POWER FACTOR/CAPACITANCE AND INSULATION RESISTANCE TESTING ISSUES ON 138 KV DRY TYPE CT

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ABSTRACT

Metering current transformers (CTs) are tested before and after installation. Important parts of the test program are power factor/capacitance testing and insulation resistance testing. There are three issues that have occurred during pre- and post- on-site testing on 138 kV dry type metering CTs. An investigation was carried out to determine the root causes of these issues. Simulation tests were performed to determine these root causes. Results from this investigation not only provide technical information, but also support recommended testing configurations for future testing on this design of dry type CTs.

INTRODUCTION

In recent years, BC Hydro has been using dry type metering CTs. In many installations, the locations for these metering CTs can be very remote. As a result, these CTs are tested before shipping the CT to the site, at the site prior to installation, and post-installation to make sure the unit will be trouble-free.

In the series of tests, the power factor/capacitance [1] and insulation resistance [2] tests are important to ensure the CT's insulation is in good condition and has no potential issues. However, during testing, the following issues have occurred on some of the units.

1. Power factor and capacitance tests performed at different times had different results.
2. BC Hydro power factor and capacitance test results did not agree with the CT's factory test results.
3. Low insulation resistance readings were measured on the CT secondary terminals.

These test results perplexed both the testers and the commissioning engineers. The root cause of the above issues needed to be determined. The investigative testing and circuit analysis work described in this paper were carried out to ensure the installed CTs were in good condition.

POWER FACTOR/CAPACITANCE AND INSULATION RESISTANCE TESTING ISSUES ON 138 KV DRY TYPE CTS

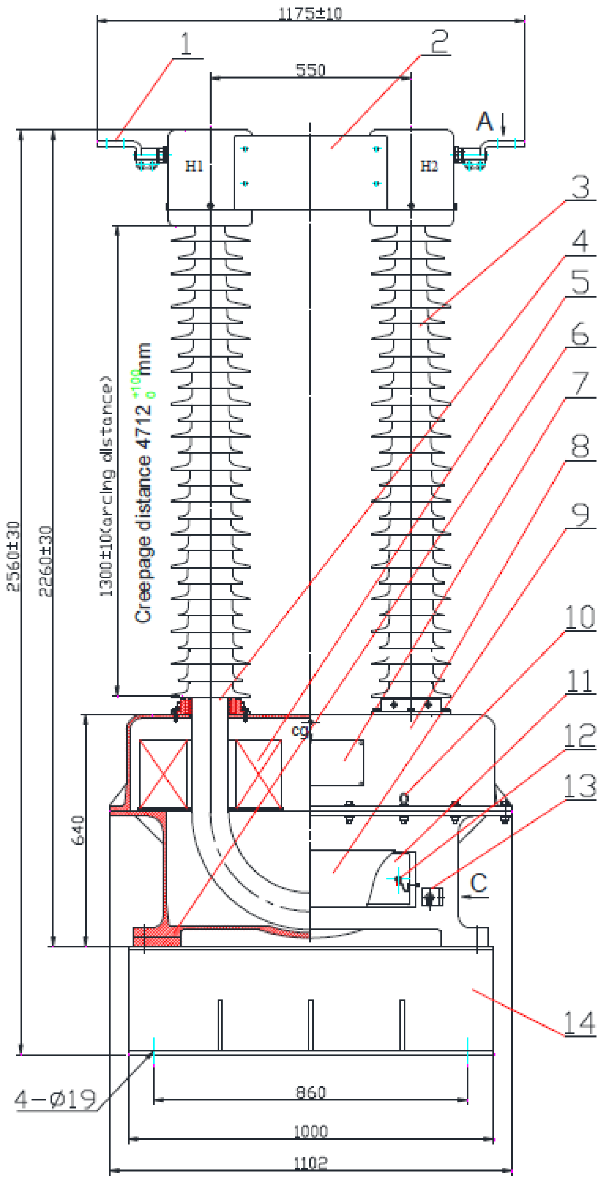
138 kV Dry Type CT Information and Description

This dry type CT has two high-voltage bushings, one U-shaped primary winding, and two secondary windings. Each secondary winding has a separate core that is mounted on each side of the U-shaped primary winding. Figure 1 shows the CT drawing and Table 1 shows the CT legend. The specifications of the 138 kV dry type CT are given below.

Maximum system voltage:	152 kV rms
Primary continuous current:	200×400×800 A
Secondary continuous current:	5 A
Accuracy and rated burden:	0.15B0.9
Number of primary turns:	1/2/4
Number of cores:	2
Ambient temperature range:	- 50℃ to +45℃

- Maximum altitude: 1000 m
- Wind loading: 160 km/hr.
- Humidity: 100%
- Seismic level: High

138 kV CT Drawing and Parts Description



CT Drawing
Figure 1

Table 1
CT Legend

No.	DESCRIPTION	QTY.	MATERIAL
1	Primary Terminal	2	Copper
2	Connection Cover	1	Stainless Steel
3	Sheds (Light Grey)	54	Silicone Rubber
4	Primary Winding	1	Copper and PTFE (Polytetrafluoroethylene)
5	Secondary Winding	2	Copper
6	Pedestal	1	Aluminum
7	Nameplate	1	Stainless Steel
8	Casing	1	Aluminum
9	Casing for Terminal Box	1	Stainless Steel
10	Lifting Lugs	4	Stainless Steel
11	Secondary Terminal Block	4	SMC (Sheet Molding Compound)
12	Capacitive Tap	3	Unknown
13	Earthing Plate	2	Stainless Steel
14	Support	1	Steel

Power Factor/Capacitance and Insulation Resistance Testing Issues with 138 kV Dry Type CTs

