NEW SPECIFICATIONS ON MV SWITCHGEAR FOR CABLE TEST FEATURES

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ABSTRACT

For years, the dielectric tests on cables have been performed using the connection points available within the switchgear units. The specifications applicable to such operation were not completely addressed by the international standardisation, neither in the switchgear standards nor in the cable standards. In addition, the use of dedicated devices integrated in switchgear is increasing, as it provides easier and safer testing procedure.

The recently revised switchgear standard IEC 62271-200 [1], which covers most of the switchgear used under such conditions, now defines optional ratings, and the associated type tests, to cover the fact that part of the switchgear is stressed when performing cable tests, and that possibly disconnection gaps can be also subjected to combined dielectric stresses.

The paper provides:

- a review of the historical solutions and practices;

- some trends driving the evolution of the topic;

- the presentation of the new ratings and requirements included in the standard;

- a discussion on how these performances should be understood and implemented by the manufacturers and the DNOs..

INTRODUCTION

In the most recent years, the electricity market evolved in such a way that asset management came as a clear concern. The ageing of underground cables and the need of increased service continuity make cable testing more and more frequently used, both for curative and for predictive maintenance as cable diagnosis.

In the other hand, the access to primary circuit without disconnecting the cable is now difficult to get, because of the increasing use of isolated and screened plug-in connectors, embedded sensors or arresters etc. That's why dedicated devices integrated in switchgear, allowing cable testing without interfering with cable ends, are more and more appreciated. Furthermore, such devices allow the test of the entire cable circuit, including cable connectors, joints etc. while providing easier and safer procedures.

More frequent cable testing using access points in the switchgear itself rose the need of clarification and assessment of relevant performance in the second edition of IEC 62271-200 standard [1].

WHY SHOUD CABLE TESTING BE A CONCERN FOR SWITCHGEAR?

Cable test is a field operation which is performed in various situations along the life of the cables. As disconnecting cables from the switchgear can be a rather tricky operation, involving heavy procedures to control operators safety and system integrity, it is common to perform cable tests while keeping the cables connected. In such situation, the switchgear is submitted to stresses which have not been clearly anticipated during the design stage, especially when no dedicated cable test device is provided by the switchgear manufacturer. These stresses can be of different nature (e.g. d.c. tests performed on a.c. installations) or at higher levels (e.g. 4 x U_0 during 15 minutes) than any performance specified for the switchgear. As part of the high voltage circuit of the switchgear remains connected, this part sees the same stress to earth that the cable under test itself. Furthermore, the open point along the high voltage circuit of the switchgear is subjected possibly, according to the single line diagram, to a combined stress never anticipated even for a disconnecting function. If the access is got by opening a connection compartment, this compartment is also under unspecified conditions, as well for the voltage value as for the field configuration created by the test probe. Nevertheless, the safety record of cable testing did not reveal any major concern and the topic never became critical up to now, with the existing well-known solutions as SF6 or air isolation.

ABOUT STANDARDS AND SWITCHGEAR

Cable testing became a topic for concern with the increasing use of metal-enclosed switchgear, as previously the access to conductors was not a problem, and the post insulators provided dielectric margins and self-restoring insulation. In the legacy standard IEC 298 for metal-enclosed switchgear, a requirement was expressed (5.107) about the dielectric withstand of the parts remaining connected, and a single note drew attention of users that while performing dielectric tests on connected cables, the open gap could have little or no margin, if the busbar is kept energised. The requirements referred to "relevant cable standards", wording which let several generations of designers wondering about the right values to be used...

This wording remained almost unchanged in the first edition of the IEC 62271-200 (2003), even if, during this period from 1980's to 2000, the switchgear market showed a growing part of G.I.S. and plug-in connectors, both points calling for more cable test functions embedded in the

switchgear.
This led to an increasing request for condition assessment of the equipment, including cables, and then to the development on predictive maintenance.

CHANGE IN IEC: STANDARD EVOLVES TOWARDS BETTER CLARIFICATION

During the revision process leading to Edition 2 of the IEC 62271-200 [1], it has been decided to introduce a rated value dedicated to characterisation of the withstand of the switchgear to a voltage applied for cable testing purpose. Main points are:
- the rating is optional; the manufacturer can deny the possibility of performing cable tests while the cables remain connected;
- the rating is differentiated in d.c. and power frequency values (two ratings can be assigned);
- no preferred value is provided, and manufacturer should select a value according to the targeted market;
- a type test is introduced to check that such a test voltage can be applied without exceeding the withstand to earth of the part of switchgear under stress, and with keeping a margin with any service voltage which could be maintained on the other parts of the switchgear.

This change is not a big technical one, but it means that:
- situation is now clearer than the previous wording;
- the manufacturers shall commit on numerical values and demonstrate them with a relevant type test;
- users shall investigate if they need such a withstand, according to their test procedures, which value they need, according to the cables and cable test equipment, and then possibly specify a minimum value for these ratings.

