FIELD TEST ON CASCADE CURRENT TRANSFORMER – EXPERIENCES AND DEVELOPMENT OF GUIDELINES

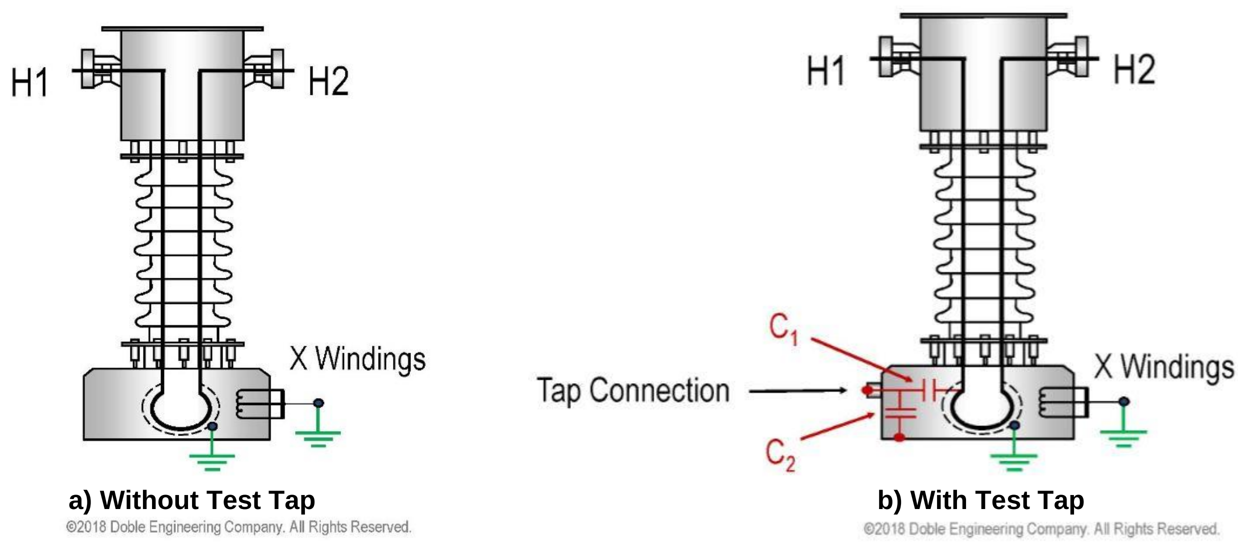
John Vandermaar, Blake Veerman, BC Hydro
Long Pong, Doble Engineering Company

ABSTRACT

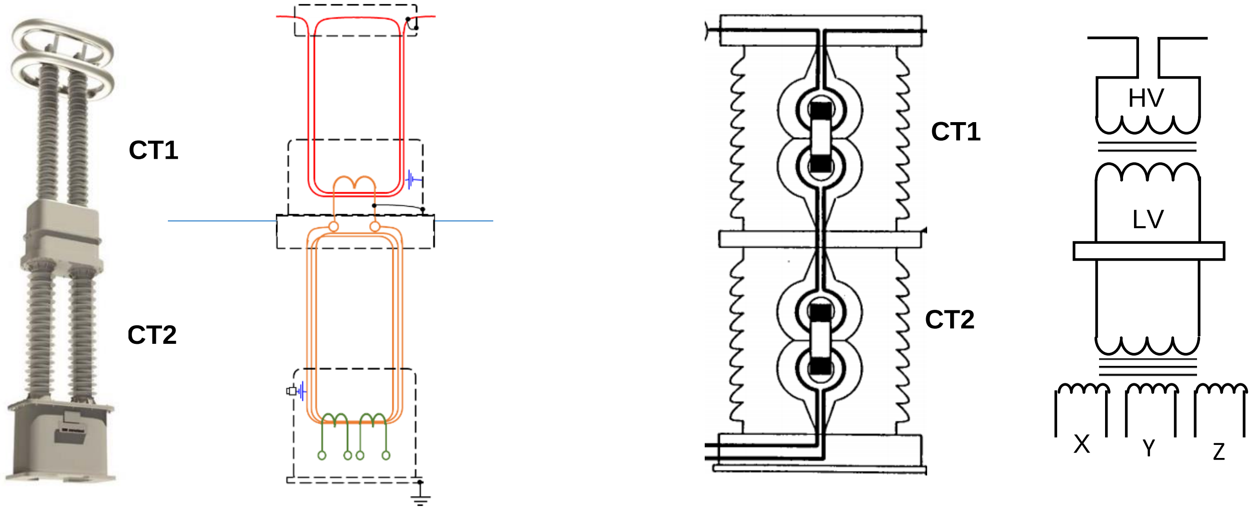
Cascade current transformers (CTs) are typically used in high and extra high voltage systems and are made by stacking two or more CTs in series adding complexity for testing and condition assessment. Test standards have been developed based on non-cascade CT's; therefore, the manufacturers typically test the cascade CT only as one combined device. This paper examines the CT component systems including the magnetic and the insulation systems. It studies the use of tests on the individual CT stacks delivered to the site before assembly and further tests after final assembly. This paper proposes a field test guide for this type of CT.