The installation location for these metering CTs is typically very remote and the power outage duration to install and test the CTs is very short. If the installed CT fails the testing, the installation will be subject to delays of up to one year or more. To minimize this risk these CTs are tested before shipping to the site, onsite prior to installation and post-installation. In the series of tests done, the power factor/capacitance and insulation resistance tests are used to ensure the CT's insulation is in good condition without potential issues, and to make sure the unit shipped and installed is a trouble-free unit. BC Hydro compared the individual test results with the factory test (FAT) results. However, in some cases these test results were significantly different, both in the capacitances and power factors. These results perplexed both testers and engineers. The following test result issues occurred in some of the CTs:

Issue 1:

Power factor and capacitance test results on some 138 kV dry type CTs were different each time at pre-shipping, on-site before installation and post installation. Each time, the test results showed that both capacitance and power factor values of C_s and C_{ps} were changing. Why were both capacitance and power factor values changing, and what was the cause of these changes?

Issue 2:

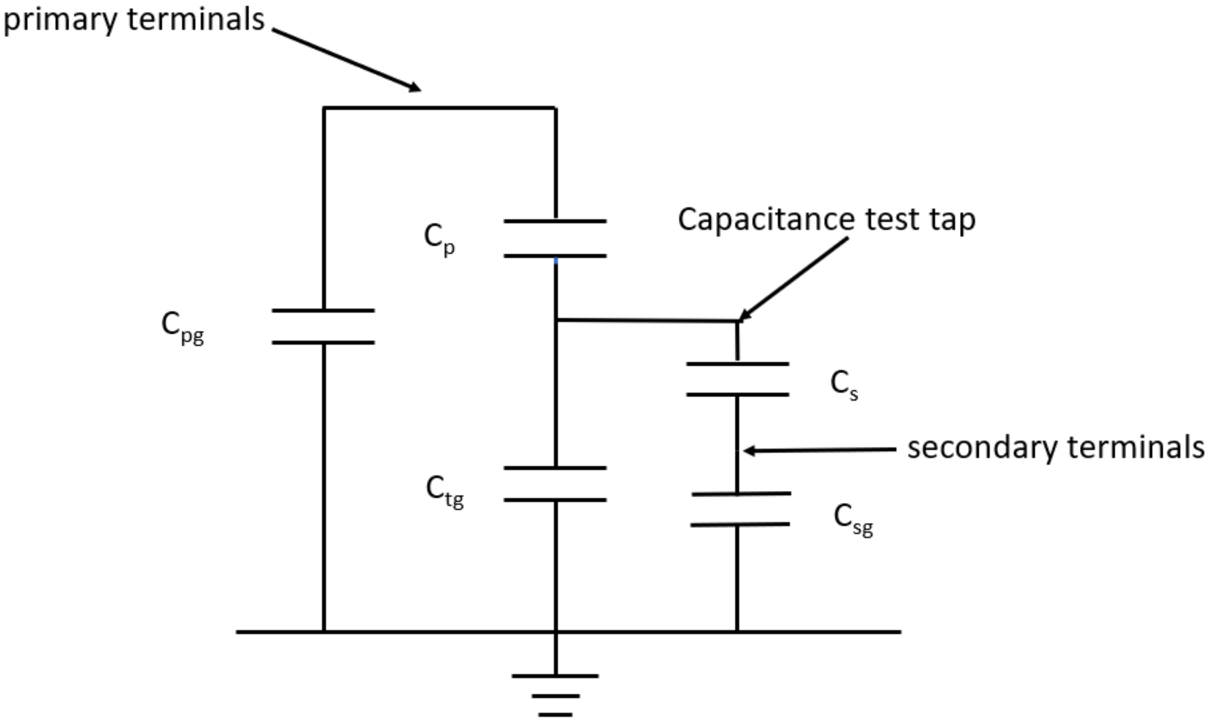
During the power factor and capacitance testing, comparing the field test results to the FAT results showed that they did not match on the CT secondary section (C_s) and on the primary in series with the secondary section (C_{ps}). This made testers wonder what test configurations should be used to compare with the FAT results.

Issue 3:

The CT secondary, measured from the terminals, showed low insulation resistance readings even after drying the terminal board in accordance with the instructions in the manufacturer's manual [3]. The results caused testers to wonder which sections caused the low insulation resistance readings.

Dry Type CT Equivalent Circuit

To investigate and analyze the above issues on dry type CTs, an equivalent circuit was constructed in accordance with the CT's physical structure and connections. The equipment circuit is shown in Figure 2.



CT Equivalent Circuit
Figure 2

C_p – Capacitance between the high voltage primary terminal and test capacitance tap.

C_s – Capacitance between the test capacitance tap and CT secondary winding terminal ($C_s = C_{s-1}$ (cable composite part) in series with C_{s-2} (air part)).

C_{sg} – Stray capacitance from secondary terminals to ground.

C_{pg} – Stray capacitance between the high voltage primary terminals and ground with capacitance tap guarded.

C_{tg} – Stray capacitance between the test capacitance tap and ground ($C_{tg} = C_{tg-1}$ (composite part) in series with C_{tg-2} (air part)).

C_{ps} – Capacitance of C_p in series with C_s

$C_{t\text{-}grd}$ – Capacitance of C_{tg} plus C_s with the secondary terminal grounded.

Issue 1: CT Power Factor/Capacitance Test Results Changed from Test to Test

Power factor and capacitance testing was performed on three dry type CTs in the shop and onsite. The test results showed that both the capacitance and power factor of the secondary capacitance – (C_s) capacitance primary to secondary (C_{ps}) and capacitance terminal to ground and to secondary terminals ($C_{t\text{-}grd}$) changed each time the test was repeated. The biggest change of the C_s value was 13%, and the change of C_{ps} value was 131%. One set of three CT results is shown in Tables 2, 3 and 4. The test results show that both capacitance and power factor changed on C_s, C_{ps} & $C_{t\text{-}grd}$.