DIELECTRIC STRESSES DURING CABLE TEST OPERATIONS

General

Under the general wording of "cable tests", one should make the difference between two situations:
- corrective maintenance, when there is a fault on the network and tests are performed to localise the fault;
- predictive maintenance, performed to assess the condition of cables, joints, connections, and diagnose weak points before they evolve to actual faults. Commissioning can be considered as predictive maintenance and be requested either on new cables, or to validate a repair; at least in the later case, the switchgear is already connected.

Corrective maintenance

Corrective maintenance uses several test methods, as reflectometry or burn-out, but these methods involve voltage levels below the service voltage of the cable. The insulation of the cable, or any accessory, being damaged, applied voltage can't reach values bringing significant dielectric stresses on the cable and connected equipment. For that reason, corrective maintenance can be disregarded when specifying the cable test withstand voltages of the switchgear.

Predictive maintenance

For predictive maintenance, several methods are used, with various stress levels:
- short time power frequency voltage withstand test: such test is consistent with the specification of the switchgear, and it is almost easy to assess the acceptability of the stress level; however, the rated withstand of the switchgear is demonstrated through a one minute test, while cables are sometimes tested with a longer duration. It does not seem to be an issue for power frequency, for which no significant cumulative effect is anticipated.
- direct current voltage withstand test: the use of d.c. test voltages is introduced to get rid of the capacitive current, and to keep a low kVA rating on the test equipment. The d.c. tests on cables are usually specified for a fifteen minutes duration, and the new switchgear rating "rated cable test withstand voltage (d.c.)" is demonstrated with a type test of fifteen minutes. However, d.c. tests are not recommended by cable manufacturers, mainly due to premature ageing phenomena, and a.c. are preferred. *(Nexans-Olex: HIGH VOLTAGE D.C. TEST AFTER INSTALLATION*
The D.C. testing of the primary insulation is not recommended. There are two important reasons for not using a High Voltage DC Test.
1) The DC field in the cable and accessories applies different electric stresses (both in magnitude and in physical location) to an AC field. So much different, that it is considered to be a poor process to find faults.
2) The application of HV DC leads to premature failure of aged and“ wet” primary insulation. This has been proven in the Laboratory and has been proven repeatedly in the field.)
- in order to apply diagnosis methods, as partial discharges measurement or tgt δ measurement, while keeping the advantages of a low power test equipment, several Very Low Frequency test methods have been introduced during the last two decades. The range of frequencies used by the test equipments is between 0.01 Hz and 1 Hz, typical frequency at 0.1 Hz, with waveforms not completely defined and being dependant on the test equipment itself.
The equivalence of VLF stresses with either d.c. tests or power frequency tests is not demonstrated. Then, the IEC switchgear standard has not addressed the VLF tests in the cable test voltage ratings, but a note suggests that a d.c. rating may cover VLF tests. The topic is still controversial, especially because of the different wave shapes generated by the different test equipments on the market. There is no general agreement about the equivalence of VLF with either power frequency or d.c. but the stresses seem to be closer to d.c. effects than power frequency effects. For "true" sinusoidal waveform, the suggested equivalence is between

VLF peak value, and d.c. value. Further guidance information can be found in the IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency [2].

Voltage values

The test values for cables are often expressed as multiple of U_0. It is possibly confusing for users, as the switchgear rated voltage is expressed as phase-to-phase value, and refers to the "highest voltage for the equipment" and not to the service voltage. Insulation levels are expressed with a set of phase-to-ground values: power frequency and basic impulse level. Table 1 below provides an example of how these various voltage values can be ranged.

Table 1: voltage levels rated for cables and switchgear

Network	Cables (extruded solid insulation) IEC 60502-2 [3]	Switchgear IEC 62271-1 [4]
Nominal voltage U_n = 20 kV	Designation 12 / 20 (24) kV U_0 = 12 kV	Rated voltage U_r = 24 kV
Service voltage 20 kV ± 5%		
Insulation level 50 kV p. f. 125 kV BIL	Insulation level 48 kV p. f. (42 kV routine) 125 kV BIL	Insulation level 50 kV p. f. 125 kV BIL

In the example provided, a cable test with power frequency voltage at four times U_0 remains within the dielectric performances of the switchgear, and such a test is considered as a type test (sample test) in the relevant cable standard. A VLF test voltage between one and three times U_0 (usual range recommended in [2], and provided by test equipment on the market) does not seem to exceed the dielectric withstands, but, as already stated, the actual effect of VLF voltage is not assessed and remains controversial.
The standard for cables introduces a possible d.c. tests for commissioning, as an alternative to a.c.. In that case, the test voltage should be four times U_0, but a note reminds that "a d.c. test may endanger the insulation system under test.". No mention is made of VLF.

