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**Research and Development of a New Innovative
Dry-Type Capacitor Voltage Transformer**

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SUMMARY

This paper introduces the design, development process and technical characteristics of a new composite insulation high voltage dry-type capacitor voltage transformer (GCVT). This new product includes several innovations: 1) a dry insulation structure for the capacitor voltage divider, 2) a dry, fully shielded electromagnetic unit and 3) an innovative automatic error adjustment device. A 110 kV 10,000 pF GCVT has successfully passed its type tests according to IEC standards [1].

KEYWORDS

High voltage, dry-type, composite insulation, capacitor voltage transformer (CVT), electromagnetic unit, automatic error adjustment device.

1 Introduction

The fluid-immersed CVT has been an industry standard for many years providing economic voltage sensing and anti-ferromagnetic resonance performance for high voltage power grids. This device also has the added benefits of being able to be equipped with carrier coupling accessories to couple high frequency PLC signals to the powerline. However, as the capacitor elements age there is the risk of the fluid-immersed CVT failing catastrophically due to cascading capacitor element failures. In fact, the failure rate of fluid-immersed CVTs is 5 times higher than that of the inductive voltage transformer [2]. This is recognized by utilities and most utilities have maintenance programs in place for their aging fluid-immersed CVTs that closely monitor for oil leaks, decreasing secondary voltage and contamination of the oil due to failures in the gasket seal and expansion membrane.

To get away from the disadvantages of oil-paper insulation a new dry-type, paperless insulation technology was developed in the early 1990's. This solid insulation technology is used in wall bushings and current transformers ranging in voltage classes from 10 kV to 600 kV and has operated safely and reliably without maintenance for many years by users in over 30 countries around the world. In 2018 a research and development team was established to develop a dry-type, solid insulation capacitive voltage transformer (GCVT) that could replace the use of fluid-paper/film CVTs. In 2023 a 110 kV 10,000 pF dry-type prototype capacitive voltage transformer that complied with IEC 61869-5:2011[3] successfully passed its type testing program.

Table 1 – Technical Sheet for the 110 kV GCVT Prototype

No.	Item/Parameter		Description
1	Model		GTVD110-0.01
2	Rated frequency		50Hz
3	Service temperature		-40 to +40C
4	Rated primary voltage		110/ $\sqrt{3}$ kV
5	Rated intermediate voltage		20kV
6	Rated secondary voltage		0.1/ $\sqrt{3}$ kV
7	Rated voltage ratio		110kV/ $\sqrt{3}$ /0.1/ $\sqrt{3}$ /0.1/ $\sqrt{3}$ /0.1 /0.015 *
8	Accuracy		0.2/0.5/3P/6P *
9	Rated output		50/50/100 /10VA
10	Power factor (cos ϕ)		0.8
11	Rated capacitance		10,000pF
12	Rated 1 min power frequency withstand voltage on primary (wet)		230kV
13	Rated lightning impulse voltage on primary	full	550kV
		chopping	632.5kV
14	Mechanical load		1250N
15	Standard		IEC 61869-5 : 2011 [3]

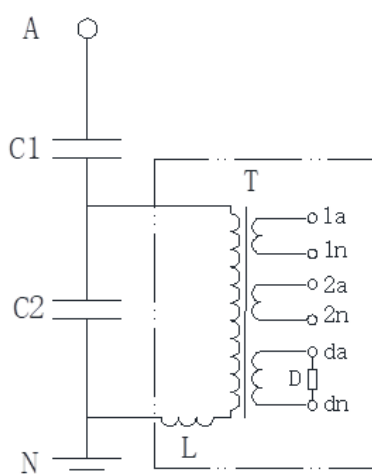
*: The power supply winding (15 V, 10 A) for the automatic error adjustment device

The GCVT consists of two components: the capacitor voltage divider and the electromagnetic unit (EMU). The capacitor voltage divider consists of two capacitor sections: a high voltage capacitor C1 and an intermediate voltage capacitor C2. The C2 is integrated into the EMU base box design and is connected to the C1 by a flange. The intermediate voltage is 20 kV. T is an intermediate voltage transformer with secondary and residual voltage windings, and L is a compensating reactor that matches the capacitor to achieve resonance. When the load changes, the output voltage is maintained to meet the accuracy requirements.

