bukit Merah T1
	A4	Lekir T2
B (Thermal Fault)	B1	Bukit Kemuning T1
	B2	Lumut T2
	B3	Meru Raya T1
	B4	Lekir T1

Only MTM transformers were selected

- Due to same size of transformers (Dimension)

4. Results and Analysis

- **DGA Analysis for Sample A**

GAS	CONTENT
H2	110
O2	11752
C2H6	11
CO	494
CO2	6157
C2H4	71
CH4	18
C2H2	47

PPU Damansara Intan T2 (A1)

Ratio		Code	
C_2H_2/C_2H_4	0.66	L	1
CH_4/H_2	0.16	I	0
C_2H_4/C_2H_6	6.45	K	2

Comment:
Discharge with high energy

GAS	CONTENT
H2	216
O2	6120
C2H6	6
CO	320
CO2	1961
C2H4	9
CH4	23
C2H2	0

PPU Bemban T2 (A2)

Ratio		Code	
C_2H_2/C_2H_4	0.00	L	1
CH_4/H_2	0.11	I	0
C_2H_4/C_2H_6	1.50	K	2

Comment:
Discharge with high energy

GAS	CONTENT
H2	225
O2	12522
C2H6	4
CO	246
CO2	2100
C2H4	11
CH4	30
C2H2	0

PPU Bukit Merah T1 (A3)

Ratio		Code	
C_2H_2/C_2H_4	0.00	L	1
CH_4/H_2	0.12	I	0
C_2H_4/C_2H_6	2.75	K	1

Comment:
Discharge with low energy

GAS	CONTENT
H2	151
O2	6979
C2H6	11
CO	559
CO2	3588
C2H4	10
CH4	7
C2H2	10

PPU Lekir T2 (A4)

Ratio		Code	
C_2H_2/C_2H_4	0.66	L	1
CH_4/H_2	0.16	I	1
C_2H_4/C_2H_6	6.45	K	0

Comment:
Discharge with high density

4. Results and Analysis

- **DGA Analysis for Sample B**

GAS	CONTENT
H2	34
O2	3828
C2H6	90
CO	263
CO2	2803
C2H4	52
CH4	91
C2H2	2

PPU Bukit Kemuning T1 (B1)

Ratio		Code	
C_2H_2/C_2H_4	0.04	L	0
CH_4/H_2	2.68	I	2
C_2H_4/C_2H_6	0.58	K	0

Comment:
Thermal Fault with 150°C-300°C

GAS	CONTENT
H2	80
O2	1555
C2H6	188
CO	615
CO2	4033
C2H4	192
CH4	79
C2H2	1

PPU Lumut T2 (B2)

Ratio		Code	
C_2H_2/C_2H_4	0.01	L	0
CH_4/H_2	0.99	I	0
C_2H_4/C_2H_6	1.02	K	1

Comment:
Thermal Fault <150°C

GAS	CONTENT
H2	225
O2	12522
C2H6	72
CO	246
CO2	2100
C2H4	81
CH4	30
C2H2	1

PPU Meru Raya T1 (B3)

Ratio		Code	
C_2H_2/C_2H_4	0.01	L	0
CH_4/H_2	0.12	I	0
C_2H_4/C_2H_6	1.13	K	1

Comment:
Thermal Fault <150°C

GAS	CONTENT
H2	145
O2	6665
C2H6	25
CO	626
CO2	4978
C2H4	61
CH4	70
C2H2	1

PPU Lekir T1 (B4)

Ratio		Code	
C_2H_2/C_2H_4	0.02	L	0
CH_4/H_2	0.48	I	0
C_2H_4/C_2H_6	2.44	K	1

Comment:
Thermal Fault <150°C

4. Results and Analysis

- **Summary of Results from DGA Analysis**

Sample	PPU	TX	H2	C2H6	C2H4	CH4	C2H2	Fault
A1	Damansara Intan	T2	110	11	71	18	47	PD
A2	Bemban	T2	216	6	9	23	0	
A3	Bukit Merah	T1	225	4	11	30	0	
A4	Lekir	T2	151	11	10	7	10	
B1	Bukit Kemuning	T1	34	90	52	91	2	Thermal Fault
B2	Lumut	T2	80	188	192	79	1	
B3	Meru Raya	T1	225	71	81	30	1	
B4	Lekir	T1	145	25	61	70	1	

