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Test Experiences and Late Market Requests on Extruded Cable Systems up to 525 Kv Dc

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Abstract

Today the world is facing the transition from traditional to renewable electricity generation and there is a need for new procedures and test facilities in order to meet new and different demands. For example, very fast polarity reversals that take into account the interconnections between markets in which the flow of energy can vary according to the climatic and / or economic conditions of the moment, or a greater ability to withstand electrical transients is required, giving greater confidence to all transient phenomena that occur in HVDC schemes such as during pole-to-ground fault, pole-to-pole fault, AC side faults etc. This paper intends to present the experiences gained in KEMA laboratories (FGH Mannheim) with reference to different aspects of the above-mentioned cable systems. Among other aspects, a suitable and scalable laboratory test setup for the imitation of expected TOV stresses is presented.

Keywords: Cable Interconnection, HVDC Cable Systems, Long Duration Tests, Polarity Reversal and TOV Tests

1. Introduction

According to the IEA[1] in 2021 electricity demand is anticipated to grow by 3% (around 700 TWh) in total, this means global demand would be higher than in 2019. The greatest uncertainty for electricity demand in 2021 is the further development of the Covid-19 pandemic, the measures taken by governments to prevent it spreading and the availability, speed of distribution and effectiveness of vaccines. This will significantly affect the commercial and services sector, which was hit hard by repeated lockdown measures towards the end of 2020. Additionally, economic prospects depend on government stimulus packages and their success in triggering new investment and supporting businesses that have experienced economic pressure in 2020.

2. European Energy Market Situation

As far as Europe is concerned, already in 2030 the ten-year development plan of the EU grid[2] foresees 58% of electricity from renewable sources in the EU mix to be tackled with 166 new grid development projects and 15 storage projects, for a total investment of 144 billion Euro, which will result in annual savings of from 2 to 5 million Euro, due to the cut in generation costs due to the greater flexibility of the system.

For example, Germany alone, will need a capacity of between 235 and 276 GW of renewable energy by 2035 (more than double the 116GW at the end of 2018) and over the next few years German Minister announce they have to build over 7,500 kilometres of transmission networks, including strengthening of interconnectors with European neighbours.

The electricity grids will therefore have to equip themselves to instantly convey the production of energy from the wind and the sun (e.g., Baltic Sea or southern Europe)) to the areas where this electricity is needed (e.g. Rhine Valley and South Germany), even thousands of kilometres away[2].

Consequence of all this is that the energy sector is undergoing a period of dramatic change.

We need shifting power across EU from where it is not needed to where it is and electricity storage, flexible demand, interconnectors could help to cut the costs of the green transition.

Typical drivers of this phenomena are the “political” change toward green energy production (i.e., EU Green

Deal and the Biden administration's clean energy drive) as well as the differential cost of energy between countries/ areas that make viable and desirable the interchange of energy in parallel or in substitution of new generation plants.

Power generation from Renewable Energy Sources (RES) and interconnection among networks are, in fact, the two main areas where energy links is developing massively and – as such – are driving technological evolution.

2.1 Everything that requires electricity requires cables

Cable market is one of the hot sectors in the clean energy transition, as demand for products such as undersea HV lines leads to order backlogs of 2 to 5 years for cable makers portfolios.

Furthermore, the consequences of climate change that bring more frequent and intense storms, floods, heat waves, fires and other extreme events are under the eyes of all, consequently the use of underground cable networks will grow as the latter are more resistant to these climate-related risks.

Examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

2.2 HVDC Revival

HVDC cable systems are used worldwide to transit high power over long distances in situations where HVAC connections are not feasible or not economical convenient.

Another important factor for the energy transition is the implementation of a large electrical grid.

The number of HVDC interconnectors in the construction stage is larger than ever before. Also, there are many projects in progress at various preliminary stages (planning, studies etc), and they are typically very long and with higher power ratings, thus pushing voltages to new levels with new cable technologies.

Demand for interconnectors is rising as the EU and other countries work to develop more flexibility in their grid systems, boost cost border electricity trade, and connect new renewable power to the cities where it is in demand. The market for interconnectors is expected to grow 14% per year over the next decade according to different consultants.

