INNOVATIVE AND SAFE CABLE CONNECTION IN MEDIUM VOLTAGE SWITCHGEAR WITH INTEGRATED EARTHING AND TESTING FACILITIES

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ABSTRACT

In networks operating at 24kV, fully enclosed and earthed cable connectors described in EN 50181 are widely used for connecting medium voltage cables to compact switchgear. During installation, and sometimes during the service life, it is necessary to remove, change or repair those connectors. Of course safety procedures are followed prior to cable access to avoid any dangerous situation. However, the full insulation combined with an earthed layer is a complicating factor for transparent access procedures. In The Netherlands where traditionally the majority of the MV networks operate at 12kV, cable connections with more easy access are in use since many years, enabling more obvious earthing and access procedures. This is of vital importance for field personnel, whose safety depends on it. In this paper we propose a new innovative cable connection that offers the unambiguous safety functionality up to and including 24kV, whereas this was only possible for 12kV until now. We describe the new insulated, non-earthed cable connection with integrated earthing and test facility, and the design process including laboratory testing up to first introduction. Furthermore, we provide a complete modern approach for interconnecting Ring Main Units (RMU's). This includes 3-phase network cables to minimize magnetic fields, special joints from 1- to 3-phase cables to connect to the RMU, an earthing method preventing significant induction currents and the innovative, crystal clear safety procedures.

INTRODUCTION

The majority of the utility grids in The Netherlands operate at 12kV. This voltage level allows switchgear with easily accessible open primary parts with safe earthing and cable connection access procedures. Todays' procedures are still based on open medium voltage substations as in use many years ago. Those are simple and clear and that is an important advantage. Internationally, in networks at 24kV and higher, enclosed, insulated and earthed cable plugs are in use to connect cables to compact MV switchgear. Of course the field personnel working in those 24kV grids follows safety procedures as well, but those are more complicated. The Dutch utility Alliander is moving from 12kV towards 24kV nowadays as a strategic direction and was in search of the same easy and clear procedures for 24kV, as they were using for 12kV. Therefore Alliander jointly worked on new solutions together with Eaton as their MV switchgear supplier, with TE Connectivity, Seher/United Electric and Cellpack as their cable connector suppliers, and with the Prof. Ir. Damstra Laboratory for testing.

ACCESSING CABLE CONNECTIONS

Safety requirements according to EN 50110-1

In the EN 50110-1 the essential needs for creating a safe working place are defined: the so called Golden Five [1]:

1. create a safe distance with a disconnector
2. protect and lock against unintended reclosing
3. check on absence of voltage
4. take care of short-circuit proof earthing
5. separate the working place from adjacent live parts

EN 50110-1 also states that earthing should be visible from the working place if possible.

Access to cables with earthed connectors

Internationally, earthed cable connectors are widely applied for 24kV and higher. However, there are some disadvantages regarding safe working practices. Voltage detection is not possible without removing the earthed end plug from the cable connector, which stays a continuing point of discussion. After removing this plug, voltage detection is only possible by touching the capacitive test point. Thereafter, the araldite cone needs to be removed and that is often no sinecure. Finally there is some risk that the primary cable connection is loosened together with removing this cone. For a switchgear manufacturer the earthed connectors are easier to design for, as no precautions are necessary in the cable compartment for electrical design such as partial discharge (figure 1).

Figure 1: Example of an RMU with earthed cable connection plugs, applied widely in international networks.

Alternative possibility for access to cables

An integrated Cable Test Facility (CTF) can be used as well to check the quality of a cable connection before installing or during the service life of the switchgear. Within this design a fully interlocked access to the cable connections is possible using the internal connections of the switchgear for injecting test currents and test voltages without disconnecting the actual cable connection. Reference is made to the CTF options in the Xiria and FMX switchgear from Eaton [2]. Test rods can be placed under safe earthed conditions before performing the test (figure 2).

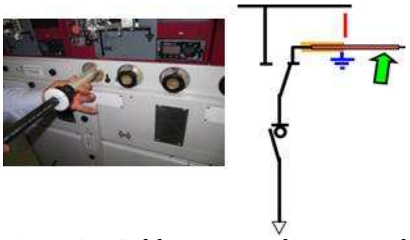

Figure 2: Cable Test Facility as an alternative solution.

Access to 12kV cables in the Netherlands

In history, open air switchgears with loose components connected with non-insulated copper bars were applied often in The Netherlands. In those open installations it is obvious how to adhere to the Golden Five. With a switch the safe distance is created, this is being locked, with dedicated accessories the absence of voltage is checked and by connecting a flexible earthing device to the fixed earthing bolts the earthing is realized. This is a clear and visible procedure. The earthing procedures which are currently in use with enclosed switchgear for 12kV do still originate from this period. Actual MV switchgear in the Dutch network is mainly insulated switchgear, such as Magnefix for Ring Main Units and SVS for Substations complying with IEC 62271-201 [3]. Here the cable connection points can be accessed directly. This access is interlocked and can only be reached after switching-off and creating a safe disconnecting distance. In this situation the absence of voltage can be checked via the direct access points, and then a short-circuit proof earthing can be applied with a flexible accessory. Provisions are available for safe phase comparison and cable testing (figure 3).

