Dielectric Loss Factor Measurement in A Gas-Insulated Transmission Line by Using Very Low Frequency Test

Tritod Nganpitak
Department of Electrical Engineering,
Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang
Bangkok, Thailand
ng.tritod@gmail.com

Nattachote Rugthaicharoencheep
Department of Electrical Engineering,
Faculty of Engineering,
Rajamangala University of Technology Phra Nakhon
Bangkok, Thailand
nattachote.r@rmutp.ac.th

Phop Chancharoensook
Department of Electrical Engineering,
Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang
Bangkok, Thailand
kcphop@kmitl.ac.th

Norasage Pattanadech
Department of Electrical Engineering,
Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang
Bangkok, Thailand
norasage@yahoo.com

***Abstract*—Very low frequency tan delta measurement (VLF-TD measurement) is one of the insulation diagnosis methods usually uses to diagnosis the condition of electrical cable insulation. However, this research focuses on using VLF-TD measurement with a gas-insulated transmission line (GIL). The 230kV, 2500A, single phase, GIL with 2.0 m length was installed and prepared for experiments. in this paper, VLF-TD experiments were divided into 5 cases, classified by using types of artificial defects as a criterion, i.e. 1) The clean GIL without any defect, 2) The GIL with scratched on the surface of cone insulator, 3) The GIL with tracking path on the surface of cone insulator, 4) The GIL with protrusion on high voltage conductor and 5) The GIL with protrusion on enclosure. The average tan delta, VLF tan delta stability, and VLF differential tan delta were presented and compared in this paper.**

Keywords—gas-insulated transmission line, very low frequency measurement, tan delta measurement

I. INTRODUCTION

Nowadays, gas-insulated transmission lines (GIL) are widely used in order to transmit the electrical power energy. When compared with electrical cable, The GILs take advantage of smaller size, higher reliability and outstanding safety in operation. Moreover, the GILs take up much less space when transmit the same power as an electrical cable. However during installation and operation processes, the failure can be occurred to the GIL insulation system. Some of the failures, usually appear inside the GILs, are defected cone insulator and protrusion.

Most research are recommended to perform the PD measurement in order to detect and eliminate such defect inside the GIL. However, this research focuses on an alternative way which is using very low frequency withstand test in order to measure tan delta from the GIL insulation system.

II. RELATED THEORIES

A. *Very low frequency withstand test*

The dielectric withstand test or high potential test is an electrical test that usually used for determining the capability of insulation in high voltage apparatus. In case of high capacitive load, such as electrical cable and GIL, due to high capacitance, the dielectric withstand test is difficult to perform under power frequency. Many studies have recommended to reduce the frequency of testing AC sinusoidal to 0.01 – 0.1 Hz (Very low frequency range: VLF range), in order to scale down the burden from voltage source. The benefit of frequency reduction can be explained by using equation (1),

$$P = 2\pi f C V^2 \quad (1)$$

Where,	P	=	Power (Watt)
	f	=	Frequency of AC sinusoidal (Hz)
	C	=	Capacitance of the test object (F)
	V	=	Applied test voltage (V)

From above equation, by changing the frequency of AC sinusoidal from power frequency (f = 60 Hz) to VLF (f = 0.1 Hz), at same voltage and same load (same capacitance), the required power in case of using VLF is reduced 600 times from the case of using power frequency. This advantage makes VLF testing unit size more compact than normal power source. From this reason, it makes VLF withstand test easy to perform onsite. Moreover, The VLF withstand test also takes advantage of "created less partial discharge degradation" which are reported in many research [1-5]

978-1-7281-6486-1/20/$31.00 ©2020 IEEE

B. Dielectric loss factor / Tan delta [1-3]

The ideal insulator, when connected to the electrical circuit, is acted as a pure capacitor. From this reason, the phase angle of total electric current, which is only capacitive electric current, leads the applied voltage by 90°. However, this angle is shift from angle in practical case. In real case, the real insulator consists of capacitor and resistor. The equivalent circuit of real insulator can be shown in Fig. 1(A). A resistor element, which is appeared in that equivalent circuit, comes from aging and impurity of the real insulator. Due to the addition of resistive component, as shown in Fig. 1(B), the phase angle of the total electric current will change.