Table 2
CT-1 Test Results

CT-1 AU20082	Shop Pre-Test Results		Site Test Results		Capacitance Differences	PF Differences
	C (pF)	PF (%)	C (pf)	PF (%)	∆C%	∆PF%
C_s	68.63	-11.67	76.69	0.830	12	93
C_{ps}	37.27	-22.57	49.25	0.260	32	101
$C_{t\text{-}grd}$	620.858	24.311	428.128	1.714	-31	93
C_p	767.79	0.018	769.62	0.017	0.0	-5.5

Table 3
CT-2 Test Results

CT-2 AU20083	Shop Pre-Test Results		Site Test Results		Capacitance Differences	PF Differences
	C (pF)	PF (%)	C (pf)	PF (%)	∆C%	∆PF%
Cs	69.62	-10.02	78.53	0.767	13	108
Cps	32.73	0.087	48.08	0.121	47	39
Ct-grd	844.794	11.308	479.887	2.543	-43	-78
Cp	763.2	0.013	765.4	0.018	-1.1	38

Table 4
CT-3 Test Results

CT-3 AU20085	Shop Pre-Test Results		Site Test Results		Capacitance Differences	PF Differences
	C (pF)	PF (%)	C (pf)	PF (%)	∆C%	∆PF%
C_s	78.9	-0.01	77.8	0.822	-1.4	83.2
C_{ps}	20.36	-5.324	46.96	-0.3374	131%	94%
Ct-grd	542.17	9.893	495.475	3.079	-8.6%	-69%
C_p	751.29	0.009	769.62	0.017	2.4%	88%

The Cause of the Changes

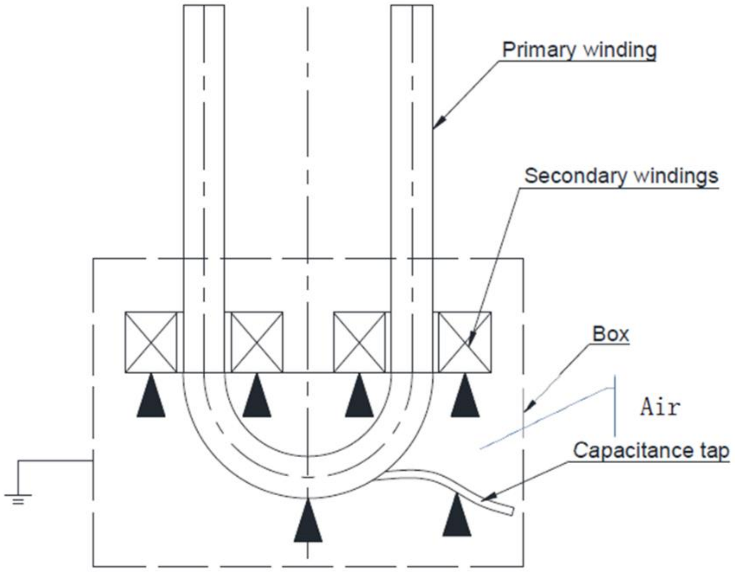
The CT test results in Tables 2 to 4 show that both capacitances and their associated power factors were changing from test to test. The results showed C_{ps} had a negative power factor. The negative power factor usually indicated that there was a shield and a leakage current between the primary and secondary that had not been directly measured [4], [5], [6]. However, this shield was unstable due to the power factor changing from test to test. An investigation was carried out to identify the shield. A borescope was used for an internal inspection, and it did not find any additional shield between the primary and secondary windings. An additional condition was reported that there was some water on the CT primary cable surface during shop testing, Figure 3. During the onsite testing, the CT primary cable's surface was in a dry condition, Figure 4. A summary of the findings and questions are shown below:

- The power factor and capacitance test results showed that it seems to have another unstable shield in the CT.
- The CT design/drawing does not have any other shield in the CT structure.
- After checking the inside of the CT, again no other shield was found.
- Water was observed on the surface of the CT cable insulation during shop testing.
- Testers wondered if water formed a shield and caused these changes.
- The following needed to be done:
  - Draw an equivalent circuit for the water situation in the CT.
  - Simulate the water/moisture situation to perform investigative testing.

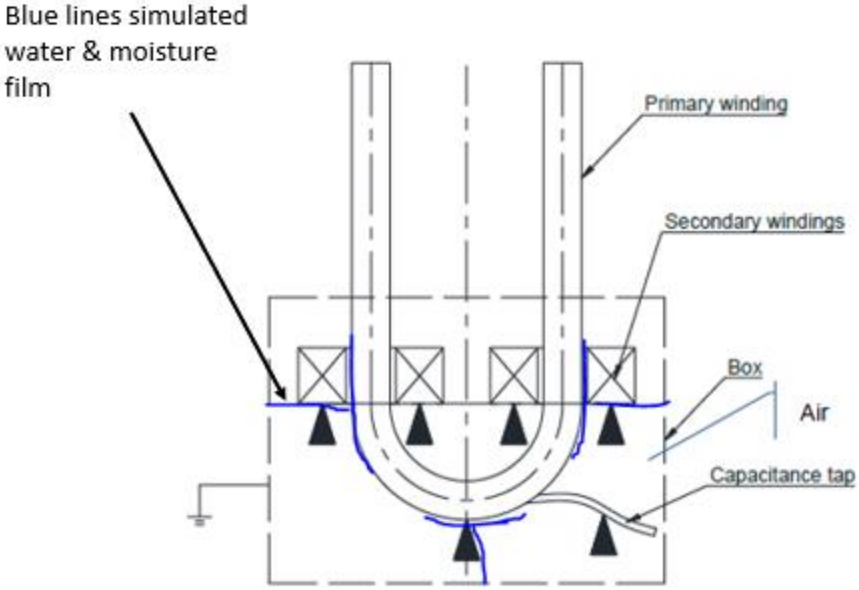
CT Internal Wet Condition
Figure 3

CT Internal Dry Condition
Figure 4

Was this water layer the cause of the negative power factor, and did it cause the capacitances changes? Figure 5 shows the CT internal structure drawing in a dry condition, and Figure 6 shows the CT internal structure drawing in a wet condition.

