LOW-POWER VOLTAGE TRANSFORMERS FOR USE WITH SEPARABLE CONNECTORS IN MV SECONDARY GAS-INSULATED SWITCHGEAR – NEW CHALLENGE FOR STANDARDIZATION

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ABSTRACT

This paper deals with low-power voltage transformers (LPVT) installed together with a separable connector inside medium-voltage (MV), gas-insulated switchgear (GIS). It describes tests defined by existing standards for each of these components and points out issues the user might be facing when testing only according to these standards. We recommend extending LPVT type tests to additional tests specific to separable connectors and to perform all type tests on LPVTs mated with a separable connector. The paper proposes a specific set of tests to be included in a future standard for LPVTs. We propose this set of tests to make sure the separable connector is not affected by the LPVT installation and that it will work properly in this environment, without safety risks or effecting the performance of the LPVT and the separable connector.

INTRODUCTION

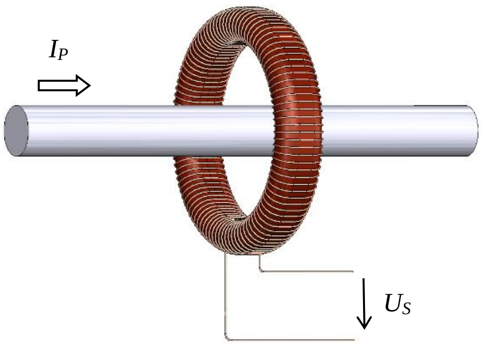
The evolution of smart grids and the broad application of renewables has created a need for the extensive use of current and voltage measurements for the proper management of power networks. These trends therefore require the use of advanced, low-power sensing technologies instead of traditional solutions using iron-core instrument transformers, due to their physical limitations, see [1] and [2]. One example of this new demand for current and voltage measurements is represented by medium voltage (MV), secondary gas-insulated switchgear (GIS). This type of switchgear usually has very limited space, which means adding other devices such as conventional instrument transformers is not possible without redesigning and retesting the whole switchgear or adding a new panel. These limitations have resulted in new solutions based on low-power sensing technologies suitable for both new installations and retrofitting.

A generally accepted solution is the installation of a low-power current transformer (current sensor) and a low-power voltage transformer (voltage sensor) in a separable connector; see Figure 1. The low-power current transformer (LPCT) is installed over the head of the separable connector and the low-power voltage transformer replaces the insulating plug of the separable connector. The application of a low-power current transformer is not so demanding from an electrical field point of view and different technologies can even be used (if space allows). Nevertheless, the application of a low-power voltage transformer needs to access the medium voltage point, which is a challenging task for GIS separable connectors due to the high level of electric field strength in this area.

Figure 1. Installation of LPCT and LPVT with separable connector

LOW-POWER CURRENT TRANSFORMER

The requirements of low-power current transformers are described in the existing standard IEC 60044-8, released in 2002. This standard must generally be used for electronic current transformers. Due to the evolution of sensing technologies, there is now a need to update existing standards. There is ongoing activity within IEC TC 38 WG 37 to introduce a new set of standards for the IEC 61869 standard family to cover the latest needs and requirements. The new standard IEC 61869-10 will cover the low-power passive current transformer (without active electronics), whereas IEC 61869-8 will cover the electronic current transformer (with active electronics). Most common in MV applications today is the use of low-power, passive current transformers. These do not contain any active interior electronics and therefore do not require an additional power supply, which makes them very reliable, highly accurate devices, with a broad dynamic range of measurements. The most convenient technology for such current measurement, providing the smallest size and the widest range of measured current, is Rogowski coil technology; see Figure 2.



$$u_S(t) = M \frac{di_P(t)}{dt}$$

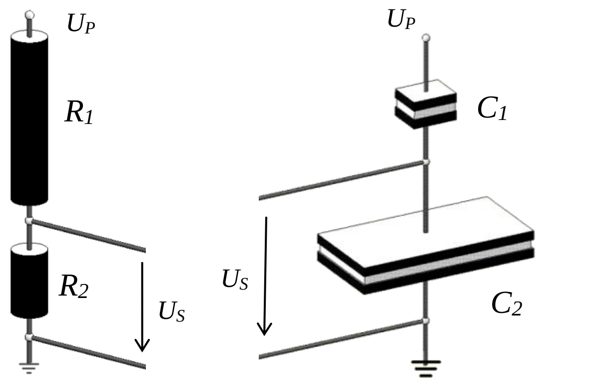
Figure 2. Basic principle of a Rogowski coil (see [1])