HOW TO SPECIFY SWITCHGEAR RATINGS

Considerations on the cable system

It is established that cable systems have a longer life span than switchgear, and when installing a new substation it is common that the connected cables are of an older generation (e.g. paper insulated or oil filled cables). Furthermore, on old systems, it is common that a single cable length can mix several technologies, due to modifications or repairs; the weakest part of the cable length to be tested shall be considered for limiting the value of any applied stress. Old cables are never subjected to such high test voltages as discussed above, and not only the technology is relevant, but also the age. Some service companies consider that beyond five years old, test values should be decreased. The Ergon Energy Corporation suggests 75 % of the value used on new cables. As long as a system experiences a low fault rate, it is useless to stress it at a level which could damage the insulation.
If there is any project for cable replacement, including change of technology, this should be considered for determination of the applied stresses on the switchgear.

Considerations on the working procedures

Depending upon local habits, applying regulations, installed switchgear and available test equipments, the working procedures can vary from one user to the other.
If cables can be easily disconnected from the switchgear to perform dielectric tests, then there is no more concern about switchgear ratings; however, the dielectric surrounding of a disconnected cable is not clearly demonstrated as withstanding test voltages, and precautions are needed. It shall be reminded that a cable length has two ends, and the one not used for test voltage application shall be secured as well.
If cables remain connected at one or both ends, then the switchgear shall be operated according to instructions to allow the test voltage to be applied safely. It usually needs going through a number of operations to separate the cable from the network, to ground it while test connections are put in place, to unground it for the test itself... All these operations needing to be properly documented and checked. The final test configuration, at each end of the cable section, defines which part of the switchgear will be stressed with the cable.
Some accidents, by return voltage application, are reported by test equipment manufacturers, and most of them are linked to difficulties in proper application of working procedures and especially the fact that positive interlocking with the remote end of cable can't to be done easily.

Considerations on the rate of cable tests

Commissioning tests are clearly seldom performed, and when it is a new cable section, the tests are performed usually before connection to the switchgear. When commissioning a repair, or a new split, existing switchgear could be subjected to test voltage. How often does it happen, and how complicated could be the applied procedure, remains a user's appreciation.
Cable condition assessment tests are expected to be performed on a regular basis, even if not very often. The current trend for more efficient predictive maintenance could increase this rate in a foreseeable future...
If the rate is actually low, and according to cable and switchgear technology, perhaps disconnecting the cables is an acceptable option. If it is not considered so, then the switchgear shall be specified with relevant ratings, and possibly also with dedicated cable test feature to ease the connection of test equipment. Extra cost for such a device is

to be balanced with the fact that it avoids any interference with switchgear or cable end, so keeps the insulation integrity of the whole system unchanged.

Specification of the switchgear

After due consideration of the expected service conditions, a user could choose to look for rated cable test voltage values when browsing available offers, or specify rated cable test voltages when issuing a tender. As usual, the values should cover all the identified stresses which are likely to be applied. Requesting dedicated cable test feature on the switchgear, providing easier connection of test equipment, can be wise if the technology of both the switchgear and the cable connections makes difficult the direct access to the main conductors of the cables.

Fig 1: example of dedicated access for cable test purpose

Over-specification, which is generally considered as conservative, should be avoided as it could drastically reduce the panel of choice and/or increase significantly the cost. It seems especially relevant for such a "new" performance which is not yet stabilised on the market place. A general rough consistency could be identified between all the values quoted in the "voltage values" chapter, especially if a switchgear is rated with cable test voltages equal to its power frequency withstand value. For instance:
- rated power frequency withstand value: 50 kV r.m.s.
- rated cable test voltage a.c.: 50 kV r.m.s.
- rated cable test voltage d.c.: 50 kV d.c.
- U_0 of the connected cables: 12 kV r.m.s.
- max recommended p.f. test voltage: 42 kV r.m.s (3.5 U_0)
- max recommended VLF test voltage: 36 kV r.m.s. (3 U_0)
- suggested equivalence of max VLF: 51 kV d.c.

That does not mean such a specification is needed for any actual network, and, as presented above, a careful analysis of the network data and operating procedures should be performed before issuing a tender for switchgear with cable test ratings.

CONCLUSION

Standardisation and specifications must follow the end users and distribution network operators habits and working procedures evolution, while aiming to get as much as possible the best clarification of switchgear specification and use. Cable testing operation should be addressed by switchgear standards, as switchgear is involved in more and more frequent practise. By integrating new ratings and type testing procedures for cable testing feature, the second edition of IEC 62271-200 will light and clarify the way of specifying switchgear accordingly.

REFERENCES

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[2] IEEE Std 400.2™-2004 "IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)", *IEEE Power Engineering Society*

[3] IEC 60502-2 (Ed2-2005) "Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 2: Cables for rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV)", *IEC International Electrotechnical Commission*

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