The GCVT prototype and circuit schematic are shown in Figures 1 and 2.



Figure 1 - 110kV GCVT prototype



A : primary terminal, N : earthing terminal
C1 : high voltage capacitor, C2 : intermediate voltage capacitor
T : intermediate voltage transformer,
L : compensating reactor
1a-1n : 1# secondary winding
2a-2n : 2# secondary winding
da-dn: residual voltage winding,
D : damping device

Figure 2 - Schematic Diagram of the GCVT

The GCVT prototype successfully passed a full sequence of type tests in 2023 in accordance with the relevant sections of IEC 61869-5:2011[1]. Table 2 summarizes the key results of the type tests passed.

Table 2 – Summary of Type Tests Performed

No.	Test	Parameters	Results
1	Accuracy check	0.2, 0.5, 3PT1 Class	Passed
2	Temperature-rise test	60 K	Max. temp rises recorded for 20 kV Test on EMU with 300 VA burden:

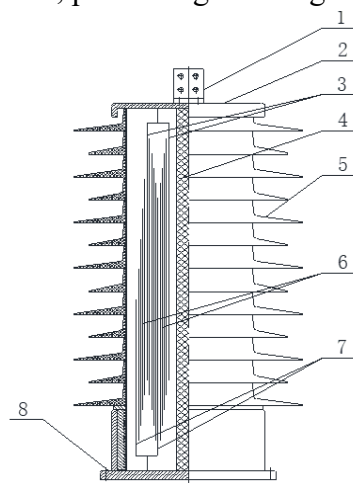
			A-N: 8.1 K 1a-1n: 9.0 K 2a-2n: 9.2 K da-dn: 10.9 K
3	Capacitance and $\tan \delta$ measurement at power frequency	$\tan \delta \leq 0.15\%$	HV terminal - 0.004 Intermediate terminal – 0.009
4	Radio interference voltage test	$\leq 2500 \mu\text{V}$	269.5 μV
5	Lightning impulse voltage test on primary terminals	15 impulses for each polarity	Passed
6	Chopped impulse voltage test on primary terminals	2 impulses for negative polarity	Passed
7	Wet test for outdoor type transformers	230kV, 60s	Passed
8	Transient response test	3PT1Class	Passed
9	Ferro-resonance test	-	Performed on 1a-1n winding: Passed
10	Short-circuit withstand capability test	110/ $\sqrt{3}$ kV, 1s	Passed
11	Power-frequency withstand test on capacitor voltage divider	230kV, 60s	Passed
12	Partial discharge measurements	126 kV ≤ 10 pC 87.3 kV ≤ 5 pC	6 pC @ 126 kV 3 pC @ 87.3 kV
13	Capacitance and $\tan \delta$ measurement at power frequency (Final test)	$\tan \delta \leq 0.15\%$	HV terminal - 0.005 Intermediate terminal – 0.010
14	AC-test on the electromagnetic unit	75.9 kV/150 Hz/40 s	Passed
15	AC-test of low voltage terminal and secondary windings	Low voltage terminals 5kV, 60s Secondary terminals 3kV, 60s	Passed
16	Mechanical impact test	IK10	Passed
17	Verification of the IP coding	IP55	Passed
18	Transmitted overvoltage test	≤ 1.6 kV	Passed
19	Mechanical load	1000N	Passed

2 GCVT Prototype – Capacitor Voltage Divider

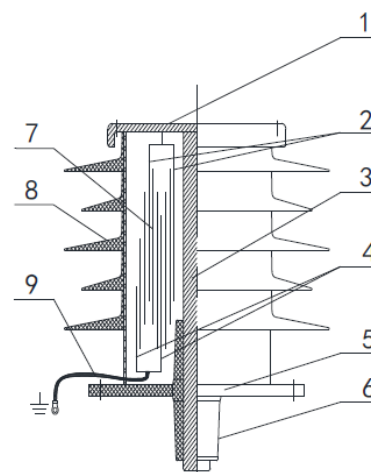
The high voltage capacitor C1 is composed of multiple sets of coaxial cylindrical capacitors connected in parallel; each set of capacitors consisting of a high-voltage screen and a low-voltage screen, as well as multiple middle screens inserted between them, arranged in a stepped manner (see Figure 3). The screens are wrapped with polypropylene (PP) insulating film

