New approach to installation of offshore wind energy cables

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ABSTRACT

To reduce costs for offshore wind parks, a method to installing non-armoured MV and HV cables into PE pipes has been developed, alternative to direct installed armoured cables. Pipes are sunk by filling them with brine. After they are in safe position, the cables are installed by floating with the same brine. Surprisingly long lengths (>10 km?) can be reached. Impact test were done to prove the excellent cable protection by the pipe. Trials (shore and semi offshore) are described, also performing Intelligent Pigging. Stop-and-go tests (12 days) demonstrated the ability to install (from land?) long cables with vulcanized joints.

KEYWORDS

HV/MV cable installation; Pipe; Floating; Pushing; Water; Pressure; Pig; Intelligent Pigging; Offshore; Wind Energy.

INTRODUCTION

To reduce costs for subsea power cables in offshore wind applications, an alternative cable installation method has been developed. Instead of armoured cables, PE pipes are laid on or trenched into the seabed. The pipes are sailed out first, next their ends are brought into position at the Transition Pieces (TPs), using telescopic risers with bend restrictors, and finally sunk, simply by filling them with high salinity water (brine). The pipes, not showing a preferred torsional direction, have less risk to kink. And when damaged they can easily be repaired. Only after the pipe is safe in position, a non-armoured "land" cable (less costly, better availability) can be installed into the pipe, even offering better protection than armouring, because of the free space (well-known in telecommunications [1]).

Installation of the cables in the preinstalled pipes is done by the floating technique, using the same brine. Surprisingly long lengths can be reached: 3 km standard for energy cables, 10 km already reached with optical cables, in the future, with tuned density of cable and brine, maybe 100 km possible (for single phase cables "pipe installable" vulcanized joints can be used)? Floating installation can be done from a vessel, maybe even from shore. The compact installation equipment also allows pre-installing cable and equipment inside the TP. This system can with minor modifications be applied to other foundation types, e.g. gravity- and jacket-foundations.

In this paper the system of the non-armoured cabling in pipe is described, as well as the telescopic risers with bend restrictors to bring the pipe into position. Cable details and the vulcanized joint, which can pass through the pipe, are presented. Different techniques to install the cable in the pipe are discussed, of which floating is the most practical. Furthermore Intelligent Pigging of the pipes is treated, offering the possibility to map the pipe trajectory after the pipe is in position (before the cable is installed). The claim of better protection of the cable in the pipe is supported by impact tests performed on some (armoured and non-armoured) cables and pipes.

Trials at Lindø, DK (onshore) and Thyborøn, DK (semi-offshore) are described. In the latter trial sailing out of the pipe, functioning of the telescopic risers with bend restrictors and pipe sinking were evaluated. Different array cables (82 mm 3x300 mm^2 Alu in 125/102 mm pipe) and export cables (60 mm 1x630 mm^2 Alu in 90/80 mm pipe) were installed with lengths of about 1 km, with water push-pull and floating techniques. Vulcanized joints were tested to pass installation device and pipe. Intelligent Pigging was done to evaluate the installed pipe trajectory. Stop-and-go tests were carried out in Kalundborg, DK, during 12 days, to check whether cable in pipe installation can be started up after waiting during production of a vulcanized joint. Also thermal (cooling) behaviour is discussed. Finally, calculations have been done on what is possible with cable in pipes: installation of density tuned export cables over lengths >10 km, from land? Installation of even array cables from land, using FreeFloating?

BEND RESTRICTORS

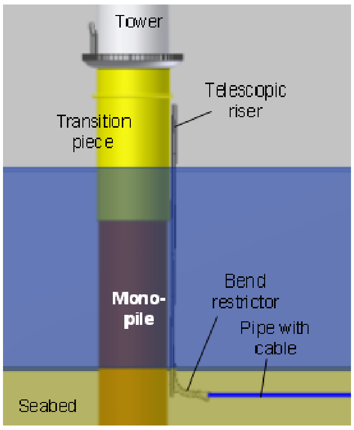

Fig. 1: Mono-pile with bend restrictor

A special telescopic riser has been developed to install pipes from the Transition Pieces (TPs), avoiding J-tubes. Specially designed bend restrictors bring the pipe into position near the feet of the mono-piles at seabed level.