HVDC connection in EU are mainly used as interconnectors in the Mediterranean area and both as interconnectors and connection of offshore windfarms in the North Sea (see Figure 1).

Figure 1. Example of laying activities for Submarine cables (source Cigrè TB610).

Many land and submarine interconnection projects have been presented and some have already started, such as Celtic Interconnector, Viking Link, Biscay Gulf, Cobra Cable, Monita and Dolwin3.

TERNA alone, has in its portfolio 4 very important links in the near future: Adriatic Link, SACOI 3, Tunisia Link and Tyrrehenian Link (see Figure 2).

Figure 2. Tyrrhenian Link proposed three circuits for Submarine cables (source TERNA).

Another big area of growth for cable makers will be the US, where several large offshore wind projects are under way on the East coast and wind development is expected to accelerate under the Biden administration.

3. Electrical Power System Complexity

Power supply systems have become increasingly complex, consequently rising the demand for different types of laboratory tests. At the same time, there is an increasing number of requests for "non-standardized" tests on objects such as HVDC valves, AC&DC cables, line insulators, cable accessories, etc.

This trend is mainly due to network equipment often exposed to service conditions not covered by design and type testing, but another factor is that requirements set out in some of today's standards are often regarded by Utilities as not stringent enough to reflect what actually occurs in the field. The a.m. point of view has resulted in longer-lasting tests, new test methodologies and more demanding pass/fail requirements.

Non-standardized tests impose special requirements not only on the capabilities of the testing personnel and the instrumentation used, but also on the test methods that will be subject to agreements between the Test Laboratory and the Customer (so called tailored test) , without forgetting also the test equipment itself, which must be flexible and easily movable although it can also be huge.

3.1 An Example of Tailored Tests: The GTSO Project

In particular, the German Transmission System Operators (GTSO), in the frame of the *Energiewende*, was looking for the first set of cable manufacturers able to supply at least 3000km of 525 kV DC extruded cables systems.

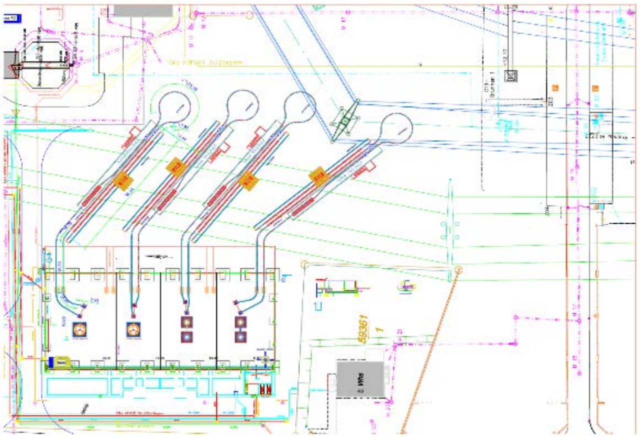

Figure 3. Example Layouts of 525kV PQTs.

In order to fulfil this need, an ad hoc qualification process was established by GTSO (Type Tests and Pre-Qualification Tests) where CESI was deeply engaged and 4 cable loops were under test in FGH[3], (see Figure 3).

For the first time ever for HVDC cable systems, the cable loops of the PQT were not tested on the floor of a laboratory[4] but mainly underground, representing real network situations like urban tunnel, pipelines and joint bays[5], (see Figure 4).

Figure 4. Picture taken from FGH layouts of 525kV PQTs.

4. Challenges for the Lab and Needs for Further Developments

The positive test experience acquired using a real layout during the execution of the PQT, according to the request of GTSO to be performed for the first time on extruded cable systems at 525 kV DC, has however revealed a remarkable complexity and efforts in all phases of tests.

In order to ensure the required reliability of the test results, particular attention was paid to all aspects relating to the preparation of the layout, the procedure and methods of testing, the final verification tests and the validation of the results.

Inter alia, attention was paid to measuring the temperature in the circuits and to the application of the final superimposed impulses. For these latter aspects, the present prescriptions of[4–6] give ample space to different interpretations.

Furthermore, the visual inspection that must be performed after the electrical tests as per the same documents, suffers of a lack of clear instructions.

It can be said that the PQT procedure on HVDC cable systems needs further standardization works, as detailed in[7]. We can summarize that the main attention has to be paid to:

4.1 Distributed Temperature Sensing (DTS)

To increase the reliability of test results, a DTS measurement should be used to support the laboratory in discovering weak points of the set-up.

