Water Propulsion Cable Laying and Non-destructive Commissioning of Power Cables

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ABSTRACT

This contribution supports modern distribution power companies in their optimization demands on flexibility, effectiveness in installation and reliable quality assurance of newly installed power cable networks.

This paper presents a combination of two technologies, innovative cable installation by water propulsion as well as non-destructive sensitive after-laying testing using the damped AC technology that have been used for distribution power cable networks.

KEYWORDS

Distribution power cables, innovative installation by water propulsion, non-destructive after-laying testing by PD monitored damped AC after-laying testing.

INTRODUCTION

Continuous grow of the electrical infrastructure and higher demands on the reliability of power cable networks trigger industries for providing modern, cost-optimal and less harmful solutions for both the power cable installation and the quality assurance.

It is known that regarding the installation, the latest technological innovations of using water propulsion, a declination of jetting-techniques as a cable laying process has to be considered.

The main advantages brought by this method are the higher security in the cable installation while needing fewer operators, a reduction of the number of connections and the cost of civil work.

The easiness of handling the equipment due to its compactness, its mobility confers superior safety during the installation while laying the cable with high speed will be discussed.

Fig. 1: Examples of (a) Watucab (WAter TUbe CABle) technology used for the cable installations and (b) Damped AC Voltage (DAC) system applications for commissioning newly installed cable systems.

Regarding the quality assurance after the installation non-destructive, sensitive commissioning of installed cable networks the use of PD monitored voltage withstand testing e.g., using damped AC (DAC) methodology is known. In particular, the commissioning the damped AC technology provides quality assurance of the newly installed cable circuits. By means of partial discharge (detection and localization) and dissipation monitored non-destructive voltage site acceptance tests the quality of the installation has been verified and a „finger print" has been generated for condition-based maintenance during operation.

In this contribution supported by practical applications a combination of both innovative installation as well as non-destructive sensitive after-laying testing will be presented, see fig. 1.

POWER CABLES INSTALLATION USING WATER PROPULSION

The traditional way to install cables into ducts is pulling them with a winch. For this, first a pulling rope has to be installed. Also, installation equipment and people are required at both ends of the duct. Furthermore, the capstan effect (friction of the cable under tensile load in bends) limits the cable lengths, which can be installed in one pull. Synchronization between winch and drum pay-off is often troublesome.

Three new techniques have been developed to install energy cables into ducts. They are known as Watucab (WAter TUbe CABle) [1-10] and are using the floating-, water-push-pulling- and free-floating techniques.

Floating

With the first technique, called Floating [1-5], water under pressure is injected into the duct together with the cable, creating a high speed (higher than the cable speed) water flow, while at the same time the cable is pushed into the duct (and pulled from the drum). The high-speed water flow creates a distributed drag force propelling the cable. This distributed force locally compensates the friction between cable and duct, avoiding axial force build up in the cable, hence eliminating the capstan effect. The same trick as with cable blowing, a technique used worldwide today to install optical cables into ducts.

The additional beneficial effect with floating is the buoyancy of the water, reducing the friction between cable and duct. With this technique extremely long installation lengths can be reached (with Low Voltage cables already 10 km has been reached, and with optical cables up to 12.4 km), also in trajectories with many (preferably smooth) bends.

Moreover, there is the benefit of single point entry (installation equipment, cable drums and people), see fig. 2, reducing operation and labour costs considerably. The technique is user and cable friendly (low forces, no cable wear) with compact equipment and does not suffer from synchronization problems with the cable drum. With the present equipment a comfortable cable speed of 15 m/min can be reached.

Water-Push-Pulling

The second technique, called Water-Push-Pulling [1-9], is mainly the same as the floating technique, except that a pig is mounted at the head of the cable, see fig. 2. Now all forces exerted by the water under pressure are concentrated at the cable head and the water flows with the same speed as the cable. The latter makes it possible to use still relatively small pumps for larger diameter pipes (e.g., larger than 100 mm internal diameter).