LOW-POWER PASSIVE VOLTAGE TRANSFORMER

The requirements of low-power voltage transformers are described in the existing standard IEC 60044-7, released in 1999. This standard must generally be used for electronic voltage transformers. Due to the evolution of sensing technologies, there is now a need to update existing standards. There is ongoing activity within IEC TC 38 WG 37 to introduce a new set of standards for the IEC 61869 standard family to cover the latest needs and requirements. The new standard IEC 61869-11 will cover the low-power passive voltage transformer (without active electronics), whereas the IEC 61869-7 will cover the electronic voltage transformer (with active electronics).

The tests addressed in this paper are therefore only related to low-power passive voltage transformers (LPVT).

Voltage measurement in most MV sensors is based on two working principles – resistive and capacitive dividers, see Figure 3.



$$u_S(t) = \frac{R_2}{R_1 + R_2} u_P(t) \qquad u_S(t) = \frac{C_1}{C_1 + C_2} u_P(t)$$

Figure 3. Basic principle of a resistive and a capacitive voltage divider (see [1])

While both technologies can be found in applications of cable connectors, the resistive voltage divider is used more often, mainly due to easier design implementation and lower requirements on used material.

SEPARABLE CONNECTORS

Separable connectors are fully insulated components that enable energy cables to be connected with electrical equipment. Contrary to open-type cable terminations, they are able to operate within much smaller spaces, under severely polluted conditions, even submersed in water. To function correctly, they need to be closely matched with the interface of the equipment bushing, which, for reasons of interchangeability, has standardized dimensions. (e.g. EN 50180; EN 50181).

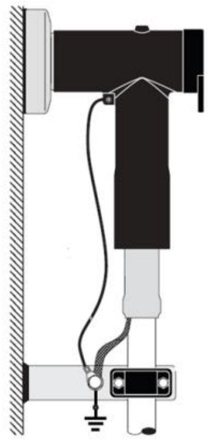


Figure 4. Separable connector

A very common type of separable connector is the T-shaped connector used with outer-cone equipment bushings; see Figure 4. It has two recessed interfaces, one that mates with the bushing interface, while the other can receive an insulating plug or be used to install other functional components such as an LPVT.

The requirements of separable connectors are described in the existing standard IEC 60502-4, released in 2010, covering testing requirements of accessories for cables with rated voltages from 6 kV (Um = 7.2 kV) up to 30 kV (Um = 36 kV). At the same time, another standard, CENELEC HD 629.1, also defines requirements for accessories for use on power cables (applicable to separable connectors as well). Both standards are very similar within a set of required tests, but their requirements sometimes differ greatly for particular tests.
Both standards have a common sequence of different tests required to demonstrate the cable accessories' performance and suitability in operation. The sequence for separable connectors contains the usual dielectric and short circuit tests, heating cycle voltage tests, both in air and submersed in water, as well as disassembly and reassembly tests to verify the "separability" aspect of the connector.

STANDARDIZATION

All related products, LPCT, LPVT and separable connectors, have some test requirements that apply to each particular product. These requirements are not always aligned, as they demand different tests, different test values or different acceptance criteria. The LPCT is not an issue, as it can work independently, without effecting separable connectors, to be used with screened types only. Therefore, only LPVT applications or installations will be discussed further. A brief summary of tests required by the relevant standards follows.

Low-power passive voltage transformer

IEC 60044-7 describes a set of routine tests (to be done on each individual piece of equipment or product) and type tests (to demonstrate that all equipment made to the same specifications complies with the requirements not covered by routine tests).