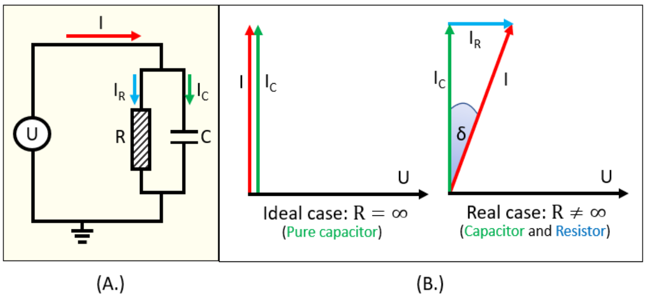

Fig.1. Fundamental knowledge of tan delta
(a) Example equivalent circuit of an insulator
(b) The comparison between ideal insulator and the real insulator

The dielectric loss factor, also known as tan delta (TD), is denoted to represent the different from ideal case and real case. When the equivalent circuit is same as Fig. 1(A), It is the ratio between current flow in the resistive component and the capacitive component. However, the equivalent circuit can also be resistor series with capacitor which is diverged from Fig. 1(A). In that case, the dielectric loss factor will be the ratio between voltage between the resistive component and the capacitive component instead.

In this paper, the VLF-TD experiments were performed with a GIL. Each experiment not only measured the magnitude and the mean of TD, but also measured the VLF tan delta stability and the VLF differential tan delta for further analysis.

1) VLF tan delta stability (VLF-TDTS): this factor represents a time dependency of the TD. It is a standard deviation of sequential measurements at U_0.

2) VLF differential tan delta (VLF-DTD): this factor represents a voltage dependency of the TD. It is a different between TD of sequential measurements. In this paper, using a different between TD at 0.5 U_0 and 1.5 U_0.

III. Experimentation

A. Preparation of experiment

For the experiments, a 230 kV, 2500 single phase GIL, which comprised of straight unit and disconnecting unit, was prepared. This GIL had 2 m in length. The diameter of external conductor, and external enclosure are specified as shown in Fig. 2

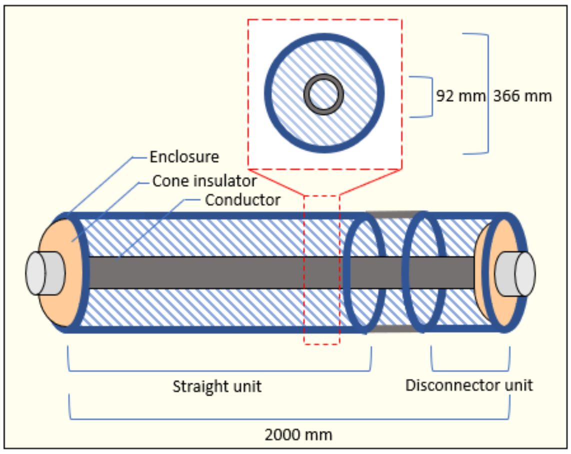

Fig. 2. The specification of GIL using in this research

In order to measure the value of TD, A total of five case experiments, classified by type of defected, were performed as follow.

1) The clean GIL without any defect (The reference case)

2) The GIL with scratched on the surface of cone insulator. This experiment was simulated by using the cone insulator attached with 2x10 mm paper tape.

3) The GIL with tracking path on the surface of cone insulator. This experiment was simulated by using the cone insulator attached with 2x10 mm aluminum tape.

4) The GIL with protrusion on high voltage side. This experiment was simulated by using a 4 cm aluminum wire attached to the conductor of the GIL.

5) The GIL with protrusion on low voltage side. This experiment was simulated by using a 4 cm aluminum wire attached to the enclosure of the GIL.

In the fifth experiment, the aluminum wire length of 4 cm was measured from the inside circumference of enclosure to the end of aluminum wire. All of artificial defect using in this research is shown in Fig. 3.

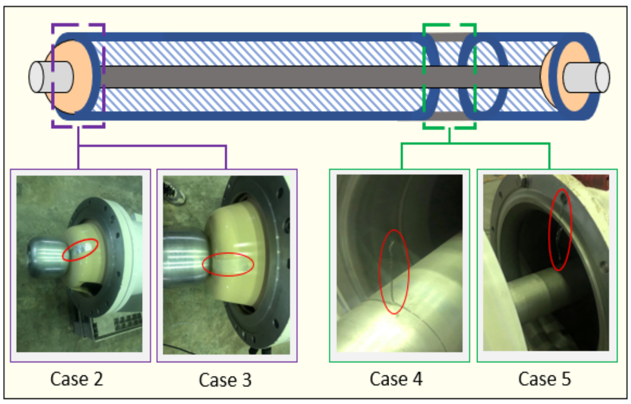

Fig. 3. Location of artificial defects using in VLF measurements

B. Experiment setup

The VLF-TD measurement experiment was performed by energizing the high voltage conductor of the GIL with the VLF testing unit and the enclosure of GIL was connected to the laboratory ground. The VLF-TD delta measurement circuit are depicted in Fig. 4.