The relatively high pulling force at the cable head also enhances passing sharp bends. However, the capstan effect is back again. Fortunately, pipe trajectories for energy cables are rather straight and buoyancy has not vanished. With balanced pushing and pulling forces (still lower than with winch pulling) installation lengths can also be very long (3.3 km reached with cables with aluminium core), usually much longer than with winch pulling.

When using a so-called "sonic head" (a pig with valve that opens at adjustable pressure) the advantages of Floating and Water-Push-Pulling can be combined and optimized to the pipe trajectory. Even when the latter is extremely curved, containing small bend radii, installation is still possible (an 82 mm 3x36 kV cable could be installed over 646 m into a HDPE pipe with internal diameter of 102 mm which was wound in 46 coils with a continuous bend radius of 2 m).

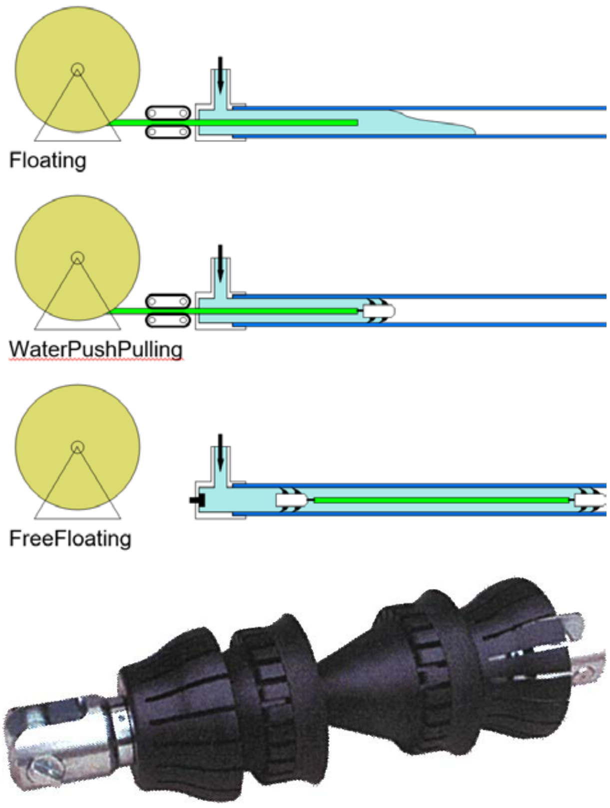

Fig. 2: Laying underground power cables in ducts using floating-, water-push-pulling- and free-floating methods (top) and the pig that is connected to the cable for water-push-pulling and free-floating (bottom).

Free-Floating

The third technique, called Free-Floating [3-9], is maybe the most appealing one. It starts after a cable has been entirely installed by Water-Push-Pulling, with a special pig used. Then the pipe is extended at the entry side such that the cable is entirely inside, and with some space to insert a rear pig, see fig. 2. Next, the pipe is closed and water under pressure admitted. The rear pig is "communicating" with the front pig such that they share the water pressure.

In this way, the cable is effectively Push-Pulled by the sole action of water, and travels further like "tube post". The cable can be placed at any desired location. There is in fact no limit on how far the cable can be transported, as the water pressure difference is mainly effective at the pigs. There might be some viscous pressure loss over the feed length of pipe, but this can be reduced at wish by reducing the cable (and water) speed. In fact, higher cable speeds are reached with Free-Floating (28 m/min is the current record, theoretically speeds up to 60 m/min are still safe) than with Water-Push-Pulling, when the pipe is not too narrow and not too long.

EXAMPLES OF CABLE INSTALLATION

The Watucab technique has been used in several projects, both on land and offshore. In most cases the Water-Push-Pulling technique is used, on land, and single cables are installed in single pipes [1,2,3,4,5,9], see fig. 3.

It is also possible to install 3 cables in one pipe, as was done in France [1,2] and in 2 projects in Poland (in Kamien Podorski and Katowice), see fig. 4.