INTRODUCTION

Conventional CTs consist of one primary and one or more secondary coils as shown in Figure 1. In a cascade CT there are two or more CTs connected in series adding complexity for design, construction, and testing. Figure 2 shows two stage cascade CTs. Reference [1] describes a four-stage cascade CT.



Conventional Current Transformer
Figure 1



a) Dry type (parallel bushings)

b) Oil filled type (single bushings)

Cascade Current Transformer
Figure 2

In this paper the advantages and disadvantages of cascade CTs are reviewed with a focus on two section CTs. The magnetic circuit and the insulation circuit of two section CTs are examined. Test requirements are reviewed, and procedures and guidelines are proposed for field tests. Example data is reviewed.

ADVANTAGES AND DISADVANTAGES OF CASCADE CURRENT TRANSFORMERS

Advantages

- In a two-stage cascade CT the major insulation is divided between two stages. Each stage carries approximately one half of the total applied voltage.
- Since the total volume of insulation on a given coil varies as the cube of its operating voltage [1] the volume and thickness of insulation required is less than that required by a single-stage design. This results in a lighter CT.
- Separating a CT into two sections makes the construction and handling of the CT easier.
- The CT sections can be shipped separately as smaller individual pieces which minimizes shipping problems.

Disadvantages

- The exciting currents of each CT add in a cascade design and therefore careful design is required to achieve accuracy.
- Proper division of voltage among the insulation sections is important. It makes the design work more complex.
- Testing is more complex and takes longer due to additional test configurations as well as an inability to perform assembled tests prior to installation and assembly on the platform.

FIELD TESTING OF CTS

In field testing of CTs we typically test the magnetic circuit and the insulation systems separately [2].

For the magnetic circuit we measure:

- Winding Resistance test on LV winding (first test to be run because demagnetization can be done immediately).
- Excitation curve and knee point, which demagnetizes the CT.
- Ratio (VX/VH), phase angle, polarity and accuracy (error).
- Insulation Resistance on LV winding (500 or 1000Vdc).

For the High Voltage insulation system, we measure the capacitance and the power factor [3].

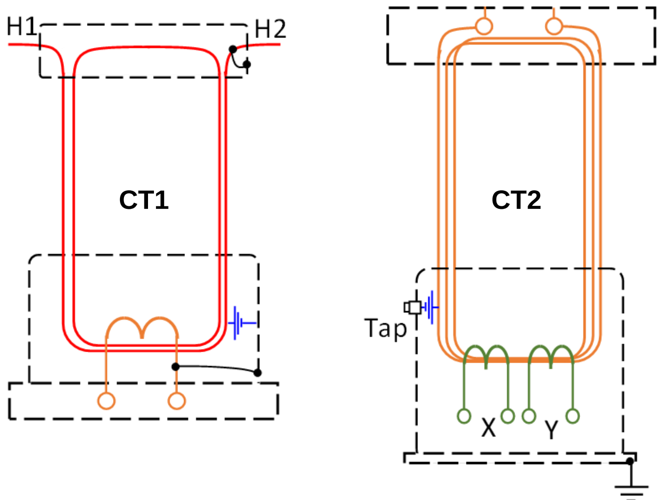
TEST PROCEDURES DISCUSSION

Cascade CT Magnetic Circuit Testing

If we test an assembled two-stage cascade CT in Figure 2 as if it is a conventional single stage CT, we will have some issues caused by having two CT stages:

- Winding Resistance: the CT1 secondary winding resistance will not be measured, the secondary winding resistance measurement is only measuring CT2 secondaries.
- Excitation:
  - CT1's secondary excitation voltage will be reduced compared to CT2's secondary excitation voltage by the ratio of CT2.
  - In field testing using the Vanguard EZCT, we are exciting from the secondary of CT2, while in service we excite from the primary of CT1. This means that during the test the winding resistances of CT2 primary and CT1 secondary, shown in Table 2, reduce CT1's voltage, while in service CT1 voltage will be increased by these resistances, adding to CT1 burden and thus increasing its possible contribution to error (leakage) current.
  - The leakage currents will add together, shifting the excitation curve to the right, however, as long as the knee point of CT1 is well above the knee point of CT2 corrected by CT2 ratio, then CT2 knee point will dominate.
- There is a possibility that the normal demagnetization procedure may be insufficient. Can we be sure that we are demagnetizing CT1 when demagnetizing from CT2 secondaries? This question is still open, it stands to reason that some typical checks, such as that excitation current reached at least 0.8 A to ensure demagnetization [4] needs to be examined in the context of Cascade CTs.
- Ratio and error.
- Insulation Resistance measurements, similar to winding resistance, will measure only the CT2 secondaries.

It may be noted that many of the above challenges can be compensated by performing tests in two steps, first testing the magnetic and electrical circuits as two separate CTs CT1 and CT2 as shown in Figure 3, then testing the whole CT after assembly of CT1 with CT2. This method is discussed in further detail in the proposed cascade CT test procedure, later in this paper.



Two Stage Cascade CT shown Separated for Shipping

Figure 3

Table 1 shows the test results of winding tests done on a dual ratio (primary configurable) 300 kV two-stage cascade CT using a Doble Vanguard EZCT. Testing was performed in advance of installation with CT1 and CT2 separately, then after installation with CT1 and CT2 assembled into one complete cascade CT. The primary configuration was changed from 1000 A to 500 A during installation, changing the overall ratio by a factor of 2. The Appendix contains the nameplate data relevant for comparison.

Table 1
Cascade CT (with two secondary windings) Magnetic Circuit Test Results

		Knee point (IEEE 30)		Secondary Winding Resistance (mΩ@75°C)		Ratio	
Unit	**Sec.**	**Sep.***	**Assembled****	**Sep.***	**Assembled****	**Sep.***	**Assembled****
1	CT1	58.84	-	141	-	100.034	-
	CT2 X	80.76	85.44	120	117	2	100.041
	CT2 Y	83.28	85.88	118	113	2.001	100.063
2	CT1	59.88	-	150	-	100.03	-
	CT2 X	80.56	83.68	114	114	2	100.035
	CT2 Y	85.56	87.64	123	113	2	100.017
3	CT1	62.4	-	165	-	100.028	-
	CT2 X	88.32	84.36	116	112	2.001	100.028
	CT2 Y	84.48	83.6	114	111	2	100.046

* - sections separated for pre-testing at BC Hydro stores, tested 16.5°C (NP ratio 1000:5 – 200),
** - at site testing with sections connected in cascade, tested 5°C (NP ratio 500:5 – 100), measurement includes cabling from junction box terminal strip to CT

Temperature correction to 75°C was performed with the below formula, from reference [5].

$$R_{75°C} = R_{test} \times \frac{75 + 234.5}{T_{test} + 234.5}$$

There are differences and a lot of scatter in the measured knee points on the CT2 secondaries when CT2 is tested separated from CT1 as compared to the test with the CTs cascaded. The percent differences and the scatter are about double the typical variability of a conventional CT. No excitation curves were available for comparison to factory results, however excitation tests for the assembled unit showed comparable leakage currents to the factory measured accuracy test results.

The resistances measured on the CT2 secondaries are higher with CT1 and CT2 separated than when they were connected in cascade. The resistance measurements are also lower when measured in the factory. The percent differences and the scatter for the resistance readings are over five times the variability of a conventional CT.

Further work is required to determine if the knee points and resistance differences are related to the cascade design or are due to other causes.

Table 2 below shows the resistances of the intermediate circuit, shown in orange in Figure 3. As discussed earlier, this resistance must be considered when evaluating the error contribution of the CT1 excitation.