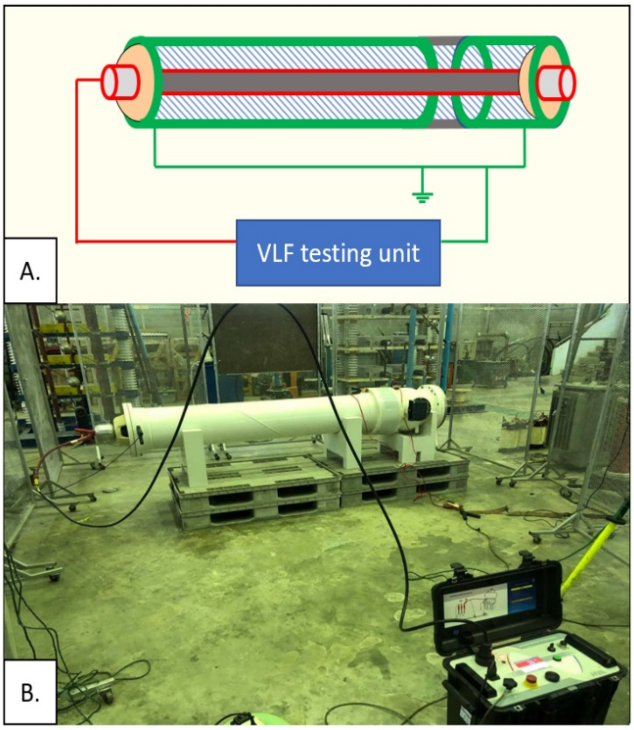

Fig. 4. Test circuit diagram and test circuit arrangement for VLF-TD measurements
(a) Test circuit diagram
(b) Test circuit arrangement

C. Experiment procedure

At the present, there is no standard or guide for testing GIL with VLF. So, the VLF-TD experiments, in this paper, were performed according to IEEE Std 400.2-2013 by assuming that the GIL as an electrical cable. The values of TD were measured at 0.5 U_0, U_0 and 1.5U_0. and each step consisted of ten single TD measurements at the interval of 10s between each measurement at 0.1 Hz [1-3]. All cases were performed three times. The summarization of voltage sequence applying the high voltage conductor of the GIL is shown in Fig. 5.

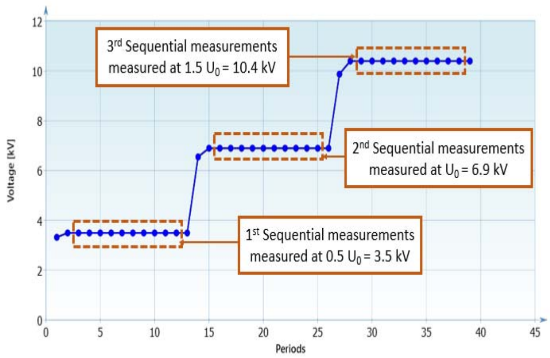

Fig. 5. The voltage sequence applying the high voltage conductor of the GIL

IV. Test Results

The result of VLF-TD measurements obtained from each experiment as shown in Table 1 – 6.

A. The clean GIL without any defect (Reference case)

Average TD and standard deviation obtained from case 1 are represented in table 1.

TABLE I. AVERAGE TD AND STANDARD DEVIATION FROM CASE 1

	1st experiment		2nd experiment		3rd experiment	
Voltage [rms]	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**
3.5 kV	14.0	6.75	13.3	2.31	12.1	3.17
6.9 kV	23.0	1.49	25.5	3.00	22.2	2.57
10.4 kV	66.2	4.38	67.6	2.39	69.6	4.89

B. The GIL with scratched on the surface of cone insulator

Average TD and standard deviation obtained from case 2 are represented in table 2.

