TNB Experiences Using Dielectric Response Technique to Assess Insulation Condition of High Voltage Current Transformers

Gobi K Supramaniam, P.Eng,C.Eng.[#1], Mohd A Talib[*2]

[#]Tenaga Nasional Berhad, Transmission Division, Malaysia
[*]TNB Research, Kajang, Malaysia
[1]gobiks@tnb.com.my; [2]mohdaizam@tnbr.com.my

***Abstract*-Tenaga Nasional Berhad (TNB) has experienced over 40 cases of high voltage Current Transformers (CT) failures since 2001 to 2011. Post failure analysis indicated that these failures are suspected highly due to deterioration and contamination of the main insulation system. To reduce premature failures and improve the reliability of the asset, TNB has embarked on a trial study on the use of dielectric response technique known as Frequency Dielectric Spectroscopy (FDS) to assess the insulation condition of in-service high voltage CTs. Field measurements were conducted on selected 137 units CT of voltage class 132 kV and 275 kV in TNB Transmission system. Analysis guideline and flow-chart was developed based on typical value of measured parameters for accurate assessment. To reduce premature failures on CTs, strategic decisions were made based on measured CT conditions and its assessment results.**

***Keywords*- Current Transformer; Assessment; Dielectric Response Technique; Analysis Guideline**

I. INTRODUCTION

Over 40 cases of high voltage Current Transformers (CT) were reported failed in TNB substations from 2001 to 2011. Typically CTs are deemed as inexpensive and require minimal maintenance as compared to power transformers. However, the failures had lead to loss of assets, revenue, jeopardize safety to personnel as well as threat to company image. Post failure root cause analysis of the CT in TNB system as illustrated in Fig. 1 reveals that approximately 78% of failures were contributed due to insulation degradation mainly due to moisture ingress and ageing effects. It is noted that the CTs in TNB system are typically operated at adverse environmental condition with average relative humidity of 60-80% and isokeraunic level 200 lightning days per year. This has triggered TNB management to study and review current maintenance practices as in Table I [1, 2]. It was revealed that the current maintenance strategies were inadequate to pin-point and only revealed minimal information on the insulation condition prior to any failure event. Thus, the management has embarked on a study to perform trial measurements and develop guideline to implement the dielectric response technique over wide frequency range on CTs. Using this new technique, it was possible to distinguish between different effects for more detailed analysis of the insulation condition.

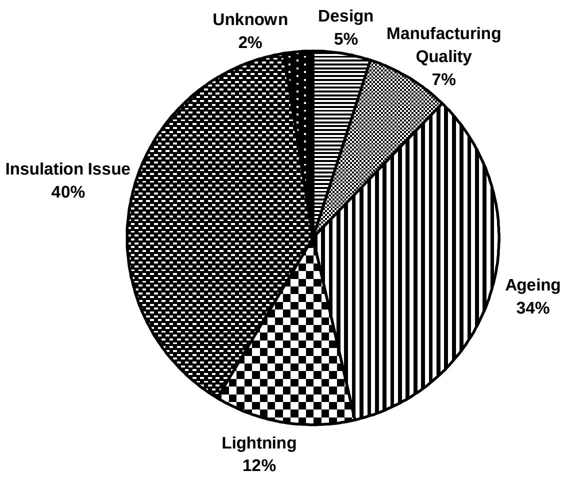


Fig. 1 Causes of CT failures in TNB from 2001 till 20011

DOI: 10.5963/IJEE0302001

TABLE I TNB CONVENTIONAL MAINTENANCE STRATEGIES FOR HV CURRENT TRANSFORMERS

No	Task Details		
	Task	**Intrusive/Non Intrusive**	**Recommended interval**
1	Visual Inspection	N	2 months once
2	Check Oil Level/ Bellow Level	N	2 months once
3	Dissipation Factor and Capacitance measurement at single power frequency 50Hz	I	As required
4	Dissolve Gas Analysis and/or Moisture in oil	I	As required, under OEM supervision only

The trial measurements were performed on selected 137 units of CTs of voltage class 132 kV and 275 kV at different operational age in TNB Transmission system. Fig. 2 illustrates the type of CT populations selected with age distribution information conducted under the work.

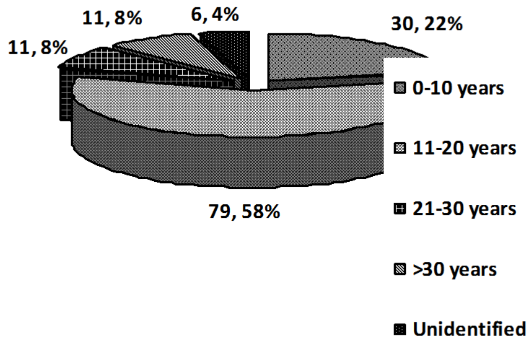


Fig. 2 Field Trial Measurement Population with Age Distribution

II. DIELECTRIC RESPONSE MEASUREMENT ON INSTRUMENT TRANSFORMERS

Majority of high voltage CTs are hermetically sealed designs which require minimal maintenance alike visual inspection. But for more reliable insulation assessment, Dissolved Gas Analysis (DGA) and moisture in oil are used as diagnostic tools to detect a range of insulation conditions as well as to insulation discharges. However, this technique is deemed impractical as routine task due to limited amount of oil in the CT as well as its dependency on the oil sampling technique, human competency factor and environmental factors (i.e humidity, temperature).

On the other hand, initial study made by a few researchers has indicated that traditional electrical measurements like loss power factor (tan δ) at single power frequency, only provide a relative indication of the loss factor in the insulation, and cannot be used to identify either causes of the higher losses or the quantity of moisture, if it is indeed the cause [3].