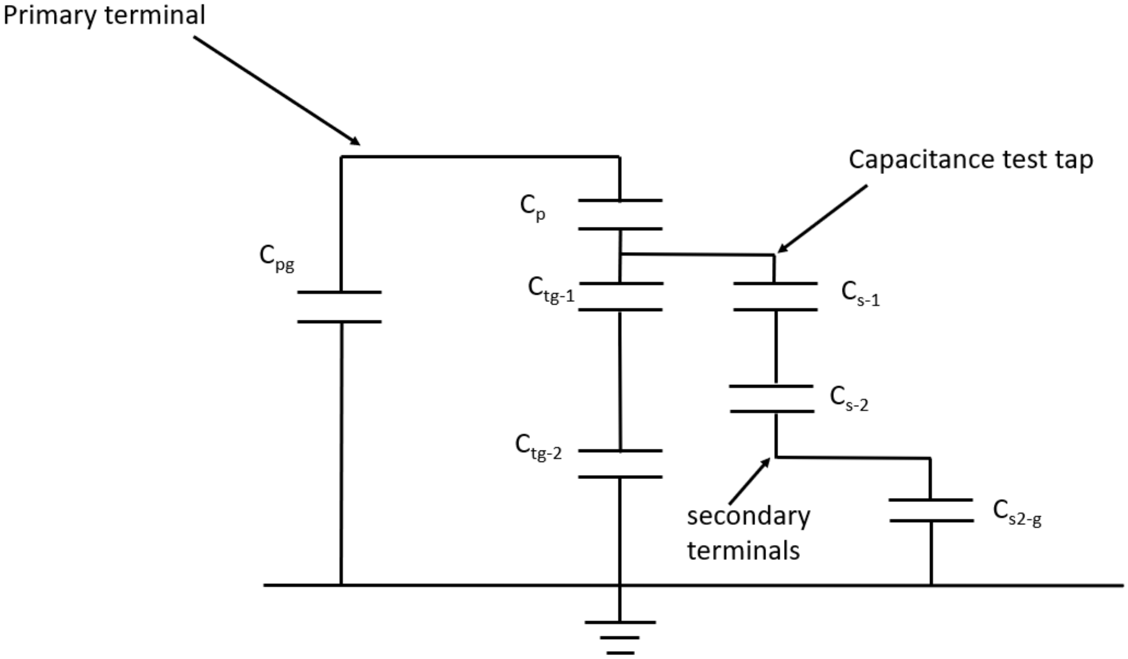


CT Internal Structure Drawing with Dry Condition
Figure 5

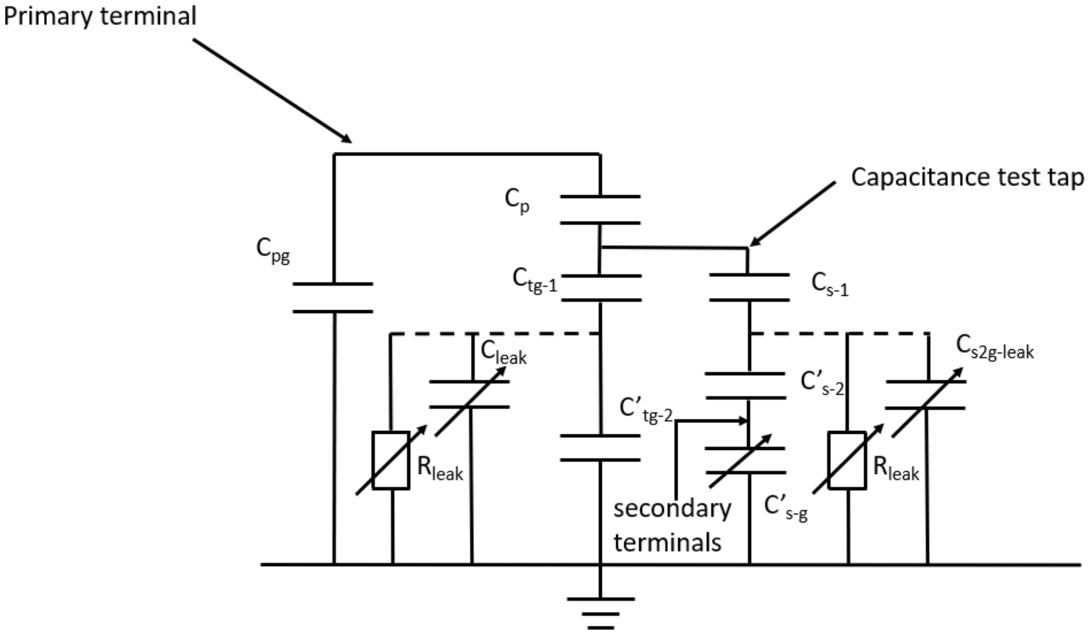


CT Internal Structure Drawing with Wet Condition
Figure 6

Figure 7 is the CT equivalent circuit in a dry condition and Figure 8 is the constructed equivalent circuit in a wet condition for analysis. The equivalent circuit demonstrated that with the primary cable in a wet condition, the negative power factor and capacitance changes could happen. The water that covers the area can lead to a resistance leakage path, and changes in the capacitance and in the power factor. Water can form a non-stable shield-like layer between the primary winding and the secondary windings. This non-stable layer can shield or even short the capacitance between the primary winding and the secondary windings that can cause CT capacitance changes and power factor changes. These changes can be unstable depending on the amount of water on the surface and the water location. The presence of water can happen at various locations and with different amounts. Based on these factors, the wet condition can cause the capacitance and power factor to change over time and the location of these changes depends on where the water is and the amount of water inside the CT.