IEC 60044-7	
Test name	**Test value e.g. for 22/√3 kV 50 Hz products**
Routine tests	
Verification of terminal marking, §9.1	visual check
Power frequency voltage withstand test on primary terminals, §9.2.2	50 kV / 1 min
Partial discharge measurement, § 9.2.4	28.8 kV / max 50 pC 16.6 kV / max 20 pC
Power frequency voltage withstand test for low-voltage components, § 9.3	not applicable
Tests for accuracy, § 9.4	at 0.25 kV to 24.1 kV
Type tests	
Lightning impulse test, § 8.1	125 kV, 15 impulses of each polarity
Basic accuracy test, § 8.3.1	at 0.25 kV to 24.1 kV
Test for accuracy versus temperature, § 8.3.2	at 12.7 kV, -40 to 40°C
Test for accuracy versus frequency, § 8.3.3	at 12.7 kV, 48 Hz – 51 Hz
EMC tests: emission, § 8.7.1	
EMC tests: immunity, § 8.7.2	
Impulse voltage withstand for low-voltage components, § 8.8	not applicable
Transient performance test, § 8.9	

Table 1. Tests defined for LPVT

In addition, there are also special tests, which depend on other specific requirements agreed upon between manufacturer and purchaser. Table 1 shows a summary of necessary tests to be done on purely passive LPVT, which do not contain active electronic components.

Separable connectors

IEC 60502-4 describes a set of tests for screened separable connectors. This standard does not require any routine tests, it just describes a set of type tests. Nevertheless, it is good practice for the manufacturer to perform some tests in order to check each individual piece. In addition to IEC 60502-4, all manufacturers delivering to the EU also adhere to CENELEC HD 629.1. Both standards define similar tests but may consider, in some cases, different test values or different evaluation criteria. Table 2 shows a summary of tests and examples of test limits and criteria for both of these standards.

TESTING

Testing according to IEC 60044-7 on a standalone LPVT results in it passing all required test levels. Nevertheless, experience shows that tests performed on an LPVT assembled to a separable connector may have different results, with a higher level of stress resulting from tests on separable connectors.

The main deviations in tests according to separable connector standards compared to the LPVT standard are:

- Power frequency test (voltage value is only slightly higher, but test duration is **5 times** longer)
- **DC** voltage testing applied for **15 min** (DC tests do not exist in the LPVT standard)
- PD test (done at a lower pre-stress value, but max. limit is **10 pC**)
- **Heating cycles** (the LPVT standard requires only one cycle, but separable connectors have up to 63 cycles, even at 30 kV)
- **Heating cycles in water** (same as above, but under water; there is no such test required for the LPVT)
  Disassembly and reassembly (there is no such test required for the LPVT)

More details can be seen by comparing Table 1 and Table 2. Because of these additional tests and limits, improper LPVT design might have an effect on:

- **Voltage accuracy**, either amplitude or phase (depending on measuring principle)
- **Dielectric withstand**
  (both for LPVT or separable connector)
- **Ageing**
  (especially due to heating cycles, water submersion tests and disassembly and reassembly)

Therefore, practical test experience (e.g. Figures 5 and 6) shows the importance of tests being done on a fully assembled LPVT within a separable connector, making sure both designs are fully compatible to ensure there will be no field failures or safety issues.

IEC 60502-4 (configuration 4.1), IEC 61442		CENELEC HD629.1 S2 (configuration D1), EN 61442	
Type test name	**Test value e.g. for 24 kV 50 Hz products/system**	**Type test name**	**Test value e.g. for 24 kV 50Hz products/system**
AC voltage, §4	54 kV / 5 min	DC Voltage dry, §5	72 kV / 15 min
DC voltage, §5	48 kV / 15 min	AC voltage dry, §4	54 kV / 5 min
PD at ambient, §7	Pre-stress at 27 kV 20.8 kV (24kV) / max 10 pC	PD at ambient, §7	Pre-stress at 27 kV 20.8 kV (24kV) / max 10 pC
Lightning impulse, §6	125 kV - 10 impulses of each polarity at elevated temp.	Impulse voltage, §6	125 kV - 10 impulses of each polarity at elevated temp.
Heating cycles in air, §9.2	30 cycles at 30 kV	Heating cycles voltage in air, §9.2	63 cycles at 30 kV
Heating cycles under water, §9.3	30 cycles at 30 kV	Heating cycles voltage in water, §9.3	63 cycles at 30 kV
Disconnect/connect	5 times	Disconnect/connect	5 times
Partial discharge at elevated temp., §7	20.8 kV (24kV) / max 10 pC	Partial discharge at elevated temperature, §7	20.8 kV / max 10 pC
Lightning impulse, §6	125 kV - 10 impulses of each polarity	Impulse voltage, §6	125 kV - 10 impulses of each polarity
AC voltage, §4	30 kV / 15 min	AC voltage dry, §4	30 kV / 15 min
Examination	For information only	Examination	For information only
Screen resistance, §15	Maximum 5 000 Ω	Screen resistance measurement, §15	Maximum 5 000 Ω
Screen leakage current, §16	Maximum 0.5 mA at 24 kV	Leakage current measurement, §16	Maximum 0.5 mA at 24 kV
Fault current initiation, §17		Screen fault current initiation, §17	
Capacitive test point, §20	Ctc > 1.0 pF Cte/Ctc <= 12	Operating force, §18	< 900 N
		Capacitive test point performance, §20	Ctc > 1.0 pF Cte/Ctc <= 12