In recent development, dielectric response measurement using combination of Polarisation- Depolarisation Current (PDC) and Frequency Dielectric Spectroscopy (FDS) techniques has been developed to estimate insulation dryness and ageing state of oil-paper insulation based on complex insulation dielectric response like polarisation currents and dissipation factor [3], [4], [5-10]. This technique is sensitive to detect the changes in the complex insulation system and estimate moisture in the paper insulation which acts as a catalyst and by-products of hydrolysis, pyrolisis, and oxidative aging processes. Increase in moisture content within the high voltage insulation can significantly lead to decrease in dielectric strength of insulating oil as well as reduces mechanical strength of the solid insulation. This phenomenon can cause accelerated ageing of the equipment and failures at critical conditions. Due to wide frequency range (10 mHz to 1 kHz), it is possible to establish among different effects and gain information about insulation condition itself, moisture in solid insulation or oil conductivity [11-13, 18] as illustrated in Fig. 3.

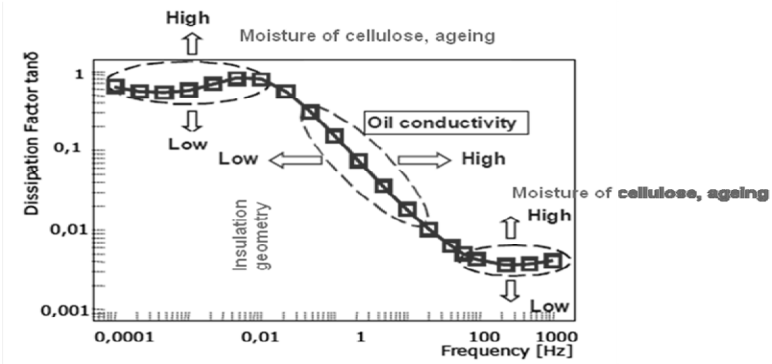


Fig. 3 A typical dielectric response in frequency domain of oil-paper insulation system

DOI: 10.5963/IJEE0302001

A. *Measurement and Connection Technique*

The technique is generalisation of the capacitance and tan delta measurements usually done at power frequency. The impedance of a sample is measured by applying a voltage across the sample. This voltage will generate a current through the sample. By accurately measuring the voltage and the current, the impedance of the sample can be calculated. The measurement of the impedance at one point, i.e. at a specific frequency and amplitude will allow other various parameters such as resistance, capacitance and dielectric loss to be calculated.

To avoid nonsensical results and to obtain healthy and successful measurement, some suggestions are:

- Ensure the ground reference of the dielectric response analyser has the same potential as the ground terminal of the CT;
- To eliminate or decrease any interference during on-site measurement, a guarding connection from the top terminal of the CT to the ground terminal is sometimes required to prevent any surface leakage current which may introduce to the bushing.

A typical measurement circuitry for Current Transformers is done between HV termination and secondary winding or tank for CT with and without Screen are shown in Fig. 4 and Fig. 5 respectively [14, 17].

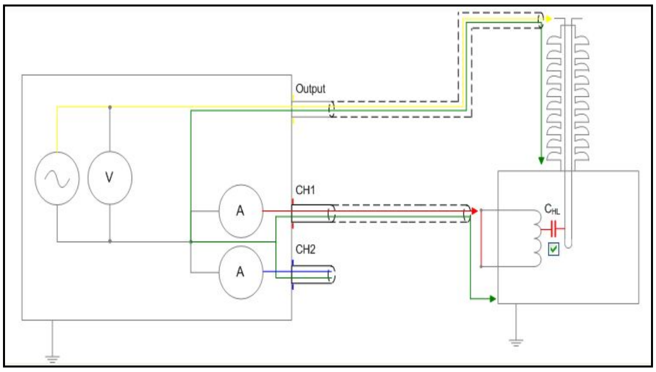


Fig. 4 Example dielectric response measurement setup for Current Transformer (CT) without screen

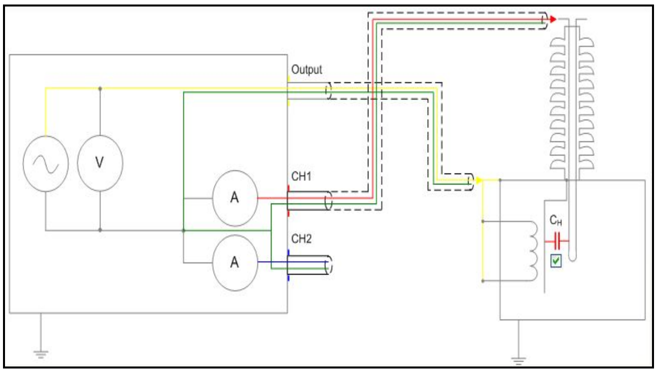


Fig. 5 Example dielectric response measurement setup for Current Transformer (CT) with screen

III. MODELLING DIELECTRIC RESPONSE

The combination of oil and pressboard used in power transformer and instrument transformer can be modelled as a simple network to calculate the composite response. The material properties and the geometric design are needed as an input. In frequency domain, each material is characterised as a complex permittivity, which depends upon frequency, *f* and temperature, ***T***.

$$□(□,T)= □'(□,T)-i.□''(□,T) \quad (1)$$

and the dielectric dissipation factor, *tan δ(□),*

$$\tan\delta\,(□) = □''(□)/\,□'(□) \quad (2)$$

The real part of Eq. (1) represents the capacitance of a test object, whereas the imaginary part represents the losses. The aging of insulation system will change these quantities in quite different and specific frequency ranges.

The geometric design for the modelling is the combination of oil and cellulose in the duct and lumped together to an "insulation module" as shown in Fig. 6. The insulation structure are characterised by the relative amount of barriers in the main duct (X) and the relative spacer coverage (Y).

DOI: 10.5963/IJEE0302001

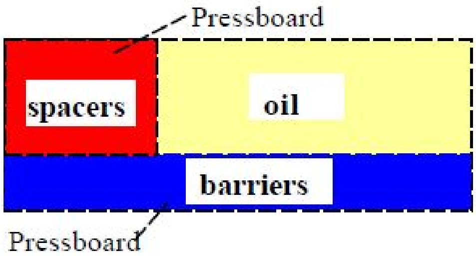


Fig. 6 Simplified geometry model for the main components oil, barriers and spacers

IV. INTERPRETATION GUIDE

Diagnostic rule as described in Table II below was developed to facilitate and standardise the asset management process. It was a challenge to the asset managers to prioritise the corrective action plans solely based on quantified moisture in paper and oil conductivity assessment, thus it was crucial to analyse other parameters which can determine the severity of insulation condition or ageing rate more precisely.