TABLE II. AVERAGE TD AND STANDARD DEVIATION FROM CASE 2

	1st experiment		2nd experiment		3rd experiment	
Voltage [rms]	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**
3.5 kV	21.1	4.94	17.8	4.79	21.4	2.79
6.9 kV	37.9	4.74	37.6	2.54	36.5	3.01
10.4 kV	82.7	1.45	103	39.0	78.0	1.28

C. The GIL with tracking path on the surface of cone insulator

Average TD and standard deviation obtained from case 3 are represented in table 3.

TABLE III. AVERAGE TD AND STANDARD DEVIATION FROM CASE 3

	1st experiment		2nd experiment		3rd experiment	
Voltage [rms]	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**
3.5 kV	32.1	3.36	31.1	3.50	34.2	4.42
6.9 kV	46.4	2.94	46.1	2.08	49.8	1.40
10.4 kV	85.4	3.66	87.7	2.52	91.0	3.00

D. The GIL with protrusion on high voltage side

Average TD and standard deviation obtained from case 4 are represented in table 4.

TABLE IV. AVERAGE TD AND STANDARD DEVIATION FROM CASE 4

	1st experiment		2nd experiment		3rd experiment	
Voltage [rms]	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**	**TD [E-3]**	**Std.Dev. [E-3]**
3.5 kV	61.9	5.15	58.7	5.86	50.2	4.60
6.9 kV	995	3.03	982	5.10	958	6.12
10.4 kV	>999	5.27	>999	6.84	>999	3.27

E. The GIL with protrusion on low voltage side

Average TD and standard deviation obtained from case 5 are represented in table 5.

TABLE V. TD AVERAGE AND STANDARD DEVIATION FROM CASE 5

	1st experiment		2nd experiment		3rd experiment	
Voltage [rms]	**$\overline{TD}$ [E-3]**	**Std.Dev. [E-3]**	**$\overline{TD}$ [E-3]**	**Std.Dev. [E-3]**	**$\overline{TD}$ [E-3]**	**Std.Dev. [E-3]**
3.5 kV	19.4	2.66	19.7	3.31	15.8	5.15
6.9 kV	133	3.88	169	4.27	179	3.42
10.4 kV	698	15.7	719	2.21	730	6.70

F. *VLF tan delta stability and VLF differential tan delta*

VLF tan delta stability and VLF differential tan delta are represented in table 6.

TABLE VI. FURTHUR ANALYSIS OF VLF TAN DELTA STABILITY AND VLF DIFFENTIAL TAN DELTA

	VLF-TDTS			VLF-DTD		
1st case	1.49	3.00	2.57	52.2	54.3	57.5
2nd case	4.74	2.54	3.01	61.6	85.2	56.6
3rd case	2.94	2.08	1.40	53.3	56.6	56.8
4th case	3.03	5.10	6.12	> 500	>500	>500
5th case	3.88	4.27	3.42	> 500	>500	>500

V. CONCLUSION

From the experiment, The TD measured by using VLF test technique can be used to detect the defect in the GIL. Using the first case as a reference, it clearly seen that the TD measurement is a potential way to detect the abnormality.

In case of VLF-TDTS and VLF-DTD, these parameters also show the different among clean GIL case, defected cone cases and protrusion cases. However, the result cannot be interpreted by using criteria, which developed for electrical cable.

ACKNOWLEDGEMENT

The authors wish to acknowledge all staff of dielectric analytiká laboratory, Faculty of Electrical Engineering, King Mongkut's Institute of Technology Ladkrabang and Data Entry Group Co., Ltd.

REFERENCES

[1] IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)(less than 1 Hz)," in IEEE Std 400.2-2013 , vol., no., pp.1-60, 9 June 2013

[2] CIGRE 751, "Electrical properties of insulating materials under VLF voltage," December 2018.

[3] B. V. Wong, Y. Tian and T. Neier, "Practical experience using VLF Tan Delta and partial discharge measurement in medium voltage cable," 2016 China International Conference on Electricity Distribution (CICED), Xi'an, 2016, pp. 1-5.

[4] Jean Carlos hernandez-Mejia, Joshua Perkel and Nigel Hampton, "Methods and Experience of Very Low Frequency (VLF) Diagnostic Testing to Support Asset Management of Critical MV Circuits," Jicable'19 - Versailles, France - June 20-22, 2019

[5] Eppelein, Friedmann & Weindl, Christian. (2017). Comparison of VLF and power frequency measurements for diagnostic analysis of MV PILC cables.