Additional information can be collected to identify temperature hotspots at unexpected locations to avoid overheating of the cable by using a DTS (Distributed Temperature Sensing) measurement system based on optical fibres casted inside of the cable sheath or wound on the outer surface of the cable.

4.2 Final Superimposed Impulse Test

After the end of the cycles, the superimposed impulse voltage test concludes the electrical part of the PQT. While on AC cables only an impulse test has to be carried out, on XLPE DC cables the test has to be carried out with DC voltage permanently applied and the impulse voltage superimposed. As the GTSO required the final superimposed impulse test to be applied to the whole cable loop, the impulse generator must have sufficient impulse energy and charging voltage to reach the required test voltage values.

The standard for the impulse tests[8] prescribes to adopt a test circuit in which the impulse generator is connected to the DC source either by a spark gap or by a coupling capacitor.

Both procedures have their advantages and disadvantages. Anyway, there is no clear indication if one of the procedures stresses the cable more than the other.

We have chosen the coupling capacitor solution, see Figure 5, in order to avoid to discharge the energy of the cable into the impulse generator.

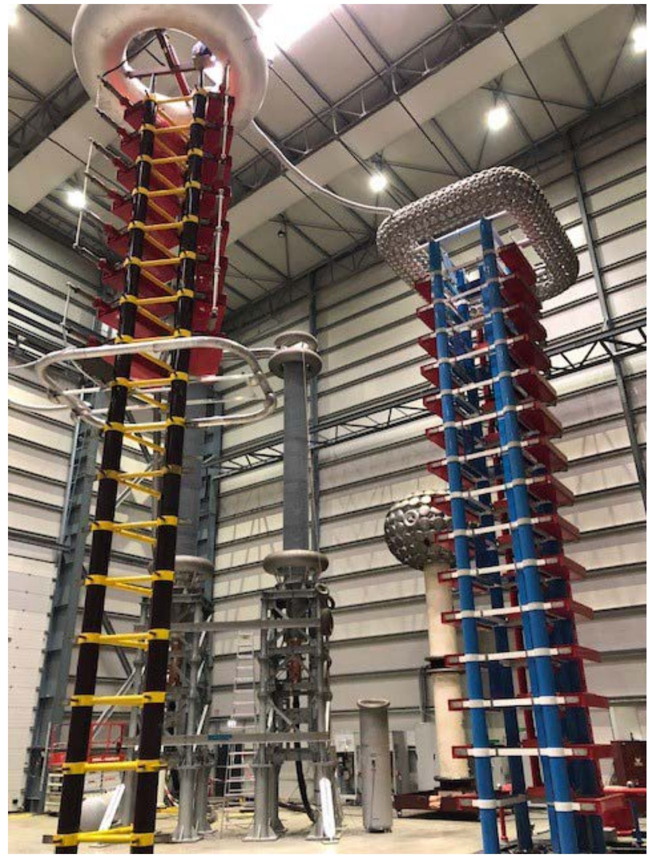

Figure 5. Picture taken from FGH layouts final impulse tests.

5. Late Demands from Utilities

5.1 Polarity Reversals

The extruded HVDC cables, now required by the main European utilities[9], have been qualified for both LCC and VSC applications: this means that the insulation is able to withstand polarity reversals like paper insulated cables, further proof of the advantages of these updated solutions, see Figure 6.

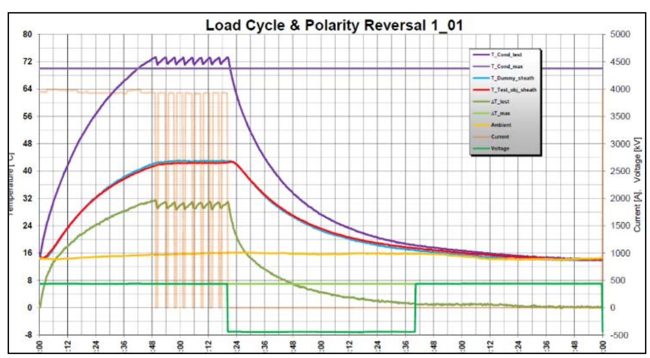

Figure 6. Example of Polarity reversal test.