TABLE II TNB GUIDELINE FOR DIELECTRIC RESPONSE ON HIGH VOLTAGE CURRENT TRANSFORMER

Tier 1 : Preliminary Insulation Condition Analysis(1)				
Tier 1 Parameters	**Reference**	**132kV**	**275kV & above**	**Action**
% Dry Weight of Moisture Content in Solid Insulation	IEEE Std 62-1995	≤2%	≤2%	Acceptable. If exceeded perform Tier 2 analysis
Oil Conductivity (pS/m)	OMICRON DIRANA Manual	≤25	≤25	Acceptable. If exceeded perform Tier 2 analysis
% DDF@50Hz	TNB guide	<1.0	<1.0%	Acceptable. If exceeded perform Tier 2 analysis
Tier 2: Insulation Condition Severity Analysis(2)				
Tier 2 Parameters	**Reference**	**132kV**	**275kV & above**	**Action**
Capacitance Ratio(50Hz – 10mHz)	Typical value limit	<2.0	<2.5	Retest /Return to Service. If exceeded Replace
DDF (tanδ) over 50Hz – 10mHz	Typical value limit	DDF increasing across frequency spectrum and DDF@10mHz <100mW/VAR	DDF increasing across frequency spectrum and DDF@10mHz <200mW/VAR	Retest /Return to Service). If exceeded Replace

The interpretation of the measured dielectric response data was subdivided into Tier 1 and Tier 2 analysis respectively based on parameters as outlined below:

A. Tier 1: Preliminary Insulation Condition Analysis

Tier 1 analysis is done as preliminary analysis to screen the insulation condition of the measured instrument. Basic parameters considered for this analysis include moisture content in solid insulation, oil conductivity and dissipation factor value at 50 Hz as briefly explained below:

1) Tier 1.a: Moisture in % by dry weight in solid insulation

Moisture in solid insulation is a good indicator on the level of insulation degradation or contaminants within the solid insulation which is crucial. The estimation of moisture based on dielectric spectrum qualitatively is difficult. Thus, the moisture determination is based upon a comparison of the instrument's dielectric response to a modelled dielectric response. Since for instrument transformer measurement where the measurement is restricted to 1 kHZ to 10 mHz, the estimation of moisture sub- divided into two parts of dry or wet condition based on IEEE Std 62-1995. Moisture content below 2.2% is deemed dry insulation condition [15, 16].

2) Tier 1.b: Oil Conductivity

Oil Conductivity increases as the presence of contaminants mainly due to increase in acidity level of the oil insulation. It indicates increasing rate of ageing of oil/paper insulation system. Oil conductivity is given in Siemens per metre. New oil typically has a value of 0.5 pS/m and conductivity of oil above 20 pS/m indicates progressed aging in the insulation.

3) Tier 1.c: Dielectric Dissipation power factor (tanδ) at 50 Hz

The dielectric loss in an insulation system is the power dissipated by the insulation when subjected to AC voltage. Dielectric Dissipation Factor (DDF) or tanδ test provides great benefits to indicate problems in the insulation structure due to

DOI: 10.5963/IJEE0302001

aging, presence of contaminants, moisture, chemical substances, partial discharges and even due to mechanical stresses. Limits used as per standard TNB Conditon Monitoring Manual requirement only for Current Transformers where any value exceeding 1% for both 275 kV& above and 132 kV equipment requires further advance analysis as per Tier 2 [20].

B. Tier 2: Insulation Condition Severity Analysis

Tier 2 analysis is done as further analysis to determine the severity of insulation degradation or ageing rate of the measured instrument. This tier requires dielectric spectrum analysis both quantitative as well as qualitative technique. The parameters like capacitance ratio and increase of dissipation factor over frequency used as illustrated below.

1) Tier 2.a: Capacitance Ratio (C10 mHz/C50 Hz)

Relative change of capacitance over frequency spectrum is deemed a crucial sensitive parameter to detect severity of insulation degradation or aging. Capacitance ratio for this analysis is calculated over capacitance value at lower frequency (10 mHz) over capacitance value of power frequency 50 Hz. The limit of detection is done based on 90 percentile of typical value of the measured value in TNB system by TNB Research unit (TNBR). Fig. 7 and Fig. 8 illustrate the measured capacitance ratio value and typical value for both 132 kV and 275 kV instruments respectively.

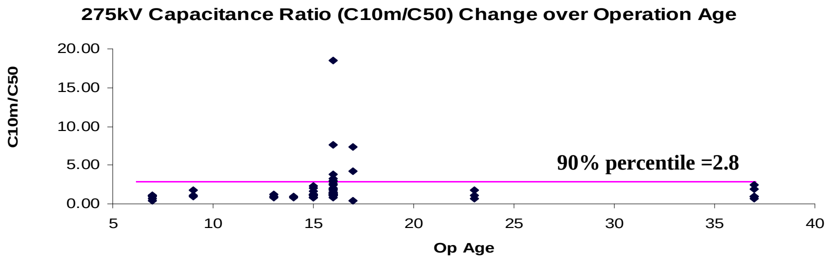


Fig. 7 Capacitance ratio over Operation Age for 275 kV CT

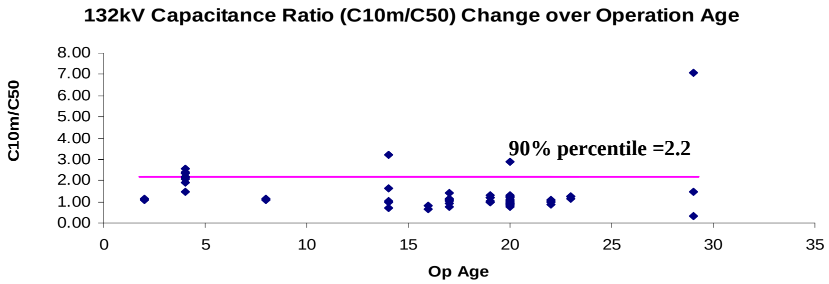


Fig. 8 Capacitance ratio over Operation Age for 132 kV CT

Thus, based on the conservative approach and discussion with external experts, TNB has decided to set the limits based on Capacitance Ratio measurement for both 132 kV and 275 kV, it is proposed that any deviation of capacitance ratio of more than or equals to 2.0 for 132 kV and 2.5 for 275 kV respectively will be considered critical.