CT Equivalent Circuit with Simulated Dry Condition
Figure 7



CT Equivalent Circuit with Simulated Wet Condition
Figure 8

To verify the analysis model was correct, a simulated power factor/capacitance test was performed onsite. Semiconductor material was used to simulate the effects of a wet CT condition on the primary winding outer surface. The simulation results are shown in Table 5.

The simulation results showed the following:

- The secondary capacitance increased with the simulated wet (semiconductor) layer,
- The secondary power factor increased with the simulated wet (semiconductor) layer,
- If there is a water/moisture layer on the CT insulation, it can cause both the capacitance and the power factor to increase compared with the dry condition.
- The level of increase of the power factor and capacitance is dependent on how much water is on the CT insulation surface.

Table 5
CT Simulation Test Results

	Test Mode	Test kV	mA	Watts	%PF measured	Capacitance (pF)
$C_{t\text{-}grd}$ (dry) ENG Tap, Grd X, Y & base, GAR H1&H2	GAR	2.0	1.869	0.575	3.079	495.48
$C_{t\text{-}grd}$ (simulated wet) Same test configuration as above except added a semiconductor layer to simulate water on the insulation surface	GAR	0.50	2.731	1.181	4.325↑	723.8↑
C_{ps} (dry) ENG H1&H2, float cap tap, UST X&Y	UST	1.999	0.177	-0.007	-0.374	46.96
C_{ps} (simulated wet) Same test configuration as above except added a semiconductor layer to simulate water on the insulation surface	UST	2.000	0.147	-0.019	-1.266	38.86↓

Issue 1: Summary

- The changes in power factor and capacitance caused by water on the surface of the CT insulation form conductive paths to ground.
- The water forms an unstable conductive shield that causes high power factor loss and change in capacitance.
- If this problem occurs during the testing, ideally, the water should be dried up and/or the water path to the ground should be broken.
- Only drying out the terminal box of the CT will not solve the issue. The dry out procedure has to be done on the whole CT. Either leave the CT unit vertically inside for a period of time or put the CT unit in an oven to dry it out at a temperature of 40˚C to 60˚C for a minimum of 24 hours.

Issue 2: Site Power Factor and Capacitance Test Results Disagree with the CT FAT Results

When the testers were working onsite, there were discrepancies between their tests results and the FAT test results. We investigated why this happened and what the root cause was for the variations.

Table 6
CT Site Test & FAT Results

CT-3 AU20085	On-Site Test Results		FAT Results		Comments
	Capacitance (pF)	PF (%)	Capacitance (pF)	Tan δ (%)	
C_p	752.59	0.013	758	0.021	Similar
C_s	77.85	0.80	502	3.299	Totally different
C_{ps}	46.96	-0.374	300	2.027	Totally different

The above differences (Table 6) could be caused by definition or test circuit differences. First, the FAT reports show the results as capacitance and the losses as tan δ, so this indicates that the FAT testing was done by using a tan δ bridge. In fact, when using a tan δ bridge the tested equipment usually required isolation of the base of the tested CT from the ground to input the signal to the tan δ bridge. Therefore, the CT cannot be tested in the base grounded condition, the CT base must be floating for the comparison testing. A UST (unground specimen test) test mode can be used with the CT base in the floating condition. Fortunately, the CT unit onsite was on a wooden frame (Figure 9). Therefore, a UST mode could be performed for the FAT comparison.

Site Testing CT
Figure 9

To simulate the FAT conditions and to compare with the FAT results, the following test configurations were applied and found to be the closest to the FAT configurations for comparing Cp, Cs and Cps, (Table 6):

Table 6
CT Power Factor/Capacitance Test Configuration with CT Base Floating to Simulate FAT Configurations

Doble test mode	ENG	UST	GAR	Floating	FAT		Measured on Site		FAT & Site Differences	
					C (pF)	Tan δ (%)	C (pF)	PF (%)	ΔC	ΔPF
Simulating FAT C_p	H1&H2	Cap tap, X&Y base	-	-	758	0.021	758.34	0.051	0.04%	143%
Simulating FAT C_s	Cap tap	X&Y, base	H1&H2	-	502	3.299	497.58	3.257	0.88%	-1.3%
Simulating FAT C_{ps}	H1&H2	X&Y& base	-	cap tag,	300	2.027	298.49	1.985	-0.5%	-2.1%

The above simulation testing showed most of the test results were close to identical to the FAT results. This proved that the FAT used these test configurations in their testing lab. This investigation found that in the future, to compare with FAT results, the above power factor and capacitance test configurations (Table 6) and CT set up (isolate the CT base) should be used. From this testing we also clarified how the FAT had been performed.

The above test configurations are the most identical test configurations and CT test set ups to the FAT settings, but they are not easy to apply to the field-testing circumstances because the CT bases are grounded in most site conditions.

Further investigation was carried out to find the power factor and capacitance test configurations closest to the FAT with the CT base grounded condition. The following test arrangements were proposed and evaluated, (Table 7). These test configurations were the closest we could do onsite to simulate the FAT configurations and obtain the closest test results. The tests were performed on five onsite CTs, and the comparison results are shown in Table 8-a.