4. Results and Analysis

- **Acoustic Emission Data for Sample A (PD)**

Sample A1

E	D	A
12	1727	47
14	2124	48
17	890	55
18	2177	48
19	1129	60
20	1896	49
29	1223	62
32	3581	48
35	2145	55
39	2516	54
46	4179	51
52	5108	52
55	3619	54
56	3686	63
61	4513	52
63	5329	52
67	4264	55
70	2626	57
71	5373	53
77	4485	56
82	4389	59
83	2807	68
83	4879	56
88	2954	65
88	5916	56
97	4387	59
101	3428	63
123	5663	60
124	4830	60
126	5537	60
138	6330	63
153	5282	63
261	6236	67
275	601	72
414	7821	71

Sample A2

E	D	A
1	59	46
1	92	46
1	161	46
2	207	48
4	460	47
8	521	58
6	530	49
7	539	51
6	714	47
11	925	52
15	979	53
20	1104	55
23	1471	54
27	1554	65
43	1705	69
25	1823	64
32	2341	61
81	2944	69
117	3609	76

Sample A3

E	D	A
3	400	47
3	550	47
7	842	47
8	797	51
10	978	52
10	1313	47
11	1268	47
14	1576	47
19	1905	49
28	2069	53
30	2002	57
38	2551	58
40	2534	54
41	3000	52
46	2735	55
49	2592	58
51	2791	57
67	2310	64
68	3150	59
76	3560	61
98	4151	60
113	3920	63
148	3811	57
263	3290	62

Sample A4

E	D	A
103	1071	57
216	1076	71
329	1290	77
425	1396	77
342	1951	78
80	2036	55
125	2184	83
170	2188	61
197	2637	87
478	2643	79
211	2813	87
430	2899	79
270	3380	72
215	3400	66
195	3429	82
24	3717	90
45	3757	51
230	3799	88
321	3823	69
351	3854	66
444	3942	72
228	4489	70
77	4555	54

Fall within PD Acoustic Emission Range
0 < E ≤ 500 , 10μs ≤ D ≤ 5000μs , 40dB ≤ A ≤ 90dB

E : Energy
D : Duration
A : Amplitude

E : Energy D : Duration A : Amplitude

Acoustic Emission Data for Sample B (Thermal Fault)

Sample B1

E	D	A
1111	11059	46
3211	13338	49
674	6404	48
1005	8470	49
714	10584	48
614	10614	49
819	10867	49
1132	12006	57
819	12202	49
823	12797	49
591	12903	56
952	13410	60
1113	13830	63
1211	13859	59
1059	13869	58
1050	13909	55
1114	13969	64
1199	14279	60
1098	14371	63
1184	5284	66
2206	5566	68
648	10837	67
867	11309	69
862	13372	64

Sample B2

E	D	A
1076	3271	64
1088	3369	60
1168	8580	59
1183	9214	57
609	9495	64
1429	10639	67
761	10690	60
934	10734	66
1375	10797	66
741	11116	74
1605	11411	71
847	11452	62
783	11585	71
1263	11970	73
1663	16530	79
2381	23425	83

Fall beyond PD AE Range for Descriptors E & D
PD AE Range:
0 < E ≤ 500 ,
10μs ≤ D ≤ 5000μs

Sample B3

E	D	A
510	9366	71
622	10521	71
661	10343	72
720	10664	73
732	11548	72
753	11115	72
762	12064	72
782	11035	76
925	11094	78
1080	11155	77
1229	11432	78
1399	12437	78
1448	13606	81
1470	11309	83
1522	12435	82
1752	12037	82
1806	13633	82
1813	12651	84
1869	15509	80
2655	13148	90
3257	13754	92
3361	13289	88
3387	15004	93
3601	15132	90

Sample B4

E	D	A
156	12194	77
367	8958	68
368	9940	68
420	9842	72
422	10193	72
432	11208	67
599	10709	76
602	10196	71
626	6484	78
639	10391	73
648	10255	73
649	10105	74
656	11111	71
662	6965	78
662	11665	90
670	11895	69
689	10164	72
715	11196	73
751	12025	81
751	12515	73
770	11595	81
843	11641	92
892	6615	79
922	11393	88
961	7270	81
986	7016	81
990	9796	67
1030	11562	79
1046	11326	77
1061	8984	77
1136	12396	78
1168	11487	86
1224	9511	73
1251	9418	65
1251	12775	77

4. Results and Analysis

E : Energy D : Duration A : Amplitude

Acoustic Emission Data for Sample B (Thermal Fault) (Cont'd)