squeezing a capillary layer of silicone gel, which serves as insulation between the screens and fixes the screens. The structure of the C1 starts with the wrapping of a first group of capacitors where the inner side is the high-voltage screen and the outer side is the low-voltage screen. For the second group of capacitors the wrapping process starts with the inner side being the low-voltage screen and the outer side being the high-voltage screen. The outermost group of capacitors is the same as the first group of capacitors, with the inner layer being the high-voltage screen and the outermost layer being the low-voltage screen. All high-voltage screens are connected in parallel and connected to the upper flange and high-voltage terminal, while all low-voltage screens are connected in parallel and connected to the lower flange, forming a high-capacitance capacitor C1.

The intermediate voltage capacitor C2, like C1, is composed of multiple sets of capacitors connected in parallel. The medium voltage screen is connected in parallel to the upper flange and the grounding screen is directly grounded through the grounding terminal (see Figure 4). As shown in Figure 3, the lower flange of C1, which is also the upper flange of C2 has a 20 kV intermediate voltage of the capacitor voltage divider, which needs to be brought into the electromagnetic unit metal base box and connected to the high voltage terminal of the intermediate voltage transformer. In C2, instead of a lead being brought in air insulation, the central axis and bushing are used to bring the 20 kV intermediate voltage into the EMU base box. The high voltage terminal of the intermediate voltage transformer is connected through the bushing. In this way, the 20kV medium voltage lead will not be exposed to the air outside the metal box, preventing discharge caused by adverse weather or short circuits.



- 1- high-voltage terminal
- 2- upper flange
- 3- cylindrical high voltage screen
- 4- axis
- 5- silicone rubber sheds
- 6- middle screens
- 7- low-voltage screen
- 8- lower flange



- 1- upper flange,
- 2- medium voltage screen,
- 3- axis,
- 4- earthing screens,
- 5- lower flange,
- 6- bushing
- 7-middle screens
- 8-silicone rubber sheds
- 9-grounding terminal

Figure 3 - Structural Schematic Diagram of C1 **Figure 4 - Structural Schematic Diagram of C2**

The dry electromagnetic unit includes the medium voltage lead, epoxy cast intermediate voltage transformer T, compensating reactor L and damping device D as shown in Figure 5. The intermediate voltage transformer, compensating reactor and damping device in the dry electromagnetic unit are installed in a grounded metal base box. The intermediate voltage transformer is also fitted with a semiconductive shielding layer on its outer surface. The 20 kV medium voltage lead wire, which extends into the base box from the C2, is directly connected to the high-voltage terminal of the intermediate voltage transformer through a shielded cable or bushing. The shielding layer of the 20 kV medium voltage lead is electrically connected to the shielding layer of the intermediate voltage transformer T and directly grounded. In this way, the exposed parts of each component are at ground potential or low potential (which are highlighted by black lines in Figure 5). Compared with traditional fluid-filled electromagnetic units, this design prevents insulation degradation caused by moisture or condensation, reduces the risk of insulation leakage or discharge inside the box and greatly improves the safety and reliability of the electromagnetic unit. This design also reduces the size of the EMU base box, thereby helping to lower its cost.