Table 7
Simulating FAT Conditions with CT Base Grounded

FAT	Test config.	Test voltage (kV)	Test mode	Voltage applied to	UST	GAR	Ground	Float	Comments
C_p	C_p	10	UST	H1&H2	Cap tap	-	X, Y & base	-	To obtain ~FAT C_p
C_s	C_{sg}	2	GAR	Cap tap	-	H1&H2	X, Y & base	-	To obtain ~FAT C_s
C_{ps}	C_{psg}	2	GST	H1&H2	-	-	X, Y, base	Cap tap	To obtain ~FAT C_{ps}

Table 8-a
Site Power Factor & Capacitance Test Results with CT Base Grounded by Using Table 7 Updated Test Configurations

CT S#		C_p		FAT $C_s \approx C_{sg}$		FAT $C_{ps} \approx C_{psg}$	
		FAT	Site	FAT	Site	FAT	Site
AU21042	C (pF)	781	791.701	515	502.521	308	350.42
	PF (%)	0.064	0.027	1.501	1.002	0.931	0.601

CT S#		C_p		FAT $C_s \approx C_{sg}$		FAT $C_{ps} \approx C_{psg}$	
		FAT	**Site**	**FAT**	**Site**	**FAT**	**Site**
AU21045	C (pF)	773	783.493	521	510.292	309	353.85
	PF (%)	0.027	0.018	1.456	0.905	0.871	0.493
AU21164	C (pF)	803	800.434	492	493.065	303	350.88
	PF (%)	0.025	0.011	0.536	0.627	0.342	0.352
AU21166	C (pF)	821	818.607	485	492	302	353.06
	PF (%)	0.038	0.030	0.491	0.785	0.309	0.439
AU21168	C (pF)	810	809.175	502	500.845	308	354.48
	PF (%)	0.024	0.017	0.600	0.690	0.380	0.407

Table 8-b
Test Results Differences between FAT & Updated Test Configurations

	Tested CTs				
	AU21042	**AU21045**	**AU21164**	**AU21166**	**AU21168**
C_p capacitance differences from FAT	1.4%	1.36%	0.32%	0.29%	-0.1%
C_p PF differences from FAT	-58%	-33%	-56%	-21%	-29%
C_s capacitance difference from FAT	-2.4%	2.1%	0.21%	1.44%	-0.23%
C_s PF differences from FAT	-33%	-38%;	17%	60%	15%
C_{ps} capacitance difference from FAT	13.8%	14.5%	15.8%	16.9%	15.1%
C_{ps} PF differences from FAT	-35%	-43%	2.9%	42%	7.1%

The updated power factor/capacitance test configurations provided the most comparable FAT test results. They are not ideal, but this is the best we could do onsite. The C_p capacitances tested onsite with updated test configurations were very close to the FAT results. The maximum capacitance differences were within 1.4% among five tested CTs. The C_s capacitance results were also very reasonable and the maximum Cs differences were within 2.4%. The C_{ps} capacitances had the largest differences which were from 13.8% to 16.9% differences.

Based on this investigation, the following power factor/capacitance test configurations were finalized for commissioning metering CTs to compare results with the FAT results in the future (Figure 8).

Table 9-a
Site Power Factor/Capacitance Overall Testing Configurations

Test configuration		Test Voltage (kV)	Test Mode	Voltage applied to	UST	GAR	Ground	Float	Note
Overall	(1) C_{pg}	2	GST	H1, H2	-	-	Tap, X, Y, base	-	CT secondary winding must be shorted in all test configurations
	(2) C_{pg}	10	GST	H1, H2	-	-	Tap, X, Y, base	-	
	(3) C_p (~FAT Cp)	10	UST	H1, H2	Tap	-	X, Y, base	-	
	(4) C_{sg} (~FAT C_s)	2	GAR	Tap	-	H1, H2	X, Y, base	-	

Table 9-b
Site Power Factor/Capacitance Custom Diagnostic Testing Configurations

	Test Configuration	Test Voltage (kV)	Test Mode	Voltage applied to	UST	GAR	Ground	Float	Note
Custom Diagnostic	(1) C_{ps}	2	UST	H1, H2	X & Y	-	base	Tap	CT secondary winding must be shorted in all test configurations
	(2) C_{psg} (~FAT C_{ps})	2	GST	H1, H2	-	-	X, Y, base	Tap	
	(3) C_s	2	UST	TAP	X & Y	-	H1, H2	-	
	(4) Check Shield Function	2	UST	H1, H2	X & Y	-	Tap, base	-	

Issue 2: Summary

- The investigation tests identified how the FAT tests were performed and what the closest power factor and capacitance test configurations were to compare with the FAT results.
- Updated test configurations were defined for future power factor and capacitance tests with the CT base in the grounded condition.

Issue 3: Low Insulation Resistance Readings on CT Secondary Terminals

Table 10 below shows the insulation resistance readings measured on the secondary winding.

Table 10
Insulation Resistance Test Reading

Date	1 kV on X winding (AU21049)	1 kV on Y winding (AU21049)
Day 1 (Nov 04, 2022)	1.3 GΩ	>2.2 GΩ
Day 4 (Nov 07, 2022)	1.7 GΩ	>2.2 GΩ
Day 5 (Nov 08, 2022)	1.9 GΩ	>2.2 GΩ
Day 6 (Nov 09, 2022)	>2.2 GΩ	>2.2 GΩ
Day 7 (Nov 10, 2022)	>2.2 GΩ	>2.2 GΩ

The power factor and capacitance test also showed high power factor and high capacitance values which hinted at the moisture problem in the CT – AU21049 secondary (Table 11).