Sample B1

E	D	A
1111	11059	46
3211	13338	49
674	6404	48
1005	8470	49
714	10584	48
614	10614	49
819	10867	49
1132	12006	57
819	12202	49
823	12797	49
591	12903	56
952	13410	60
1113	13830	63
1211	13859	59
1059	13869	58
1050	13909	55
1114	13969	64
1199	14279	60
1098	14371	63
1184	5284	66
2206	5566	68
648	10837	67
867	11309	69
862	13372	64

Sample B2

E	D	A
1076	3271	64
1088	3369	60
1168	8580	59
1183	9214	57
609	9495	64
1429	10639	67
761	10690	60
934	10734	66
1375	10797	66
741	11116	74
1605	11411	71
847	11452	62
783	11585	71
1263	11970	73
1663	16530	79
2381	23425	83

Sample B3

E	D	A
510	9366	71
622	10521	71
661	10343	72
720	10664	73
732	11548	72
753	11115	72
762	12064	72
782	11035	76
925	11094	78
1080	11155	77
1229	11432	78
1399	12437	78
1448	13606	81
1470	11309	83
1522	12435	82
1752	12037	82
1806	13633	82
1813	12651	84
1869	15509	80
2655	13148	90
3257	13754	92
3361	13289	88
3387	15004	93
3601	15132	90

Sample B4

E	D	A
156	12194	77
367	8958	68
368	9940	68
420	9842	72
422	10193	72
432	11208	67
599	10709	76
602	10196	71
626	6484	78
639	10391	73
648	10255	73
649	10105	74
656	11111	71
662	6965	78
662	11665	90
670	11895	69
689	10164	72
715	11196	73
751	12025	81
751	12515	73
770	11595	81
843	11641	92
892	6615	79
922	11393	88
961	7270	81
986	7016	81
990	9796	67
1030	11562	79
1046	11326	77
1061	8984	77
1136	12396	78
1168	11487	86
1224	9511	73
1251	9418	65
1251	12775	77

Fall within PD AE Range for Descriptor A
PD AE Range:
0 dB< A ≤ 90dB

Selection of AE Descriptors

- Since the AE Amplitude for thermal fault fall within the AE range for PD, it was decided to remove Amplitude as AE Descriptor in this study.

AE Descriptors	Ranges
~~Amplitude~~	~~40 dB ≤ Amplitude ≤ 90 dB~~
Energy	?? < Energy ≤ ??
Duration	?? ≤ Duration ≤ ??

Observation: Values for Amplitude for both thermal fault and PD are within the same range

4. Results and Analysis

- **Location of AE Activity for Sample B (Thermal Fault)**

PPU Bukit Kemuning T1 (B1)

AE Activity	AE Location		
	x(mm)	y(mm)	z(mm)
1	2560	1200	651.8
2	2618	992.7	649.5

PPU Lumut T2 (B2)

AE Activity	AE Location		
	x(mm)	y(mm)	z(mm)
1	105.7	49.03	21.75
2	113	48.11	22.4

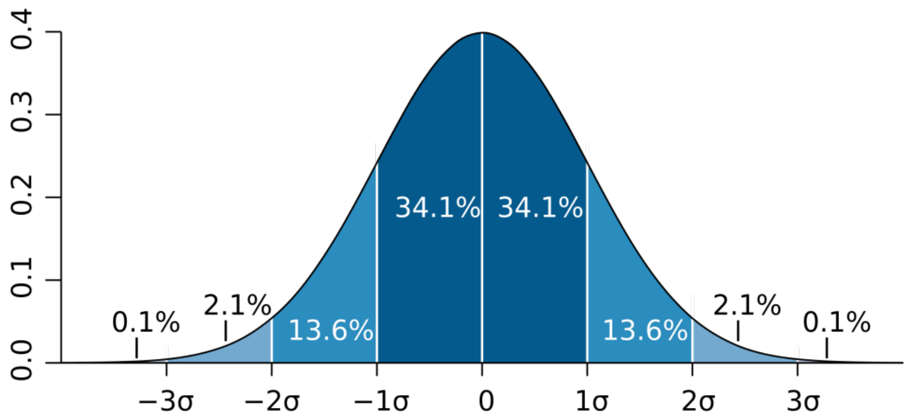
PPU Meru Raya T1 (B3)