2) Tier 2.b: Stability of DDF across frequency spectrum (50 Hz to 10 mHz)

Significant increase of DDF over frequency spectrum indicates serious insulation degradation or reduction in insulation dielectric strength. It is significant that change in DDF at lower frequency region sensitive to changes in insulation characteristics compared to DDF at power frequency value [6]. Thus, it is viable to analyse or compare the value of DDF at lower frequency, typically at 10 mHz. As stated above, the limit of detection is done based on 90 percentile of typical value of the measurement results in TNB system. Fig. 9 and Fig. 10 illustrate the measured DDF value at 10 mHz and typical value for both 132 kV and 275 kV instruments respectively.

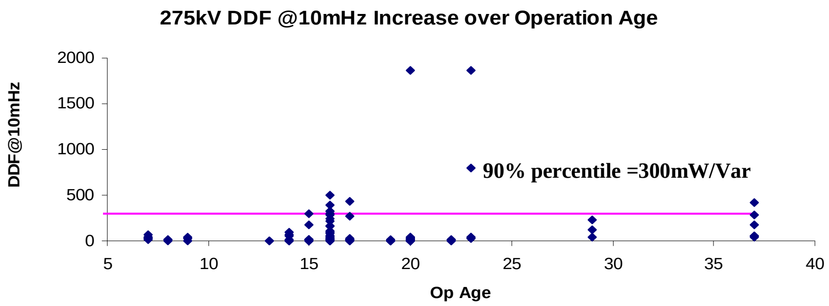


Fig. 9 DDF@10mHz versus Operation Age for 275 kV Current Transformers

DOI: 10.5963/IJEE0302001

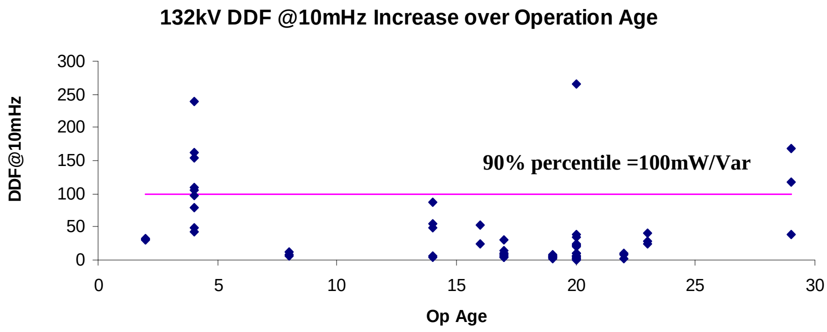


Fig. 10 DDF@10mHz versus Operation Age for 132 kV Current Transformers

Thus, based on the conservative approach and discussion with some external experts, TNB has decided to set the limits based on DDF at lower frequency measurement for both 132 kV and 275 kV, it is proposed that any significant increase of DDF over frequency spectrum and DDF@10 mHz value exceeding 200 mW/VAR for 275 kV and 100 mW/VAR for 132 kV respectively will be considered critical.

Both qualitative and quantitative analysis is done based on the guideline and flow chart illustrated in Table II and Fig. 11 below. The approach outlined is based on 90th percentile typical value limits of the field measurement data [7]. However, the interpretation should not be done solely on limits outlined but also combined with "pattern recognition" techniques. The pattern recognition techniques are done by comparing the healthy traces of DDF and capacitance response of sister or peer units with measured response. Any significant increase or deviation in the response shall be compensated with the quantitative analysis prior to any decision making.

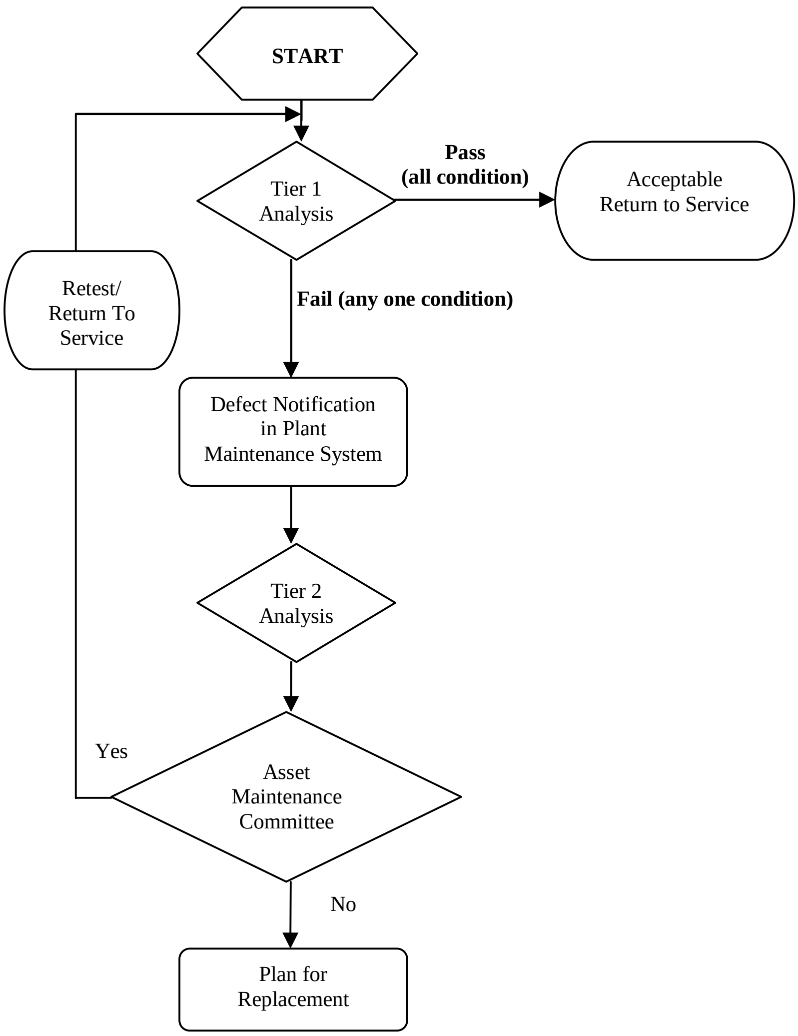
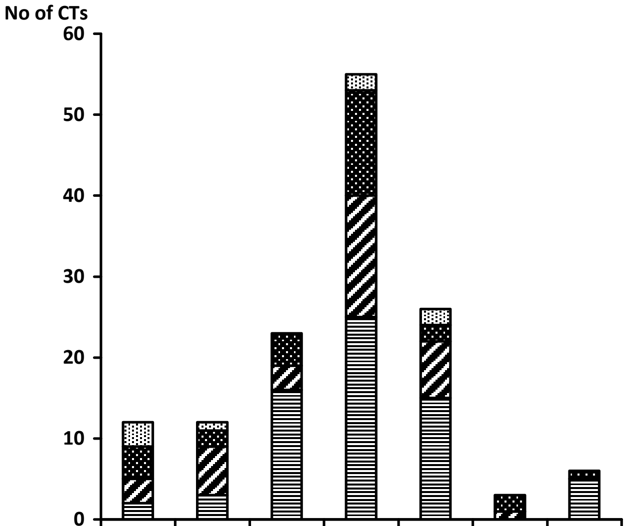