Table 11
Power Factor/Capacitance Test Data

		Cp		Cs~Csg		Cps~Cpsg		Cs	Cps
		Factory	Measured	Factory	Measured	Factory	Measured	Measured	Measured
AU21049 (wet secondary CT)	Cap (pF)	783	793.5	528	743.8	312	430.43	74.2	38.11
	PF (%)	0.047	0.014	2.416	10.055	1.470	4.631	-4.031	-8.848
AU21042 (dry secondary CT	Cap (pF)	781	791.9	515	502.5	308	350.42	78.12	47.8

for comparison)	PF (%)	0.064	0.027	1.501	1.002	0.931	3.601	1.083	0.899

Table 12 below shows a comparison of the power factor and capacitance results between the two CT secondary windings, X & Y. The Y winding was dryer than the X winding.

Table 12
X & Y Terminals Power Factor/Capacitance Testing Comparison

AU21049	Test Mode	Test Voltage (kV)	mA	Watts	% PF Meas.	Cap./Ind.
ENG Tap, UST X, GAR Y, GND H1&H2&base	UST Red	1.000	0.137	-0.100	-7.284	36.16 pF
ENG Tap, UST Y, GAR Y, GND H1&H2&base	UST Blue	0.999	0.144	-0.008	-0.547	38.12 pF

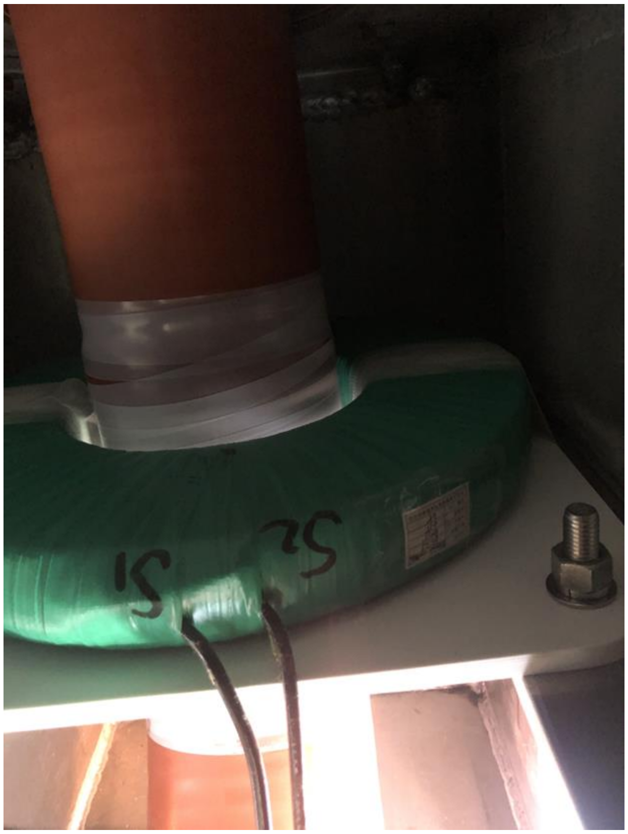
Table 13 below shows a comparison of the power factor and capacitance test results on the same CT over time. The dry out process was very slow. In addition, the terminal box was dried out per the manufacturer's instructions. This had very little effect on the power factor.

Table 13
Capacitance and Power Factor Comparison over Time

AU21049	Test Mode	Test Voltage (kV)	mA	Watts	% PF Meas.	Cap./Ind.
C_s (day 5)	UST Blue	2.000	0.280	-0.113	-4.031	74.20 pF
C_s (day 6)	UST Blue	2.000	0.280	-0.108	-3.845	74.21 pF
C_s (day 7)	UST Blue	2.000	0.275	-0.101	-3.689	72.77 pF
AU21049	**Test Mode**	**Test Voltage (kV)**	**mA**	**Watts**	**% PF Meas.**	**Cap./Ind.**
C_{sg} (day 5)	GAR Red	2.000	2.818	2.833	10.055	743.79 pF
C_{sg} (day 6)	GAR Red	2.000	2.817	2.861	10.157	743.50 pF
C_{sg} (day 7)	GAR Red	2.000	2.821	2.858	10.131	744.52 pF

Both the insulation resistance test and the power factor/capacitance test results showed that the CT moisture problem could be deeper than just the terminal box and leads parts, the moisture could go into the CT secondary winding section and take a long time to dry out. Figure 10 shows the CT terminal box and Figure 11 shows a CT secondary winding. The power factor and capacitance testing was more sensitive than the insulation resistance testing to detect the moisture problem and the dry out condition.