Fig. 3: Installation of a single cable phase in a single duct with the Watucab technology

The first Free-Floating trial was done in France in 2011.In Denmark several Free-Floating projects have been done, in Copenhagen [8,9] and Thyborøn [6-8], the latter also an offshore project. Here individual inter-array cables between the different offshore wind turbines were send from land by Free-Floating to their final position between the turbines. This was still done in rough weather conditions (wind speed of 8 Beaufort) where offshore cable installation would not be possible in another way. In the project at Thyborøn also 2 array cables were installed from a vessel, not because it was needed but just to show that this was another possible solution. All 3 methods (Floating, Water-Push-Pulling and Free-Floating) were tested in this project.

Fig. 4: Installation of 3 single cable phases simultaneously in 1 duct, a special adapter with three inlets installed on the duct (left). The three cable pushers are synchronized with each other to install with equal speed the three (right).

In [8] the limits of Free-Floating were discussed. There is no limit for the distance over which a cable can be transported by Free-Floating. In extreme cases the pressure loss of the flow through the pipe can always be limited by selecting a limited cable speed. But, in most cases high speeds are possible. As long as the speed is not higher than 60 m/min no accidents can happen. The forces at the cable at a sudden stop were calculated with a theory analogue to that of a water hammer.

Prior to each project a feasibility study will be performed where a simulation is done on the forces that will act on the cable. In this study is also the amount of water that is needed to float in the cable and the amount of water flow is calculated.

Fig. 6: Monitoring of the installed cable length and installation speed during the installation of a 3200-meter-long cable

In fig. 5 an example is shown for this study on a MV cable with a trajectory length of 3.2 km. It can be seen that the axial forces on the cable at the end of the trajectory are increasing, but will stay below the maximal force on the pig, which is required for the installation. During the installation of the cables, the total installed length and the installation speed is continuously monitored, see fig. 6. Furthermore, the water pressure and the water speed are monitored during the installation process.

NON-DESTRUCTIVE TESTING BY DAMPED AC VOLTAGES

Damped AC (DAC) is a technology that is more than 20 years commercially available for testing all types of distribution cables [11-22]. As an alternative for Very Low Frequency (VLF) and AC resonant testing (ACRT) the DAC technology has been first introduced on the Jicable conference in 1999. With DAC it is possible to energize very long lengths of power cables with high capacitance, with a low input power demand. Moreover, this technology can be combined with diagnostic measurements like partial discharges (PD). Damped AC is applicable for factory PD monitored acceptance testing and it is in use for on-site after-laying/commissioning-, maintenance-, and diagnostic testing. It is an approved testing methodology, in accordance with relevant testing parameters from international standards and recommendations (IEEE, IEC, and CIGRE).

DAC Principle

The application of damped AC (DAC) voltages, including standardized conventional PD detection and analysis, is accepted worldwide for on-site testing and diagnosis of Medium and (Extra) High Voltage power cables [11]. Sinusoidal DAC voltages (in the frequency range of 20–300 Hz) have shown equivalence compared to the 50/60 Hz network stresses and the characteristics of the applied technology meet the specification of modern on-site testing system:

1. Lightweight modular system;
2. Compactness in relation to the output voltage;
3. Low effort for system assembling;
4. Low power demand incl. long cable lengths;
5. Low level of EM noises and the possibility of sensitive PD detection and localization as well as dissipation factor measurements;
6. PD detection and localization of a complete cable system: all terminations, all types of joints and all cable sections;