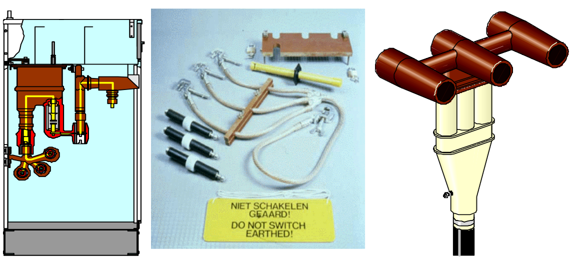

Figure 3: Example of interlocked-accessible cable connection with integrated earthing and test possibilities.

In withdrawable primary MV switchgear visible earthing can be provided by removing the breaker, proving absence of voltage and putting an earthing device in place of the breaker as described in IEC 61230 [4].

NEW INNOVATIVE CABLE CONNECTIONS UP TILL 24KV

As a major Dutch utility, Alliander has extensive experience with 12kV switchgear. Field engineers are trained and skilled with the transparent access and earthing procedures as mentioned earlier. Now the choice is made to move to 24kV switchgear, Alliander is in search for comparable clear working procedures, and that is possible with the following new and innovative cable connection solution as developed by three suppliers of connectors in parallel.

Design

The new designed connectors are based upon the use of existing accessories for testing and earthing as used for many years in the network on various types of switchgear. The following procedures are in line with the Golden Five:

- Safe access
- Safe voltage absence check
- Safe earthing

The connectors are provided with an integral standardized earthing bolt complying with DIN 48088, accessible after easy removal of the cap with a safety stick. This earthing bolt is shaped as a ball for easy fitting of standardized testing and earthing equipment. Permanent connection of the earthing bolt in the connector implies that it will face electrical fields during normal service. Due to the compact dimensions of the cable connector and the shape of the earth ball inside, it is not feasible to provide an earthed screen on the outside of the connector (figure 4). This would cause partial discharges. Instead, the plugs are single fully insulated and comply with Cenelec HD629.1 [5].

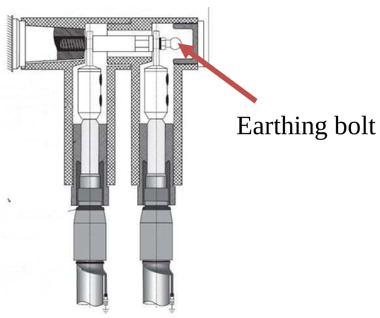

Figure 4: Cross-section of two stacked, single insulated connectors with the integrated earthing bolt.

Advantages of the single insulated connector with integrated earthing bolt are:

- The absence of the earthed layer enables detection of presence/absence of voltage without the need to remove any cap. Alliander developed the Volt Stick for this purpose [6], which is a voltage detecting device complying with IEC 61243-1. It contains a teflon thimble and works electromagnetically. It is a positive-one-way-device with no need for metallic contact, developed for safe working on MV transformers. There is surely no voltage if the device does not light up (figure 5).

- Integration of the earthing bolt as mentioned earlier. This enables easy, visible, local and short-circuit proof earthing of the cable at the cable ends. For 24kV, the same transparent safety procedures as used for decades in the 12kV grids can be applied.

Figure 5: Volt Stick in operation on a transformer.

Disadvantages of the single insulated cable connectors: The cable box becomes a high-voltage compartment. This means that electrical fields need to be controlled, sufficient clearances need to be adhered to, and that sharp edges can cause partial discharges.

Testing

The new connector designs with integrated earthing bolt, as well as new transition joints from 3-phase to 3x1-phase cable have been successfully tested in Xiria. It was quite a unique and flexible experiment. Tyco, Cellpack and Seher/United Electric developed new connectors and tested them simultaneously with high mutual respect; Eaton improved the cable compartment to prevent partial discharge. Alliander coordinated and defined the test plan. The Prof. Ir. Damstra Laboratory conducted the dielectric testing (figure 6).

Figure 6: Test object with 3 types of cable connectors in Prof. Ir. Damstra Laboratory.

Introduction at the Alliander Tech Day

To inform the utility engineers of the network operator, the new design has been introduced during the Alliander Tech Day in December 2012 with 700 participants. It received many positive comments about the easy access and testing procedures in practical situations (figure 7).

Figure 7: Introduction of the new cable connection to Alliander field engineers on the Tech Day.

COMPLETE MODERN APPROACH FOR INTERCONNECTING RMU'S

The new innovative cable connection fits in a comprehensive approach for interconnection of compact MV switchgear up till 24 kV. Reduction of magnetic fields, proper cable earthing, accessibility for inspection and standardization of working procedures are all taken into account.