CABLE

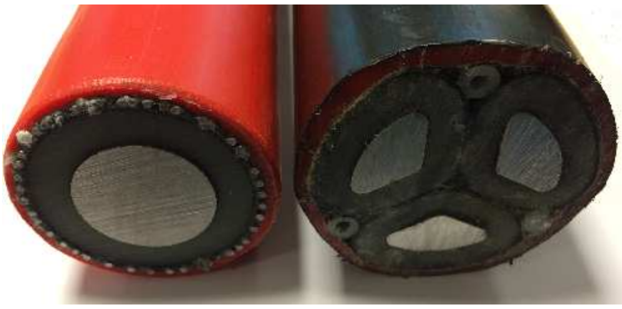

Fig. 2: Cables

Cables used: 1) 3x36 kV array 82 mm cable (between turbines) with 3 solid 300 mm^2 Alu cores, 6.42 kg/m, in 125/102.6 mm PE pipe and 2) 1x72 kV export 60 mm cable (from wind park to shore), with 630 mm^2 solid Alu core, 3.9 kg/m, in 90/79.8 mm PE pipe.

INSTALLATION CABLE IN PIPE

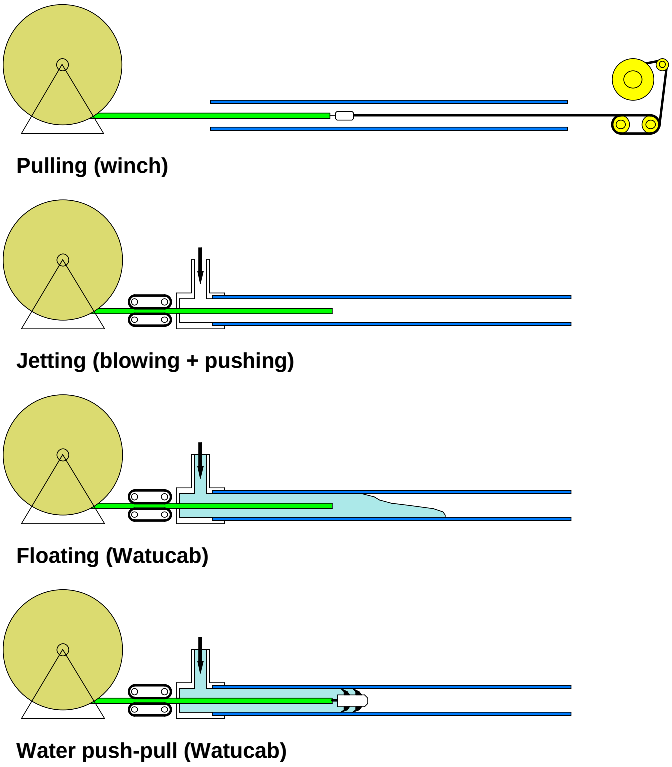

Fig. 3: Cable-in-pipe installation techniques

Pulling (winch)

Power cables are traditionally installed into pipes by pulling. Here first a winch rope is installed. Labour and equipment are required at both sides of the pipe. Pulling force is built up by gravity friction (cable weight) and capstan friction (sidewall forces generated when the cable is pulled, under tensile force, through bends) [2]. The latter effect is causing an exponential force build-up, usually the major effect that determines the length of a pull (order of 1 km). These sidewall forces also cause wear of cable and pipe, determining the allowed minimum bend radius of a bend [3-5].

Jetting (blowing + pushing)

In telecommunications the technique of jetting (not to be confused with jetting a cable into the seabed), a synergy of pushing and blowing, was developed as an alternative to pulling [2]. The distributed propelling force of a high speed airflow compensates gravity friction locally, eliminating build-up of tensile forces in the cable, hence getting rid of the capstan effect (when tensile force gets high, so does radial force and friction in pipe bends). This trick worked well. Not only installation lengths increased (3.6 km reported), also installation was made possible in tortuous trajectories. And installation is also much simpler, because no winch rope needs to be installed and equipment and labour are all at one side of the pipe.