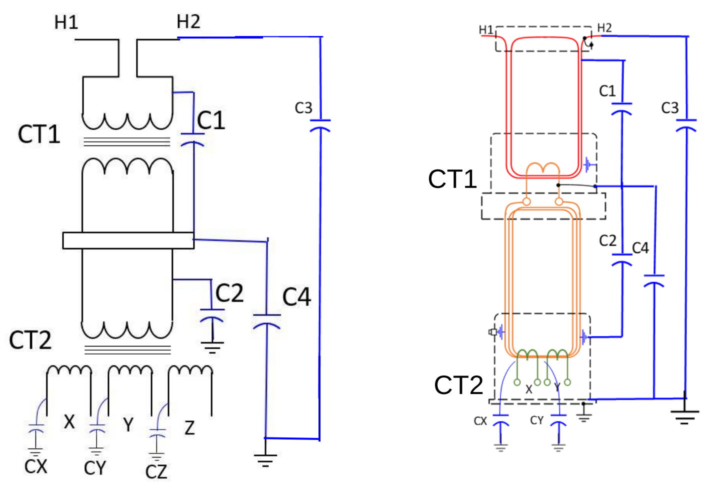
Table 2
Cascade CT Intermediate Circuit Test Results

Unit	Measured Winding Resistance (mΩ@75°C)		Sum of Intermediate Circuit Resistance* (mΩ@75°C)
	CT1 Sec.	CT2 Prim.	
1	141	367	508
2	150	366	516
3	165	410	576

* - sum of intermediate circuit resistance is a direct sum of the columns to approximate the total intermediate circuit resistance shown in orange in Figure 2a, and does not account for contact resistance of the connection.

Cascade CT Insulation Testing

Figure 4 shows the capacitances of a two-stage cascade CT. Table 3 shows the results of insulation testing with the CTs separated and with the CTs connected in cascade. These test results are on the same CTs as tested in Table 1 and Table 2.



Two Stage Cascade CT Capacitances
Figure 4

Table 3
Cascade CT (with two secondary windings) 10 kV Insulation Circuit Test Results

Test Info			Unit 1				Unit 2				Unit 3			
#	Setup	Measures	W	PF (%)	C (pF)	°C	W	PF (%)	C (pF)	°C	W	PF (%)	C (pF)	°C
1	Figure 5	C1+C3	0.01	0.05	533	17	0.01	0.05	542	18	0.01	0.05	539	17
2	Figure 6	C2+C4	0.01	0.05	544	17	0.02	0.10	555	17	0.03	0.13	551	17
3		C2	0.01	0.04	497	17	0.01	0.04	507	17	0.02	0.08	503	17
4	Figure 7	(C1 ser. C2)+C5	0.01	0.08	304	10	0.01	0.09	308	7	0.01	0.10	305	6
5		C1 ser. C2	0	0.02	234	10	0	0.01	240	7	0	0.03	236	6

“Measures” column refers to the figures identified in “Setup” column
Tests 1-3: sections separated for pre-testing at BC Hydro stores,
Tests 4-5: at site testing with sections connected into single series cascade assembly,
Tests 6-11: not performed

The maximum information, for comparison with factory test results, for failure detection and for isolation of any problems found, are provided if the capacitance and power factor of CT1 and CT2 are measured both as separate CT’s as well as when they are connected in cascade. These test results agree with the factory test results that were available.

PROPOSED CASCADE CT TEST PROCEDURE

Cascade CT Magnetic Circuit Testing

It is recommended CT1 and CT2 be tested as separate CTs and that the tests be repeated with the CT1 and CT2 connected in cascade. The tests are performed in the same test configurations as would be used for a non-cascaded transformer, with the addition to measure primary circuit resistances. This will provide maximum information for comparison with factory test results, for failure detection, and for isolation of any problems found.

For maintenance testing, it is recommended that if magnetization is a concern to separately perform a test routine including demagnetization on the CT1 and CT2, then perform overall testing to ensure proper reassembly.

It is recommended that care is taken during overall testing not to create a condition which would undo the demagnetizing performed on CT1 during separated tests prior to assembly.