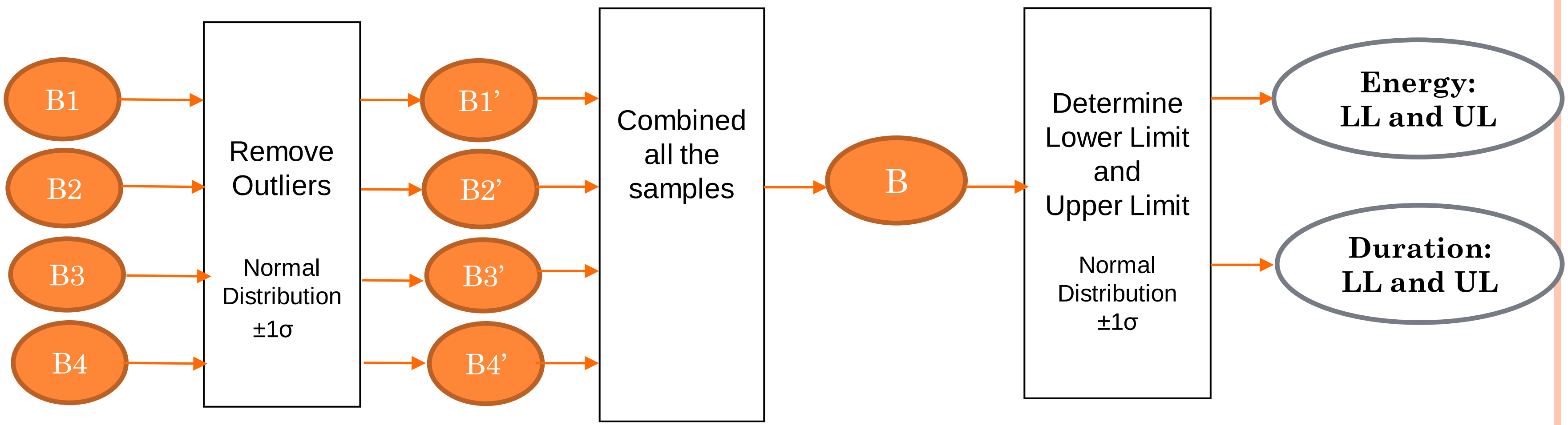
AE Activity	AE Location		
	x(mm)	y(mm)	z(mm)
1	100.7	54.33	23.92
2	101	55.17	27.39

PPU Lekir T1 (B4)

AE Activity	AE Location		
	x(mm)	y(mm)	z(mm)
1	100.9	56.35	23.23
2	101.4	57.13	24.71

Range of Values of AE Descriptors for Thermal Fault

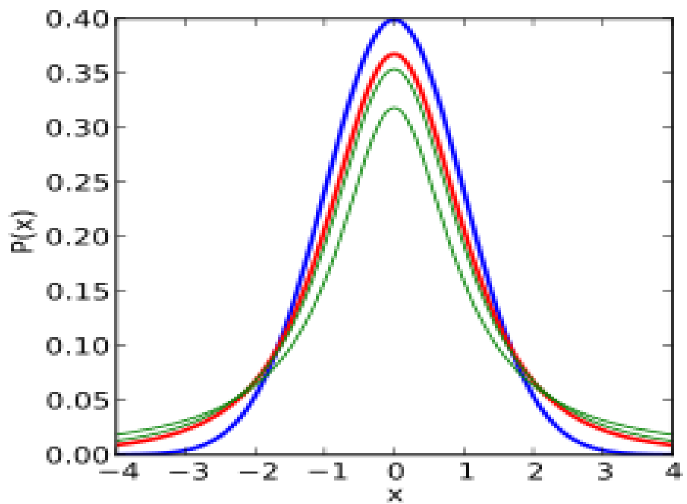




Sample	AE Descriptors Range			
	Energy		Duration	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
B	629	1338	10225µs	12891µs

Validation of Thermal Fault AE Descriptors Range (Energy)