Table 2. IEC and CENELEC tests defined for separable connectors

Figure 5. Test arrangement in air

Figure 6. Test arrangement in water

Based on the performed tests, as well as the experience and observations resulting from the testing, the following tests and test sequences are recommended each time this type of application is of concern. Furthermore, they should be added to future IEC 61869-11 standards dealing with LPVTs; see Table 3.

Future IEC 61869-11	
Test name	**Test value e.g. for 22/√3 kV 50 Hz products**
Routine tests	
Verification of terminal marking, IEC 60044-7 §9.1	visual check
Power frequency voltage withstand test on prim. terminals, IEC 60044-7 §9.2.2	50 kV / 1 min
Partial discharge measurement, IEC 60044-7 § 9.2.4	28.8 kV/max 50 pC 16.6 kV/max 20 pC
Power frequency voltage withstand test for low voltage components, IEC 60044-7 § 9.3	not applicable
Tests for accuracy, IEC 60044-7 § 9.4	at 0.25 kV to 24.1 kV
Type tests	
Power frequency withst. test on prim. terminal, IEC 61442 § 4	54 kV / 5 min
DC voltage, IEC 61442 §5	48 kV / 15 min
Partial discharge measurement IEC 60044-7 § 9.2.4 with different meas. points and limits	28.8 kV/max 50 pC 20.8 kV/max 10pC
Lightning impulse test, IEC 60044-7 § 8.1	125 kV-15impulses at elevated temp.
Heating cycles in air, IEC 61442 §9.2	30 cycles at 30 kV
Heating cycles under water, IEC 61442 §9.3	30 cycles at 30 kV
Disconnect/connect, IEC 60502-4	5 times
Basic accuracy test, IEC 60044-7 § 8.3.1	at 0.25 kV to 24.1 kV
Test for accuracy vs. temp. IEC 60044-7 § 8.3.2	at 12.7 kV, -40 to 40°C
Test for accuracy vs. frequency, IEC 60044-7 § 8.3.3	at 12.7 kV, 48 Hz – 51 Hz
EMC tests: emission, IEC 60044-7 § 8.7.1	Acc. to IEC
EMC tests: immunity, IEC 60044-7 § 8.7.2	Acc. to IEC
Transient performance test, IEC 60044-7 § 8.9	Acc. to IEC

Table 3. Tests recommended for LPVTs installed in separable connectors

Routine tests must be performed before and after the type tests in order to ensure the stable performance and accuracy of the LPVT.

CONCLUSION

Two different standards are currently available with different requirements, one for low-power voltage transformers, covering general dielectric and accuracy requirements, and another for separable cable connectors covering application specific requirements. Due to different requirements, there is currently a grey area in standardization, where specific requirements for comprehensive applications represented by a low-power voltage transformer installed in a separable connector need to be defined, see Figure 7.

Figure 7. Proposal to insert new requirements into future IEC 61869-11 standards

This paper presents a new approach in dealing with this issue and proposes testing sequences combining the requirements of all related standards. This paper also suggests integrating this approach into relevant LPVT standards. Additionally, the proposed approach has been validated by extensive, practical testing of LPVTs installed within separable connectors, and the results of these tests passed the recommended test sequences and criteria. The proposed improvement of future IEC 61896-11 standards has been also presented during the latest plenary meeting of the IEC TC38 work group, which is dealing with instrument transformers, with request for consideration of this input.

Therefore, we strongly recommend improving future IEC standards for LPVTs in order to ensure a safe and highly reliable environment for users.

REFERENCES

[1] R. Javora, V. Prokop, 2011, "Low-Power Current and Voltage Sensors for MV Applications", *Proceedings IPTS conference*, pp 0.1-0.9

[2] R. Javora, A. Hozoi, V. Prokop "Total accuracy of the whole measuring chain - Sensor & IED", *Proceedings CIRED 2013 conference*, paper 0082