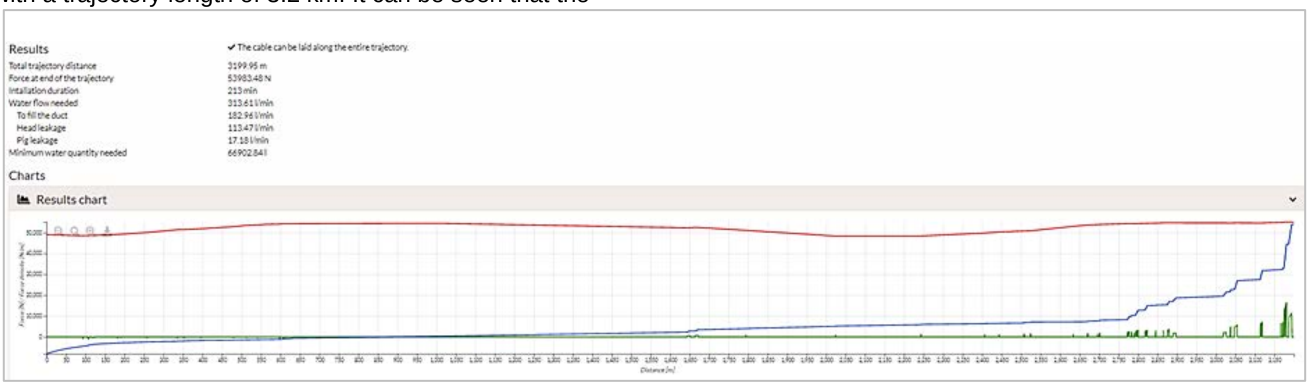

Fig. 5: Feasibility study before cable installation with Water-Push-Pulling, indicating the forces along the cable trajectory, in red the potential pulling force on the pig, in blue the axial force in the cable and in green the radial force density (side wall pressure).

DAC testing is used almost always in combination with partial discharge (PD) and dissipation factor (tan δ or TD) measurements for new installed and service-aged cables. The system consists of a digitally controlled high voltage power supply to energize capacitive load of power cables with large capacitance (e.g., 10 µF), see Fig. 7.

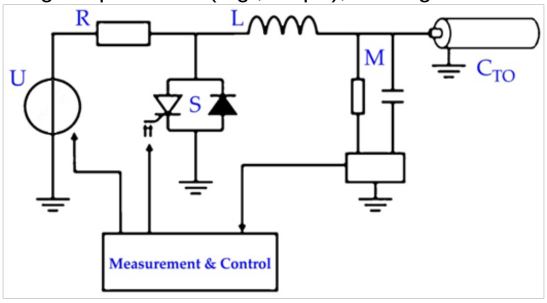

Fig. 7: Schematic overview of a damped AC (DAC) system connected to a power cable, with *U* the high voltage source, *R* the protective resistor, *S* the semiconductor switch, *L* the air core inductor, *M* the voltage divider, and coupling capacitor and C_{TO} the cable under test.

The energizing time depends on the maximum available energizing current of the high voltage power supply, the test voltage, and the capacitance of the test object and has to stay below 100 s [11].
During a number of AC voltage cycles (of several hundred milliseconds), the PD signals are initiated in a way similar to 50/60 Hz inception conditions [11-14].
In accordance with [11], no DC stresses are applied to the test object, and the DAC stress can be considered similar to factory partial discharge testing conditions, i.e., a 50 Hz AC test combined with a PD measurement.
Due to the continuous voltage increase and immediate transition to the DAC voltage after the maximum test voltage is reached, no steady-state condition occurs, and the low electric field strength in the insulation (typically below 20 kV/mm), and short durations (less than a second up to tens of seconds) of bipolar stresses, ensures that there is no space charge accumulation.
During the AC resonance phase, the DAC voltage is characterized by a decaying sine wave with a frequency given by the system inductance and the capacitance of the cable under test. Inductor values of DAC systems are chosen such that the DAC voltage frequency is in the near power frequency range of 10–500 Hz, see Fig. 8. The maximum cable length is only limited by the energizing time and the maximum current capabilities of the semiconductor switch. Therefore, DAC systems can be easily used to test cable lengths up to tens of kilometres.

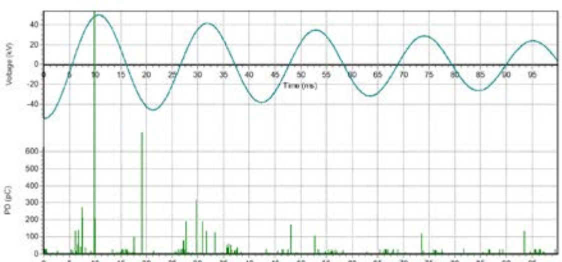

Fig. 8: Example of damped AC voltage excitations monitored by partial discharge (PD) detection. The detected PD pulses can be used to localize the breakdown site.

By applying DAC voltages, a sensitive PD detection and the PD localization of a fault in the power cables is possible. Using time-domain reflectometry (TDR), PD presences in cable terminations, joints, or cable parts can be localized and represented in a PD-mapping, see Fig. 9.