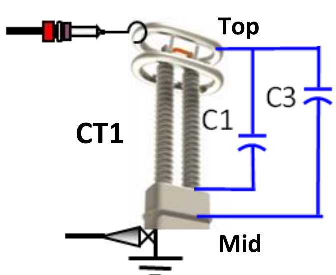
Cascade CT Insulation Testing

The test configurations defined in Table 4 and shown in Figure 5 to Figure 8 are recommended as generic measurements. Figure 9 shows an option for diagnostic testing. Some manufacturer’s designs may have special requirements which must be followed.

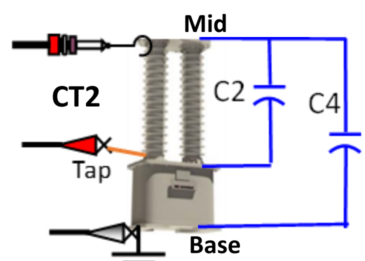
Table 4
Cascade CT Insulation Test Procedure

#	Setup	Unit	Hook	Red Lead	Blue Lead	GND	Test Mode	Measure
1	Figure 5	CT1 (top)	Top	Unused	Unused	Mid	GND RB	C1+C3
2	Figure 6	CT2 (bottom)	Mid	Tap	Unused	Base	GND RB	C2+C4
3		CT2 (bottom)	Mid	Tap	Unused	Base	UST R	C2
4	**Error! Reference source not found.**	Assembled-Series	Top	Tap	Unused	Base	GND RB	(C1 ser. C2) + C5
5		Assembled-Series	Top	Tap	Unused	Base	UST R	C1 ser. C2
6		Assembled-Series	Top	Tap	Unused	Base	GAR R	C5
7	Figure 8	Assembled-Parallel	Mid	Tap	Top	Base	GND RB	C1+C2+C3+C4
8		Assembled-Parallel	Mid	Tap	Top	Base	UST B	C1+C3
9		Assembled-Parallel	Mid	Tap	Top	Base	UST R	C2
10		Assembled-Parallel	Mid	Tap	Top	Base	GAR RB	C4
11	Figure 9	Additional diagnostics tests can be done using a collar strap and details are beyond the scope of this paper						

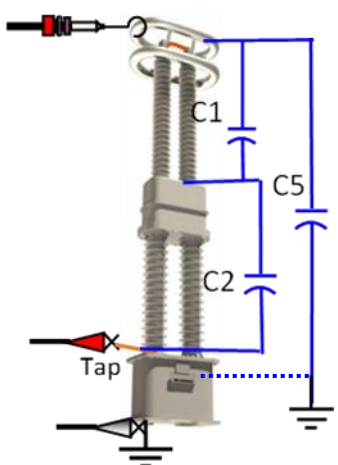
Note 1: C3 and C4 contain components of stray capacitance to the section base as well as to the ground
Note 2: C5 is about 1.5 stray capacitance of an individual CT1 or CT2 (C3 or C4 as tested in separated condition)
Note 3: C3 ≅ C4 when tested in the separated state with similar distance to the ground plane
Note 4: The geometry of C3 to ground changes once the cascade CT is assembled



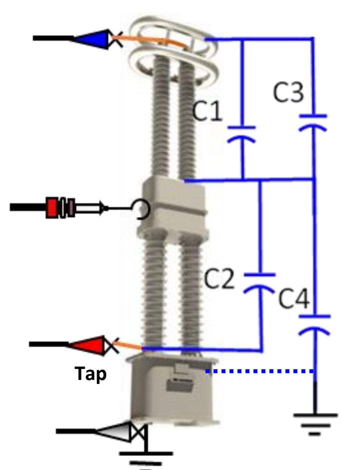
Test Setup on Top CT
Figure 5



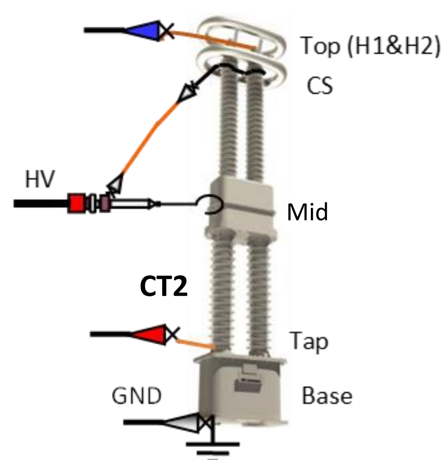
Test Setup on Bottom CT
Figure 6



Test Setup on Assembled-Series
Figure 7



Test Setup on Assembled-Parallel
Figure 8



Note: CS is collar strap
Diagnostic Test Setup
Figure 9

CONCLUSIONS

Cascade current transformers are described. The results of testing the magnetic circuits and the insulation systems of three, two-stage Cascade CTs are reviewed. Further study is recommended with additional cascade CT data.