To be able to carry out polarity inversion tests, it is necessary to be equipped with HVDC generators capable of performing a complete inversion sequence in a maximum time interval of two minutes and repeat it each one or two hours for a large number of such inversions over time, for example 1000.

This request derives from the need to verify the possibility of reversing the flow of energy circulation in the event of varying needs of adjacent markets (renewable or economic issues).

5.2 Transient Over Voltages (TOV)

Type and development tests are so far carried out on a range of equipment and components exposed to different types of HV transients during service. Such tests involve creation and application of different types of transient overvoltages.

Recently, there is also a growing requirement coming either from equipment manufacturers or from grid operators.

These requests are for enhanced capability to withstand electrical transients, giving higher confidence for all transient phenomena occurring in HVDC schemes such as during pole-to-ground fault, pole to pole fault, faults on AC side etc.

In case of failures in an HVDC cable grid two categories of overvoltage stresses are expected to occur. Zero-crossing damped oscillatory discharges in the failing pole and a very slow long impulse dynamic voltage stress, see[9]. Very slow means significantly slower compared to standard switching impulses in comparison to standard test setup as could be seen in relevant CIGRE and IEC standards.

Recently KEMA Labs Mannheim laboratory was requested to perform a feasibility study on the possibilities of setting up test circuits that could enable laboratory testing of full-scale HVDC cable systems up to 525 kV. The aim was to verify the performance of the HVDC cable system to withstand these dynamic voltage stresses, which are of non-standard nature.

Slow impulse type dynamic voltage stress on both polarities must be considered for pre-charged DC zero-crossing damped oscillatory discharge test as well.

Both categories of stress profiles will be briefly explained in the next clauses.

5.2.1 Zero-Crossing Oscillatory Discharge Test

This test can be described as an oscillating discharge of a pre-charged capacitor. Since not a complete cable length can be tested in the laboratory, the oscillation has to be generated by including a lumped inductance into the circuit. Figure 7 shows a simulated example of the expected test voltage and Figure 8 an example of test set-up.

Figure 7. Example of the expected waveform.

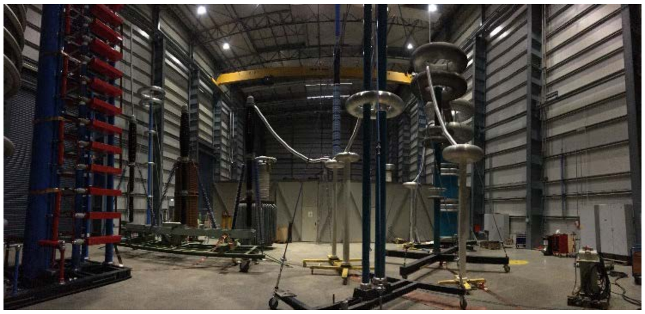

Figure 8. Example of a Laboratory set-up for the zero-crossing damped oscillatory discharge test.

Currently the following waveforms have been requested, see Table 1

Table 1. Requirements

Waveform type	High-frequency	Low-frequency
Frequency	> 5000 Hz	< 400 Hz
First peak	1 p.u.	> 0,5 p.u.
No. of oscillations	> 14	> 5

5.2.2 Slow Impulse Type Dynamic Voltage Test

In first attempt this test can be regarded as a very slow impulse voltage which is superimposed to the pre-charged DC voltage. So similarities might be found to a superimposed switching impulse voltage test as described[4,6].

The waveform corresponds to the voltage in the non-failed pole[9], an example is shown in Figure 9.

Figure 10 shows the expected test voltage and the parameters for a same polarity test in a more formalized way to explain the expected parameters.