Fig. 11 Flowchart for interpretation of dielectric response measurements

DOI: 10.5963/IJEE0302001

V. RESULTS ANALYSIS

The measurement and analysis were done on 137 units of CTs at 132 kV and 275 kV according to qualitative and quantitative interpretation developed. Based on the analysis, recommendations for strategic decisions are made to avoid premature failures. The measurement results indicated that approximately 74% (101) of total units tested are within moisture content below 2% which considered in dry condition according to IEEE C62-1995 standards classifications as shown in Fig. 12 below. About 28 units or 20% of measured CTs have moisture content in the range of 2.1% to 3% which suggested that the units in wet condition and only 8 units (6%) were in excessive wet condition as the moisture content was above 3%.



	0 to 5 yrs	6-10 yrs	11-15 yrs	16-20 yrs	21-25yrs	26-30 yrs	> 30 yrs
>3%	3	1	0	2	2	0	0
2.1-3%	4	2	4	13	2	2	1
1-2%	3	6	3	15	7	1	0
<1%	2	3	16	25	15	0	5

Fig. 12 Assessment of moisture content of CTs under field measurements

Recommendations are made based on qualitative analysis of dissipation factor and capacitance responses waveforms. In addition, quantitative analysis was performed according to developed guide and it reveals the assessment results as illustrated in Fig. 13 below.

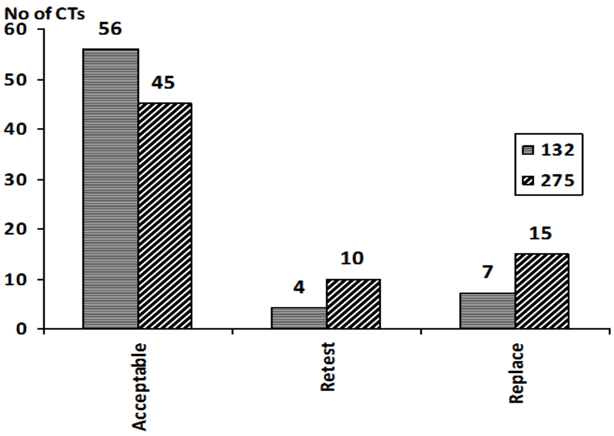


Fig. 13 Asset Strategy plan for High Voltage Current Transformers

VI. CASE STUDY 1

The 132 kV CTs at Main Intake A was tested due to the failure of previous units in the substation. The dissipation factor value at 50 Hz of red phase is 0.0033, yellow phase is 0.0124 and blue phase is 0.0024. This indicates that the yellow phase of instrument transformer was in worse condition. The dielectric response measurement was conducted on the respective CTs and the results are illustrated in Fig. 14.

DOI: 10.5963/IJEE0302001

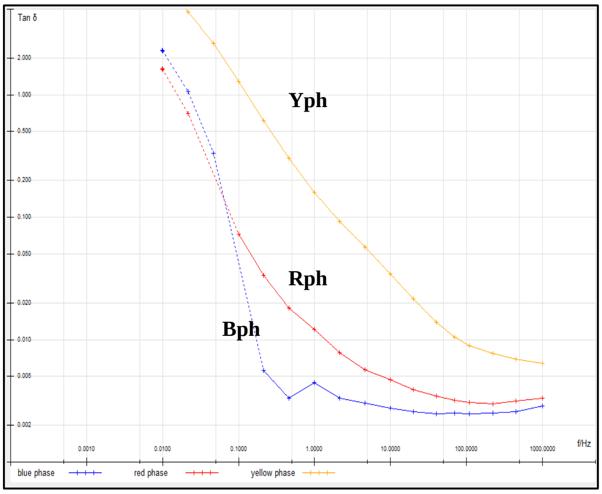


Fig. 14 Dielectric response tanδ over frequency range of the Current Transformers

The analysis of the dielectric response shows that the response at the lower and higher frequency ranges at the yellow phase is higher compared to the red and blue phase units. These results indicate that the moisture in the yellow phase is in wet conditions as compared to other twin units. The moisture content estimated in the CTs to be 1.4% at red phase, 3.5% at yellow phase and 0.9% at blue phase. The decision was to replace the unit. The dielectric response measurement was found to give better estimation about the dryness of the insulation as compared to the ordinary tan delta measurement at fixed frequency 50 Hz.

VII. CASE STUDY 2

Due to historical failures of 275 kV CTs at Main Intake B, three (3) samples of remaining peer units in the station were tested using dielectric response technique. The details of the units are as summarized below in Table III below:

TABLE III DETAILS OF TESTED UNITS

Unit ID	Phases	Operational Age (years)	Commissioned
1A	Red	16	1994
1B	Yellow	16	1994
1C	Blue	16	1994

The analysis interpretation was performed based on qualitative and quantitative analysis as per TNB interpretation guideline as shown in Table II above.