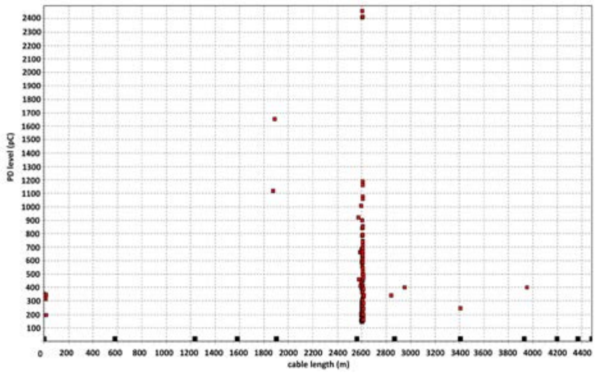

Fig. 9: Example of PD mapping as obtained from a PD monitored voltages withstand testing of XLPE cable underground circuit (4.5 km) up to 1.7 *Uo*. The PD mapping shows up to 1.0 *Uo* that joint No. 5 has concentrated PD activity at the service operating voltage level.

According to [11], to execute voltage withstand tests, this procedure should be repeated for 50 excitations followed after each on the maximum test voltage. Considering the time, from the PD initiation until breakdown and the shorter duration of the excitation and decaying characteristics of the voltage, DAC test results obtained may differ from those obtained by continuous AC withstand voltage testing [11]. Assuming that testing should not necessarily be destructive and that the PD inception indicates presence of defects, this difference in the time until breakdown has to be considered as an advantage of DAC testing. In practice, a monitored damped AC hold test is performed to determine whether the cable passes or fails the damped AC test. Due to additional information as provided by PD detection, the monitoring of the insulation properties, and the effect of the test voltage during its application can improve the evaluation of the insulation condition.

DAC Diagnostic Testing

Partial Discharge Monitored Voltage Withstand Test (PDMVW)

Conform [11] the use of voltage withstand test can be used to over-stress the cable system and to see if during the test period PD activity respectively a breakdown will occur see Figure 4. In the case of a breakdown occurrence where before PD activity has been observed the localization of breakdown can be identified by the localization of PD activities before the breakdown. [18,19,21].

Partial Discharge Measurement (PD)

With DAC a sensitive PD detection and localization of the fault in power cables is possible. Therefore, the PD monitored voltage withstand testing is a very effective method to detect most insulation weak-spots. The PD measurement can be used to pinpoint the exact location of insulation defects at an early stage [12-14], by means of time-domain reflectometry (TDR). With TDR, the PD presences in cable terminations, joints, or cable parts can be made, as shown in Figure 9.

Dissipation Factor Estimation (TD)

DAC systems are able to estimate the dissipation factor from the damping of the decaying sine wave during the LC resonant phase [11,12]. The degradation of oil-impregnated insulation of HV power cable can be investigated with this parameter.

Applying DAC voltages at different testing voltage levels can provide the change in the dissipation factor (delta TD, figures 5b and 5d) in relation to the increasing voltage. This can be especially valuable for finding insulation ageing development in power cables [11,20], see Fig. 10.

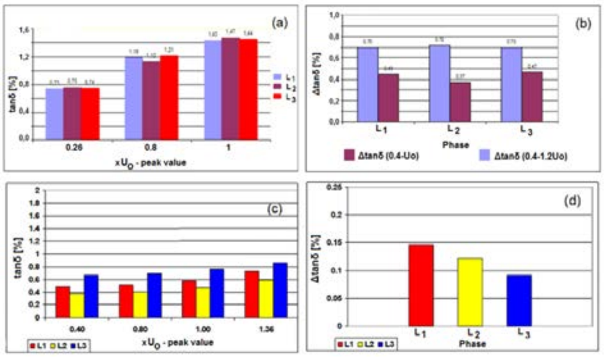

Fig. 10: Example of dissipation factor diagnosis data as obtained for two different cable circuits: (a, b) A 150 kV power cable with self-contained fluid-filled (SCFF) insulation, length: 850 m, service age 49 years, (c, d) A power cable with low-pressure fluid-filled (LPFF) insulation, length 13.3 km, service age 33 years.