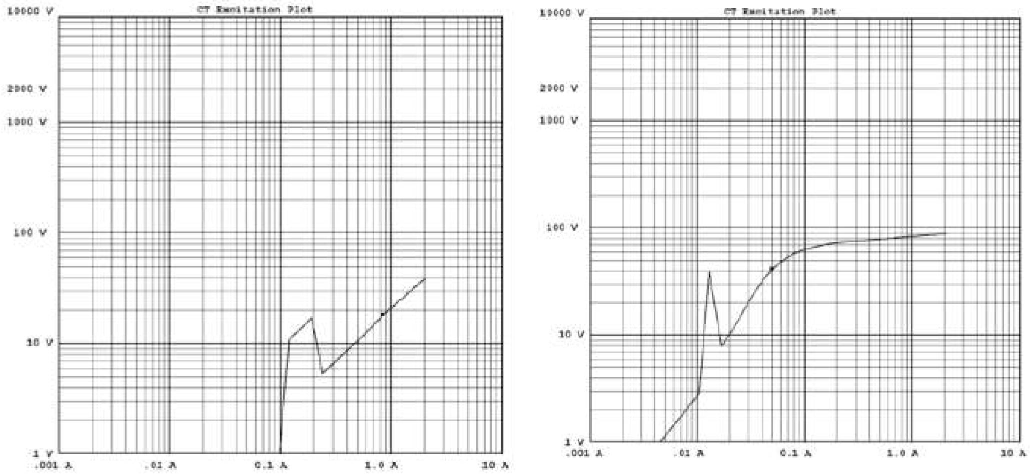
CT Terminal Box
Figure 10



CT Secondary Winding
Figure 11

Based on the testing and internal inspection, the moisture problems were not just on the secondary terminal board, and they can go deeper in the CT secondary winding parts. If the moisture gets into the CT secondary winding parts, it can take a long time to dry out, so that is why drying the terminal box will not be effective and the natural dry-out can take weeks.

In some cases, if substantial amounts of water get into the secondary winding insulation, it may cause a CT excitation test failure, ratio error increase and secondary terminal erosion. See the below excitation test curves with CT moisture problems (Figure 12).



CT Excitation Curve with Moisture Problems
Figure 12

Issue 3: Summary

- Both insulation resistance tests and power factor/capacitance tests can show moisture problems in the CT.
- The water/moisture problems can cause low insulation resistances, high power factor and capacitance change in the secondary windings. If the CT secondary winding is very wet, it can also lead to excitation test problems. The winding may not withstand the excitation voltage or the CT excitation equipment may not be able to hold the terminal voltage as the high leakage current of the CT secondary could cause the excitation voltage to collapse at some point.
- Power factor/capacitance testing is more sensitive than insulation resistance testing on the CTs to detect moisture.
- The moisture problems were not just on the secondary terminal board and can go deeper into the CT secondary winding parts.
- If the moisture gets into the CT secondary winding parts, it can take a long time to dry it out.
- If a large amount of water goes into the secondary winding insulation it may cause a CT excitation test failure, ratio error increase and secondary terminal erosion.

Recommendations:

- If possible, these dry type CTs should be stored in a vertical position and in a covered storage area.
- Ship the CT to site/shop at least a week before the testing and put them in a vertical position.
- Suggest, if possible, to test each CT secondary seal in the factory to make sure the secondaries are well sealed, and no moisture can get into the secondary windings.

CONCLUSIONS

BC Hydro metering CTs were tested pre- and post-installation and during the power factor and capacitance testing and insulation resistance testing. Three issues occurred on 138 kV dry type CT testing. This investigation was conducted to address these issues. Analysis and simulation testing were carried out and the root causes were determined. A summary of these issues is listed below. This investigation provided technical information and a testing method for future power factor and capacitance testing and insulation resistance testing on this design of dry type CTs.

Issue 1 Summary

- The changes of power factor and capacitance were caused by the water on the surface of the CT insulation which formed conductive paths to ground.
- The water forms an unstable conductive shield and causes high power factor loss and capacitance changes.
- If this problem occurs during the power factor/capacitance testing, ideally, dry the water and/or break the water path to the ground.
- Only drying out the terminal box of the CT will not solve the problem, the dry out procedure ideally must be done on the whole CT unit, either leave the CT unit vertical inside for a period of time or put the CT unit in an oven to dry it out at a temperature of 40˚C to 60˚C for a minimum of 24 hours.

Issue 2 Summary

- The investigation tests identified how the FAT tests were performed and what were the closest power factor and capacitance test configurations to compare with FAT results.
- Updated test configurations were made for the future power factor/capacitance tests with the CT in the base grounded condition.

Issue 3 Summary

- Both insulation resistance testing and power factor and capacitance testing can detect moisture problems in the CT.
- The water/moisture problems can cause low insulation resistances, high power factor and capacitance changes of the secondary windings.
- Power factor/capacitance testing is more sensitive than insulation resistance testing.
- The moisture problems were not just on the secondary terminal board, and the moisture can go deeper in the CT secondary winding parts.
- If moisture is in the CT secondary winding parts, it can take a long time to dry it out.
- If a large amount of water goes into the secondary winding insulation it may cause CT excitation test failure, ratio error increase and secondary terminal erosion.

Recommendations:

- If it is possible, store this dry type of CT in a vertical position and in a covered storage area.
- Ship the CT to the site/shop at least a week before the testing and put it in a vertical position.
- If the CT has low insulation resistance and high-power factor after drying the terminal box, the best and quickest way to dry the CT is to put it into a dryout oven at a temperature of 40˚ to 60˚C for a minimum of 24 hours.

REFERENCES

[1] Doble “M4100 Insulation Analyzer User Guide”

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BIOGRAPHIES

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May Wang received her Ph.D., MASc., and BASc. Degrees in Electrical Engineering from the University of British Columbia, Canada and Xian Jiaotong University, China, respectively. Dr. Wang is a senior member of IEEE and a registered professional engineer. Dr. Wang currently works as a specialist engineer in BC Hydro. Previously she worked at Powertech Labs for over 25 years as a research, senior and specialist engineer and HV lab manager. She carried out multiple research and failure analysis on HV power equipment and published various technical papers. She has led multiple projects on design and type testing of HV equipment. Her current work is focused on commissioning major transmission and generation power equipment. Her past research interests were in transformer condition monitoring and frequency response analysis, GIS fast transient analysis and high voltage testing techniques.

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Eric Tan works as an equipment technologist in the Site Engineer and Commissioning Department of BC Hydro. He has over 11 years of experience in the electrical utility industry and is focused on maintenance and commission of various types of equipment including transformers and switchgear. He is an ASTTBC member and obtained a Diploma from British Columbia Institute of Technology in 2012.

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