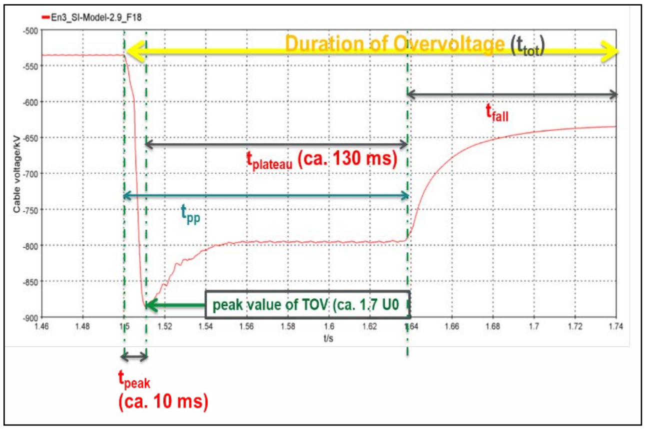

Figure 9. Example for the slow impulse type dynamic voltage

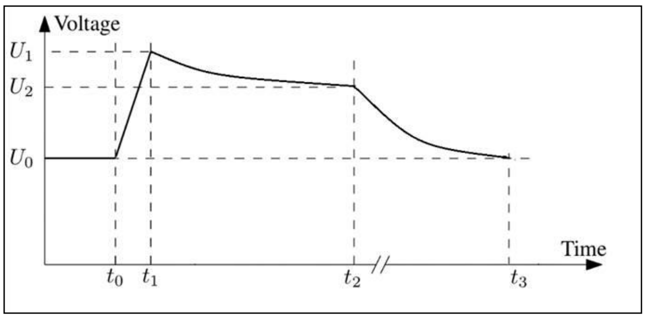

Figure 10. Example for test parameters in use.

Referring to Figure 10 it is clear that not a real curve is shown, since parts of the curve are physically impossible and the time axis is not linearly scaled. Table 2 shows some parameters that are expected for the test voltage:

Table 2. Requirements

U0 Rated Cable Voltage	525 kV
U1 Peak voltage	1,7 U0 – 1,8 U0
U2 Plateau voltage	1,5 U0 – 1,6 U0
t1-t0 Time to peak	60 µs – 10 ms Lower values for opposite polarity, higher values for same polarity
t2-t1 Time of plateau	100 - 200 ms Lower values for opposite polarity, higher values for same polarity
t3-t2 Cable discharging	Depending on the discharging system: 30 s (ground switch) > 10 min (passive grounding through the converter cell resistances)

Figure 11 shows an example of test set-up.

Figure 11. Example of a Test set-up for the slow impulse type dynamic voltage test.

Since already a number of specifications with different values for the voltage magnitudes and time parameters have become known it seems necessary to define the requirements in case it is intended to standardize this test, e.g., tolerances on test parameters must be provided.

The laboratory tests have produced an amount of test results, which give the background for simulation. Basing on the fact, that the basic frequency of the investigated waveshape is rather low, a very basic simulation model can be used to study and to verify effects of the change of components within the circuit.

Furthermore, KEMA Labs, who is fully engaged in this project in different areas, considers very important that the required impulses shall be produced in typical HV cable testing laboratories without excessive efforts.

6. Conclusion

In a changing electrical market, driven by renewable energies, the target is to get wind or solar energy to the consumption centers, transporting energy over thousands of kilometers.

Typical designs for power distribution and transmission systems are overhead power lines and/or insulated power cables (more and more in use) with increasing length. The latter are characterized by large capacity and long distance and enjoy remarkable advantages when employing HVDC transmission technology.

Interconnectors using HVAC cables are currently limited to lengths of approx. 100km, with established technologies, HVDC solutions are more and more preferred not only for submarine cables but also for land applications especially for long distances.

The request of German TSO's not to test on the floor of a laboratory but to have a replica of a real underground network layout, with 525 kV DC cables and accessories to be able to withstand each specific environmental installation peculiarities, has greatly increased the level of complexity of the long-term tests, both for the in test modalities and the management of the tests themselves.

Further requests coming from the market (cable manufacturers and utilities) were recently presented to the test laboratories in order to verify the performance of the HVDC cable system to withstand dynamic voltage stresses, which are non-standard in nature (e.g. polarity reversals and TOV).

With the appearance of technical specifications with different values for voltage quantities and time parameters, it seems necessary to define the requirements in the event that it is intended to standardize these new types of tests, e.g. tolerances on test parameters must be provided.

Furthermore, KEMA Labs, who is fully engaged in this project in different areas, such as standardization bodies, joint Cigrè working Groups, testing procedures development and so on, considers very important that the required impulses shall be produced in typical HV cable testing laboratories without excessive efforts.

7. Acknowledgment

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