EXAMPLE OF CABLE COMISSIONING

After-laying Test of a 30 kV Cable Circuit for an onshore windfarm

After the completion of the 30 kV circuit that connects several wind turbines to the substation an after-laying test has been performed. The total circuit length is 9.8 km long with a cable capacitance: of 2.5 µF per phase). The DAC test frequency was 68 Hz, which is within the recommended power frequency range from 20 - 300 Hz.

Fig. 11: Test setup with the DAC system mounted in a test van and connected to the 30 kV T-connector termination by a test adapter.

No PD activity was detected during the ramp-up test and during the withstand test in all three cables up to the maximum test voltage of 2 Uo. In fig. 12 is the phase resolved PD pattern shown. Only the external noise level of approximately 50 pC is visible at the highest test voltage level and no internal PD has been detected, which could be confirmed by the TDR analysis.

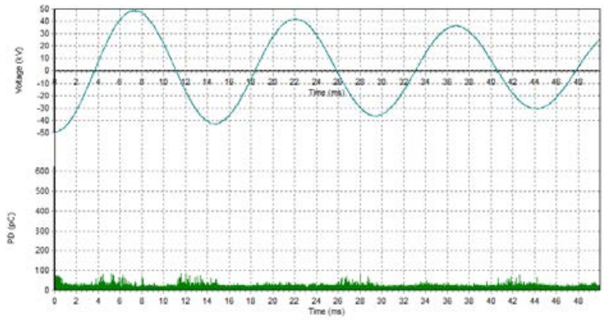

Fig. 12: Phase resolved PD pattern as observed during the test, no PD activity above the background noise level of 50 pC has been detected.

The PD mapping is a graphical representation of the cable length that shows the concentration of the localized PD pulses along the cable length, see Fig. 13. As all three phases of the cable successfully passed the test, i.e., no breakdown and no PD activity found up to the maximum test voltage level, the cable was successfully energized into service operation.

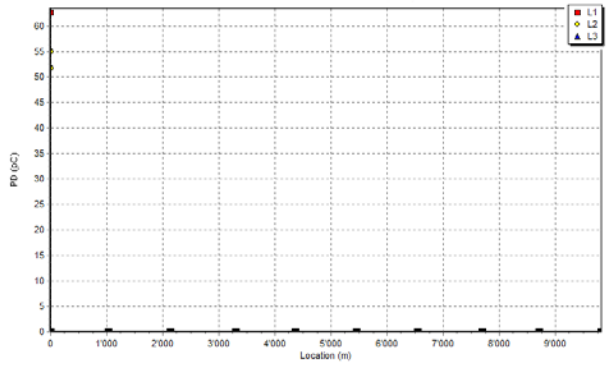

Fig. 13: PD mapping showing the overall cable length versus the PD concentration, no concentration has been found. The black dots represent the joint locations

CONCLUSIONS

In this contribution important aspects of advanced installation and dedicated after-laying testing have been presented.

A new method for installation of energy cables in pre-installed ducts has been developed and successfully applied. The method is applicable for ducts with an outer diameter superior to 60 mm. The main benefits gained from this innovation are:

1. With the three discussed technologies it is possible to install longer installation lengths in one step saving on expensive joints and longer installation times.
2. The technology provides a one-step installation process.

3. During the installation the overall control of the installation process is required at the cable-drum side only enabling easy and visual communication between the active parties, thus avoiding unnecessary hazards.
4. Increased protection of the overall cable integrity during installation.
5. Faster and less costly installation.
6. Due to the reversible installation process relatively easy network upgrade in the future is possible.

Regarding the presented cable testing technology, the following can be concluded:

1. PD monitored electrical testing on-site is an important step of quality insurance of new/repaired and service aged cable systems. Actual knowledge of the condition of power cable systems may support the network managers to obtain a fingerprint of new installed cable section
2. Combining voltage on-site testing e.g., damped AC voltages with PD detection provides information about discharging insulation defects. Moreover, it can be assessed, if the on-site test had a destructive impact on the insulation system.

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