There are some differences in the magnetizing curves knee points when comparing the individual section measurements vs cascade connected measurements. The percent differences and scatter are about double the normal range for magnetizing curves.

The resistances measured on the CT2 secondaries are higher with CT1 and CT2 separated than when they were connected in cascade. The resistance measurements are also lower than measured in the factory. The percent differences and the scatter for the resistance readings are over five times the variability of a conventional CT.

The cause of these differences is not fully understood. The sample size is very small. Further work is required to determine if this is related to the cascade design or is due to other causes.

The insulation measurements which have corresponding factory data agree well with the factory results.

It is recommended that tests be done on each of the cascade CT's sections as individual CTs and the tests be repeated with the assembled cascade CT. This approach will provide maximum information for comparison with factory test results, for failure detection, and for investigation of any problems found

A test table with recommended insulation tests and with supporting test configuration diagrams is provided.

REFERENCES

[1] L. J. Donald and R. L. Howard, "735-kV Cascade Style Current Transformer," *Transactions on Power Apparatus and Systems,* Vols. PAS-86, no. 10, October 1967.

[2] L. Pong, "Field Testing of Current Transformers (CTSs) Using Vanguard EZCT-2000," in *Doble Engineering Company Webinar*, December 2020.

[3] Doble Engineering Company, *Instruction Manual, The Doble Type M4100 10-kV Portable Insulation Test Set,* Copyright 2009.

[4] Vanguard Instruments Company, *User's Manual, The Vanguard Instruments Company EZCT-2000 Digital Current-Transformer Tester,* Vanguard Instruments Company, Copyright 2009.

[5] IEEE, "IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers," *IEEE Std C57.12.90-2021,* pp. 1-119, 2022.

[6] Vanguard Instruments Company , *Instruction Manual, The Vanguard Instruments Company EZCT-2000 Digital Current-Transformer Tester,* Vanguard Instruments Company , Copyright 2009.

BIOGRAPHY

John Vandermaar works as a senior specialist engineer at BC Hydro in the Site Engineering & Commissioning Division. He has over 40 years experience in high voltage equipment testing and research. He has performed testing, research and failure analysis for a wide variety of power utility high voltage equipment. He is an author on many technical papers and is a Senior IEEE member and a registered professional engineer in British Columbia. He has a Bachelor of Electrical Engineering from the University of Manitoba.

Blake Veerman recently joined BC Hydro's Quality Management department as an engineer. Previously working with the Site Engineering and Commissioning department, Blake has authored dozens of internal site testing standards for substation electrical equipment including instrument transformers. Prior to this, Blake completed various rotations with BC Hydro's Engineer in Training Program, as well as worked for the Integrated Optics Laboratory of University of British Columbia Okanagan, and Fortis BC. In 2015 Blake obtained a Bachelor of Applied Science from the University of British Columbia Okanagan in Kelowna.

Long Pong works as a Senior Principal Engineer in the Doble Client Service Department. He has amassed over 30 years of experiences in power utility and has published numerous technical papers pertaining to condition assessment, troubleshooting and new test techniques of power electrical apparatus. Before joining Doble in 2000, he was employed at Alcan-Énergie Électrique and Hydro-Quebec. He is IEEE member, a registered professional engineer in North Carolina and obtained a Bachelor of Electrical Engineering from École Polytechnique de Montreal, Quebec, Canada, in 1988.

APPENDIX

Comparison Nameplate Information from of Cascade Dry Type Current Transformer Tested

Manufactured	2014	
C1	246 pF	
tanδ	≤0.2%	
Turns	Primary	2
Turns	Secondary	200
	X1-X2	Y1-Y2
Rct at 75°C	0.13 Ω	0.13 Ω
Ratio series	500-5 A	500-5 A
Ratio Parallel	1000-5 A	1000-5 A