A. Qualitative Analysis

Based on dielectric response waveform response of the measured CTs, it is indicative that Units 1B and 1C have higher dielectric losses response as compared to Unit 1A. However no significant change or increase of capacitance frequency response was observed in the waveform as illustrated in Fig. 15 below:

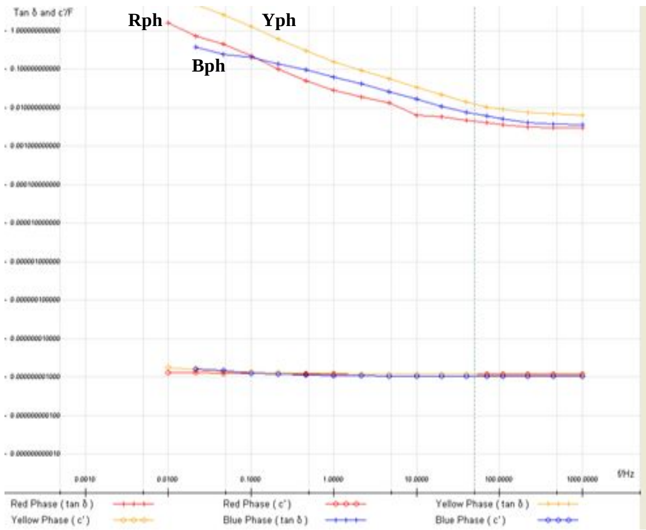


Fig. 15 Dielectric response tanδ and capacitance (C) over frequency range of the Current Transformers

DOI: 10.5963/IJEE0302001

B. Quantitative Analysis

Quantitative analysis were performed based on measured parameters of the dielectric response at Tier 1 and Tier 2 levels as shown in Table IV and Table V below.

TABLE IV TIER I PRELIMINARY INSULATION CONDITION ASSESSMENT

Parameters	Unit		
	1A (Red)	1B (Yellow)	1C (Blue)
% Moisture Content by dry weight in the solid insulation	**2.2%**	**3.4%**	**3.5%**
Oil Conductivity (pS/m)	5.2	**31**	4
DDF at power frequency 50Hz	0.45%	**1.25%**	**0.70%**

Based on Tier 1 analysis, estimated moisture content in solid insulation in Unit 1A (2.2%), Unit 1B (3.4%) and Unit 1C (3.5%) respectively indicated that all measured CTs indicated insulation is classified to be within moderately wet conditions as per IEEE limit. This assessment correlates well with measures dissipation factor (DDF) value at 50 Hz of unit 1A is 0.0045, 1B is 0.0125 and 1C is 0.0070. This indicates Yph and Bph have higher dielectric losses which require more details insulation condition severity analysis as per Tier 2 requirements.

Based on Tier 2, Unit 1B has shown significance increasing trend of tanδ value over frequency range, it is measured tanδ value over 800 mW/VAR at 10 mHz meanwhile other units (1A and 1B) is below 200 mW/VAR at lower frequency region. However, Unit 1C has shown significance capacitance ratio change at 10 mHz over power frequency 50 Hz, the value exceeds ration of 7.58 as compared with other units 1A (1.10) and 1B (1.55) respectively as computed in Table V below.

TABLE V TIER II INSULATION CONDITION SEVERITY ANALYSIS

Parameters	Unit		
	1A (Red)	1B (Yellow)	1C (Blue)
Capacitance Ratio $\frac{C_{10\ mHz}}{C_{50\ Hz}}$	$\frac{1.3225nF}{1.2nF}$ (1.10)	$\frac{1.8403nF}{1.1885nF}$ (1.55)	$\frac{8.0372nF}{1.061nF}$ **(7.58)**
DDF (tanδ) over 50Hz-10mHz Value at DDF @ 10mHz	163.20mW/VAR	**800.55mW/VAR**	100.90mW/VAR

Based on Tier 1 and Tier 2 analysis, Unit 1B (Yph) and Unit 1C (Bph) were replaced. However Unit 1A was put back in service safely and identified for retest and condition monitor after 6 months in service.

VIII. BENEFIT ANALYSIS

Benefits analysis of the diagnostic technique was performed based on risk probability model proposed by CIGRE WG A2.20 [19] as illustrated in Figs. 16, 17 and Table VI below. Assumption of constant CT historical failure rate of 0.044/100 CT-year was used for the purpose of the analysis.

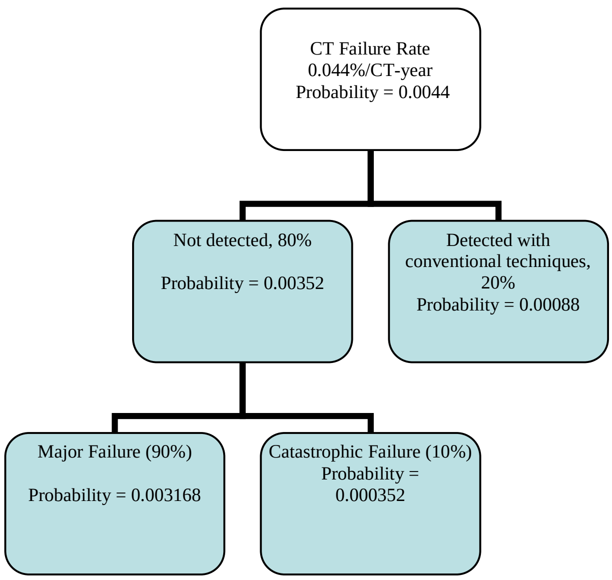


Fig. 16 Probability Tree Diagram for typical CT with Conventional Electrical Diagnostic Technique