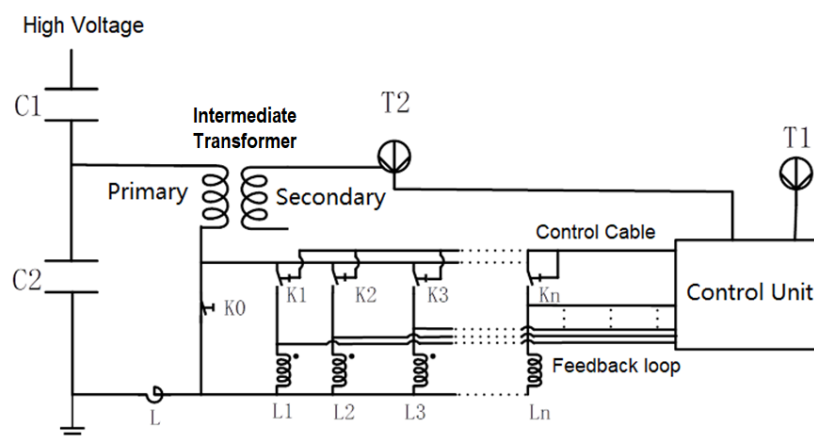
4 An Innovative Accessory for the GCVT - Automatic Error Adjustment Device (WZT)

The CVT is a device for measuring the voltage, and its error mainly comes from the following aspects:

- Error of the voltage ratio of the capacitor voltage divider.
- Additional temperature error caused by the ambient temperature change.
- Additional frequency error caused by the system frequency change.
- Error of the intermediate transformer (T) of the CVT.

The intermediate voltage transformers of traditional CVTs are equipped with multiple sets of adjustable winding taps, which are wound on the same iron core as the primary winding of the transformer. These winding taps can change the number of turns of the primary winding to adjust the output voltage and the error of the CVT. The adjustment windings are used for factory calibration of the capacitor voltage transformer and cannot be automatically adjusted during operation with changes in load and temperature. To this end, an innovative accessory (WZT) was developed for the GCVT that automatically adjusts the number of turns of the primary winding of the intermediate voltage transformer (Figure 6). Based on the signal from the T1 or T2 sensor, the control unit issues instructions to connect different regulating windings through designated switches to change the number of turns in the primary winding of the intermediate voltage transformer T, thereby reducing errors. Installing this accessory is a relatively easy design change. The current sensor is installed at the output end of the intermediate voltage transformer and the control unit is installed on the outside of the electromagnetic unit tank, which allows for the easy replacement of the electronic components, if necessary. No external power supply is required for the WZT device as an internal power supply coil is used to power the WZT.

A good analogy for the WZT is that it performs like an on-load tapchanger on a transformer. It allows the GCVT to still meet its original accuracy level under an increasing burden load without having to change the design of the GCVT.



T1 – temperature sensor, T2 – current sensor, L1.... Ln – regulating windings,
K0.... Kn - switch (or relay contact)

Figure 6- WZT Wiring Diagram

Verification tests conducted on the WZT device at 50VA and 200VA showed that the error tested at 50VA and 200VA met the of 0.2 accuracy class requirement (Table 3).

Table 3 – Accuracy Test Results with the WZT Device Installed

Winding	Test voltage % Error	80	100	120	Output (VA)	Accuracy Class
1a-1n	Ratio error (%)	-0.09	-0.10	-0.10	200	0.2
	Phase displacement (')	8.0	7.7	7.4		
	Ratio error (%)	0.02	0.02	0.02	50	
	Phase displacement (')	3.7	3.6	3.4		

5 Conclusions

The dry-type, solid insulation GCVT capacitor voltage transformer is an innovative product, which can directly replace on-site inductive voltage transformers or fluid-immersed capacitor voltage transformers. Compared with conventional fluid-immersed capacitor voltage transformers, the GCVT offers many advantages. The paperless, dry-type insulation technology used for the capacitor voltage divider structure has been used as the insulation technology for many years in products such as wall bushings and current transformers with ratings from 10 kV - 600 kV [4]. These products have performed well and have a proven record for reliability and maintenance-free operation in all types of operating environments on T&D systems all over the world. In addition, lower dissipation factor and partial discharge values (0.1% and < 5pC respectively) are typical electrical performance parameters for this technology, which equates to a longer life expectancy for the product.

The GCVT electromagnetic unit is not only dry but also fully shielded. There is no exposed high voltage inside the tank, ensuring the safety and reliability of the electromagnetic unit.

Finally, the components (C1 and C2 capacitors and electromagnetic unit) can be manufactured separately, improving production efficiency and providing shorter lead times. Transportation is also easier as the components can be shipped separately and conveniently assembled on site.

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