t - Distribution

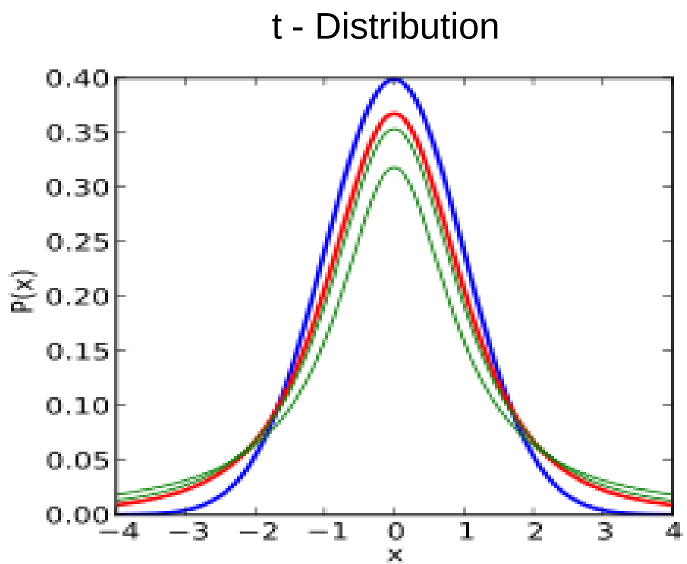


Energy						AE Descriptors Limit	
Sample	Mean, μ	Standard Deviation, σ	Lower Limit	Upper Limit	**Compare with AE Descriptors range**	Lower Limit	Upper Limit
B1”	530	1642	883	994		629	1338
B2”	733	1629	998	1193			
B3”	611	2564	1048	1321			
B4”	329	2143	814	961			

- **The range for upper and lower limits of each samples (with thermal fault) are within the AE Descriptors range for Energy**

4. Results and Analysis

Validation of Thermal Fault AE Descriptors Range (Duration)



Duration						AE Descriptors Limit	
Sample	Mean, μ	Standard Deviation, σ	Lower Limit	Upper Limit	**Compare with AE Descriptors range**	Lower Limit	Upper Limit
B1’	12579	1327	12188	12869		10225	12891
B2’	10640	1034	10257	11022			
B3’	12133	1024	11823	12442			
B4’	11038	1099	10803	11272			

- **The range for upper and lower limits of each samples (with thermal fault) are within the AE Descriptors range for Duration**

5. *Conclusion and Recommendations*

Research Findings

- The range of values of AE Descriptors for thermal fault has been determined.

Sample	AE Descriptors Range			
	Energy		Duration	
	Lower Range	Upper Range	Lower Range	Upper Range
B	629	1338	10225µs	12891µs

- AE Descriptors for Amplitude is within the same range (40 dB ≤ A ≤ 90 dB) for both Partial Discharge and Thermal Fault.

- TNB diagnostic and maintenance team can benefit from this finding by improving the maintenance operation and planning for early thermal fault detection and localization using the range of values of the AE Descriptors obtained in this research.

Accomplishment of Research Objectives

- **To correlate between DGA test results and Acoustic Emission data**
  - This study has revealed that DGA results can be correlated to the Acoustic Emission data based on the range of values of the AE Descriptors for PD and thermal fault.

- **To select the AE descriptors for characterization of thermal faults**
  - Range of values for Amplitude (AE Descriptor) for Partial Discharge and Thermal Fault, were within the same range (40 dB $\leq$ A $\leq$ 90 dB).
  - Therefore, only Duration and Energy were selected as AE Descriptors to characterize thermal fault.

- **To obtain the range of values of AE Descriptors for detection and localization of thermal faults**
  - This research has shown that, AE data beyond the PD AE Descriptors range cannot be ignored as they could indicate other fault, i.e thermal fault.
  - The range of values for AE Descriptors to characterize thermal fault for a specific type of transformer was also obtained in this research.

5. Conclusion and Recommendations

Summary of Conclusion

- All the three main objectives were met successfully.
- The method presented in this study is recommended to be carried out for an early detection and localization of thermal fault for TNB in-service power transformers using the AE Detection System already available.
- Similarly, with this approach, necessary actions or strategy can be taken to increase the transformer reliability, lifetime and save the operational cost.
- Finally, this can also lead to a better performance of the distribution network.

6. Further Work

Further Research Work

- The AE data obtained from thermal faults are to be recorded and saved with suitable data repository technique for reference in condition based monitoring of the transformer; and to further establish the trending pattern of the AE data and its location.

- More samples from AE data are to be obtained from transformer with thermal fault in order to strengthen the findings especially on the range of values for the AE Descriptors.

- Explore the possible effects on the values and characteristics of AE Descriptors for other types of fault in a transformer that cause acoustic emission such as arcing, corona and etc.

- Investigate the range of values of the AE Descriptors for thermal fault from transformers with different dimensions and sizes and also other manufacturers.

- Application of Digital Signal Processing technique such as the time-frequency analysis to obtain more parameters for a better characterization of thermal fault from the AE signals [10]. This include the possibility of determining the severity level of the thermal fault.

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End of Presentation

THANK YOU