<u>The choice for 3-phase cables at Alliander</u>

In history Alliander always applied 3-phase PILC cables. Later, when plastic cables for LV, MV and HV were introduced; 3-phase cables for MV distribution were applied. 240mm^2 Alu is used to distribute 7.5 MW at 12kV and 15 MW at 24 kV. This is done for reasons of identical working procedures and for a robust and recognizable structure in the cable trench. It prevents high magnetic fields in the neighbourhood of the cables and it allows using the easy two sided cable screen earthing system. Only for larger cables (630 mm^2 Alu) the 3-phase solution is no option, and a 1-phase option has to be chosen. To have fewer types of components in the grid, Alliander decided to standardize on 24kV cables, even at 12kV trajectories. For 24kV the isolation is normally appr. 1 mm thicker and as a result these cables are stiffer. This stiffness makes it impossible to connect 3-phase cable to compact MV switchgear and therefore transition is made to 1-phase cables for the last 15 meters near the switchgear. Round shaped instead of sector shaped conductors are selected because the outer semiconducting layer can be removed more easily.

Limit magnetic fields by applying 3-phase cables

The international norm for magnetic fields near cables is 100µT at 1m above ground level. This is a quite high limit and easy to comply with normally. However, only 0,4µT is allowed near schools and more and more near public buildings. Procedures are mandated and zones need to be designated by utilities for those situations. The tight limit of 0,4µT is easily exceeded with 1-phase cables at common ratings of 360 A and above. The magnetic fields can be held below 0,4µT at one meter above the ground by applying 3-phase cables at currents up till 360 A.

Transition from 3-phase to 1-phase cable to connect to compact switchgear

One can easily overlook earthing complications when transition joints are applied from 3- to 1-phase cables.
Significant currents with similar magnitude as the primary currents can be expected when all earthing screens are interconnected. This occurs when the earthing screen of the 3-phase cable is simply connected to the 3 screens of the 1-phase cables, and when those 3 screens of the 1-phase cables are earthed at both ends. Induction is the cause here. The loop for the induced current is short and has low impedance. Only low inductive driving voltage will cause a high current in the screens. Rather often, the mistake is made and cable screens are overloaded, heated and burned. Alliander solves this issue by applying a transition joint from 3- to 1- phase cable, which is specifically developed. The screen of the 3-phase cable is insulated from the screens of the 1-phase cables by special overlapping semiconducting layers similar to a cross bonding joint. The three 1-phase cables are earthed only at the MV switchgear side. The screens at the non-earthed ends and the three phase screen at the other end are insulated from each other with a BIL capability of 70kV in order to withstand traveling waves at lightning. This value follows from earlier Cigre cross bonding studies. A fourth, insulated, watertight 1-phase cable of 70mm2 is connecting the screen of the 3-phase cable to the earth bar on the MV switchgear (figures 8 and 9). All and all the transition of 3- to 1-phase cable needs careful attention and decent instruction.

Figure 8: The new transition joint from 3-to 1-phase cable.

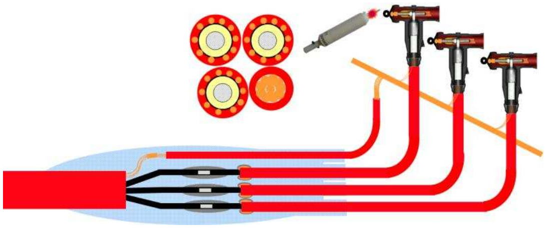

Figure 9: Modern approach for interconnecting RMU's.

Access to cable compartment for inspections

Alliander made the choice to have non-interlocked cable doors at the MV switchgear. This choice provides the flexibility they need for voltage testing, thermo graphic photos and cable inspections at switchgears in service. The risk of touching live parts is minimized by strong and stringent company guidelines and work instructions which are defined fully independent from the various switchgear designs. Highly skilled personnel provide the required safety level, and are always confronted with the same rules.

CONCLUSIONS

A new 24kV cable connection for compact RMU's was developed, tested and introduced, with simpler and clearer earthing and safety procedures. Those procedures are similar to those in use in the Netherlands since ages already for 12kV. An integral approach for interconnection Ring Main Units is introduced as well, including the choice for 3-phase cables to minimize magnetic fields at public accessible places, earthing methods that prevent overload of cable-screens, and safe access for field engineers. This development is the result of multiple companies with a trustworthy relationship joining together.

ACKNOWLEDGEMENTS

In the electrical power industry network components are kept in service for more than 50 years. Trustworthy and enduring relations enable collaborations where common interests (i.e. safety) get the full focus. The development of the new cable connection is a good example of such a joined cooperation. Awareness, desire and initiative came from the Alliander utility and led to joined actions by utility, cable connector suppliers (Cellpack, TE Connectivity, Seher/United Electric), switchgear supplier and the Prof Ir. Damstra Laboratory. The authors thank M. Goemaat, A. Valk (Seher/United Electric), R. van Buuren (TE Connectivity) and R. Kroon (Cellpack) for their cooperation in the development.

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