DOI: 10.5963/IJEE0302001

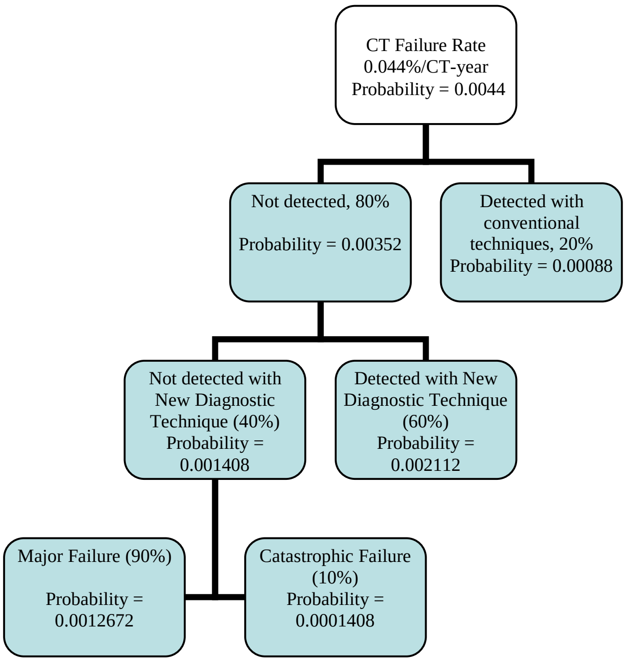


Fig. 17 Probability Tree Diagram for typical CT with New Diagnostic Technique

Calculation below is based on real case study mentioned above and the benefits to be assessed are related to failure resolutions cost and loss of revenue due to undelivered energy. Calculation of annual savings requires establishing the following costs as in Table VI below:

TABLE VI RISK BENEFIT ANALYSIS FOR NEW DIAGNOSTIC TECHNIQUE

Item	Description	Value
(1)	Busbar Maximum Loading at Main intake in TNB	700 MW
(2)	Repair cost for major failure without any advance warning	RM 250,000
(3)	Replacement cost and collateral damage in case of catastrophic failure (i.e fire, explosion, adjacent equipment damage)	RM 1 mil
(4)	Repair cost for early detection	RM 35,000
(5)	Major Failure Probability with conventional technique	0.003168
(6)	Major Failure Probability with new diagnostic technique	0.0012672
(7)	Catastrophic failure probability with conventional technique	0.000352
(8)	Catastrophic failure with new diagnostic technique	0.0001408
(9)	Probability of early failure detection	0.002112
(10)	Outage duration*(Note)	21 days
(11)	Cost of energy not supplied	RM 300/MWh

(A) Annual Risk Cost using Conventional Technique

Conventional Technique	Value
(a) Annual cost of major failure (5) x (2)	RM 792.00
(b) Annual cost of catastrophic failure (7) x (3)	RM 352.00
(c) Loss of revenue (5+7) x (1) x (10) x (11) x 24h	RM 15532.20
Annual cost of risk with conventional technique (a) + (b) + (c)	RM 16667.2

(B) Annual Risk Cost Benefit using New Technique

Conventional Technique	Value
(a) Annual cost of major failure (6) x (2)	RM 316.80
(b) Annual cost of catastrophic failure (8) x (4)	RM 140.80
(c) Loss of revenue (6+8) x (1) x (10) x (12) x 24h	RM 6209.28
Annual cost of risk with new diagnostic technique (a) + (b) + (c)	RM 6667.00

DOI: 10.5963/IJEE0302001

Based on risk cost benefits analysis, it can be estimated that the annualised risk cost saving with the introduction of new method is approximately RM 10,000 per year. Despite low risk cost factor, any catastrophic failures due to CT in TNB had great negative impact on the grid system security, company image, environmental issue and safety to personnel which is not reflected directly in computation above.

Further data analysis was done to predict the total number of CTs and the direct savings which will be prevented with the introduction of new method as summarised in Table VII below. Assumption was made for the purpose of analysis that the CT failure and system growth is constant at 0.044/100CT-year and 6% respectively.

TABLE VII REDUCTION IN FAILURE RATE AND DIRECT COST SAVING USING NEW TECHNIQUE

	Year 1	Year 2	Year 3	Year 4
Total CT	8608	9124	9672	10252
Failure Rate with conventional technique	0.044	0.044	0.044	0.044
No of CT Failure with conventional technique	3.78	4.01	4.26	4.51
Failure Rate of CT with new technique (assume 60% efficiency)	0.0132	0.0132	0.0132	0.0132
No of CT Failure with new technique	1.14	1.20	1.27	1.35
No of failures prevented	2.65	2.81	2.98	3.16
Direct cost Saving per CT failure (assume 1 major failure cost RM 250K)	**RM 0.66 mil**	**RM 0.70mil**	**RM 0.744 mil**	**RM 0.79mil**

Based on data analysis as illustrated in Table VII, despite low number of failures, the direct cost saving exceeding RM 0.6 mil per year with increased system reliability is a great benefit to TNB by introducing this technique.

IX. ISSUES AND PROBLEMS

TNB has experienced some issues or problems concerning with dielectric response measurement at site. It is important for this problem to be well understood and resolved in order for the technique to be effectively used. It was observed that a number of test situations have resulted negative response especially at higher frequency ranges as illustrated in Fig. 18.

The problem could be due to a small measured capacitance in conjunction with a large guard capacitance and high guard currents, for example dirty bushings [9].

To overcome this problem, the guard currents should be decreased by cleaning the bushing prior to the dielectric response measurement and alternatively put additional wire from the tri-axial connector at the measuring equipment to the ground terminal.

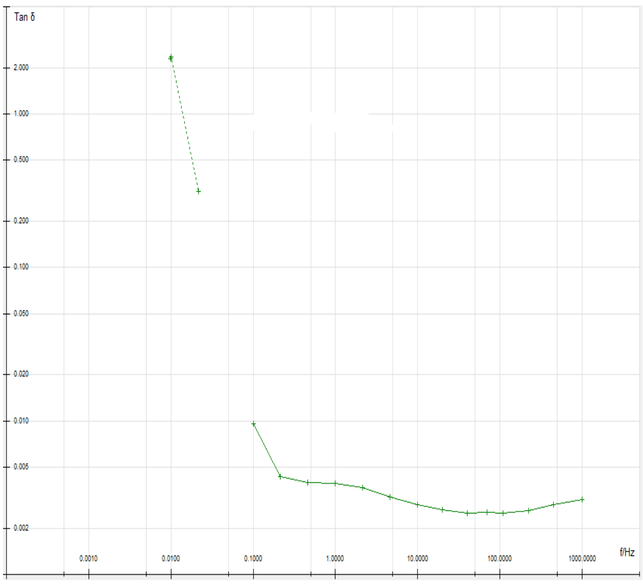


Fig. 18 Negative response during on-site measurement

X. CONCLUSIONS

The use of dielectric response technique over wide frequency range offers reliable and sensitive diagnostic technique to assess high voltage CT. Interpretation guideline developed has given a good avenue to TNB to determine the appropriate asset strategic decision to reduce similar CT failures in the future and remove problematic units early. However, continuous improvement with additional measurement data is necessary to review interpretation guideline limits for more accurate assessment or decision.

DOI: 10.5963/IJEE0302001

REFERENCES

[1] CIGRÉ Study Committee A3, "State of the Art of Instrument Transformers," Technical Brochure 394, Paris, 2009.

[2] TNB Maintenance Policy, Transmission Division, 2008.

[3] John Lapworth & Richard Heywood, “The Determination of the Dryness of Transformer Insulation: Recent NGC Experience with Polarization Tests,” Proceedings of the International Conference of DOBLE Clients Sec 8-11, 2001.

[4] Tapan Kumar Saha, “Review of Time Domain Polarisation Measurement for Assessing Insulation Condition in Aged Transformer,” IEEE Transaction on Power Delivery, Vol.18, No.4, Oct 2003, pp 1293-1301.

[5] Jorgen Blennow, Chandima Ekanayake, Kzysztof Walezak, Belen Garcia and Stainslaw M.Gubanski, April 2006; IEEE Transaction on Power Delivery Vol 21, No 2: Field Experience with Measurement of Dielectric Response in Frequency Domain for Power Transformer Diagnostics.

[6] Walter S.Zaengl (Swiss Federal Institute of Technology), Nov/Dec 2003; IEEE Electrical Insulation Magazine Vol 19, No.6: Application of Dielectric Spectroscopy in Time and Frequency Domain for HV Power Equipment.

[7] T.Leibfried, A.J.Kachle,D.Pollaro (Siemens AG): Power Transformer Ageing Assessment in Service By Means of The Polarisation and Depolarisation Current (PDC) Analysis.

[8] Maik Koch, Stefan Tenbohlen (University of Stuggart), August 2005; Publication in Tsinghua University, Beijing, China: Diagnostics of Oil-Paper Using Relaxation Current.

[9] Küchler, T.Leibfried, B.Breitenbauch, JJ.Alff, V.Der Houhanessian and W.S Zaengl, Sept 2003; 48th International Colloquium – Illmenau Technical University: Transformer Insulation Diagnosis by Polarization and Depolarization Current Analysis.

[10] Tapan Kumar Saha, October 2003; IEEE Transactions on Power Delivery Vol 18, No. 4: Review of Time Domain Polarisation Measurements for Assessing Insulation Condition in Aged Transformers.

[11] Walter S.Zaengl, “Dielectric spectroscopy in time and frequency domain for HV power equipment,” 12th Intenational Symposium on High Voltage Engineering, Bangalore, India, August 20-24, 2001.

[12] S.M.Gubanski, P.Guinninc, J.Lapworth, P.Werelius, “Dielectric response methods for diagnostics of power transformers,” IEEE Electrical Magazine, Vol. 19, pp 12-18, 2003.

[13] M. Koch, M. Krueger: “A Fast and Reliable Dielectric Diagnostic Method to Determine Moisture in Power Transformers,” International Conference on Condition Monitoring and Diagnosis CMD, Peking, China, 21 - 24 April 2008.

[14] Stephanie Raetzke, Alan McGuigan. “Measuring and Analysing the Dielectric Response of Current Transformer,” OMICRON Product Manual, August 2011, v1.0.

[15] IEC 60422, “Standards Mineral Insulating Oils in electrical equipment- Supervision and maintenance guidance.” pp. 1-78, 2005-10.

[16] IEEE Std62-1995, “IEEE Guide for Diagnostic Field Testing of Electric Apparatus – Part 1: Oil Filled Power Transformers, Regulators, and Reactors”, pp. 5-57, 1995.

[17] OMICRON Application Guide. “Measuring and Analyzing the Dielectric Response of Current Transformer,” August 2011.

[18] S. Raetzke, M. Koch and M. Krueger, “New approach to assess the insulation condition of instrument transformers,” OMICRON Publication, 2011.

[19] CIGRE WG A2.20, Guide on Economics of Transformer Management, pp 21-22, June 2004.

[20] TNB Transmission Condition Monitoring Guideline, 2010.

Ir. Gobi K. Supramaniam was born in Kuala Lumpur, Malaysia, in 1977. He obtained his BSc degree in electrical engineering with Cum Laude from Western Michigan University, Michigan, USA in 1999 and Master Degree in power engineering from Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia in 2008. He has worked with the Malaysian Electricity Utility Company (TNB) since 1999, being in charge of operations and maintenance works on high voltage substation installations in the transmission division. Currently, he is the Technical Expert in charge of EHV Transformers, looking specifically on new technology studies and improvements in power and instrument transformer design and diagnostic improvements in TNB System. He is also a Chartered Engineer with the IET (UK) and Professional Engineer registered with the Boards of Engineers Malaysia. His research interest includes transformer condition monitoring, equipment health indices and assessment, insulation coordination, insulation diagnostics and dielectric measurements.

Mohd Aizam Talib received his Bachelor in Electrical Engineering from the University of Portsmouth, UK in 1997, and Master degree in Electrical Engineering from Universiti Tenaga Nasional (UNITEN), Malaysia in 2001. Upon graduation in 1997, he worked with ABB Transmission and Distribution Sdn Bhd as a Design Engineer. Since 1998, he has been employed by TNB Research Sdn Bhd as a Research Engineer. His research interests are in transformer condition monitoring, insulation diagnostic and dielectric measurements. Presently, he is Senior Researcher at High Voltage Diagnostic Research Group, TNB Research Sdn Bhd.

DOI: 10.5963/IJEE0302001