Floating

Instead of air, also a high speed water flow can be used to propel the cable, a technique called floating (a WATUCAB = WAter TUbe CABle technique) [6]. The uplift working of water reduces gravity friction, further increasing the distance reached (12 km reported). The technique can be used for both telecommunications and power cables. When matching cable and water density (by making the cable lightweight, or by making the water heavy, e.g. by using brine) extreme distances (100 km?) will be possible. For this the last friction contributor, the effect of cable stiffness in bends and undulations, must be minimized.

Water push-pull (WATUCAB)

Fig. 4: Cable installed by water push-pull

When using large pipes (HV cables) the flow resistance might be too small to allow pressure build-up (needed for successful floating) by the pump (except when using high capacity pumps). This problem is solved by using a pulling pig (using water pressure) at the front end of the cable [3-5]. The force is concentrated at the cable head again and the capstan effect returns, reducing installation length. But, still lengths of 3.3 km have been reached with this water push-pulling technique (also WATUCAB) [3-5]. When techniques are improving (lower coefficient of friction and density matching), floating becomes also feasible for larger cables, and longer (>10 km) lengths.

Advantages WATUCAB over pulling

With floating and water push-pull techniques longer lengths can be reached than with pulling, while the initial step of installing a winch rope is not needed. Also all equipment and operation is at one side of the pipe. For both floating and water push-pulling the forces in the cable are smaller than for pulling, reducing wear of the cable (no wear seen at all!), which is further minimized by the cooling working of water (wearing goes with heating up cable and pipe). This allows tighter bends in the pipes.

INTELLIGENT PIGGING

Fig. 5: Intelligent Pig

Intelligent Pigging is a method whereby an Intelligent Pig - a tool housing minimum 3 gyroscopes, battery pack and data recording - is pumped or dragged through a pipe with purpose to detect and ensure that the pipe has no impacts and with purpose to determine the trajectory of the pipe. For alignment 2 sets of 3 wheels under spring load are used. The Intelligent Pig is usually pulled through the pipe. For this application it was attached behind the cable pulling pig which was pumped through the pipe by means of brine (same as used for sinking the pipe). Calibration of the recorded trace, with vertical sections at start and end and the 180° turn midway to the start position (as in the Thyborøn trial), was new but did not cause a problem.

The perspective of performing the Intelligent Pigging operation prior to cable installation is: 1) the pipe can be controlled for impacts, 2) the pipe can be controlled for minimum bending radius and 3) the trajectory can be determined before or after trenching in seabed which ultimately may eliminate need for and thereby reduce cost for as built and inspection surveys significantly

IMPACT TESTS

Test pieces comprising cut lengths of pipe and/or cable were subjected to a single blow by a falling striker (10 kg, with nose of 12.5 mm bend radius) from a height of 3 m onto random positions around the circumference of the pipe/cable. Quite some damage was seen in case of a “bare” non-armoured cable. The pipe prevented for this damage (no visible damage). Also tests were done on “bare” armoured cables. The armouring wires were seriously affected, while the cables inside showed little marks (wires pressed into insulation screen), although the cable is judged as still functional.

Fig. 6: Impact test on unarmoured cable in pipe

LINDØ TRIAL

Fig. 7: Cables installed in Lindø trial

The first trial to evaluate the feasibility of subsea power cables for offshore windparks was done at the Siemens Windpower site Lindø at Munkebo, DK, in 2012. Two cables were tested: a 82 mm, 3 x 300 mm^2 Alu (36 kV) array cable in a 125/102.6 mm PE pipe and a 60 mm, 630 mm^2 (72 kV) kV export cable in a 90/79.8 mm PE pipe. Both pipes were laid flat on the test field, but with 2 bends of 90° (bend radius 5 m) to simulate 50 m vertical risers (from sea bottom to connection in turbine) at both ends. The trajectories were 904 m and 1037 m long, for array and export cable, respectively. The pipe trajectories were made by coupling 100 m sections (from coils). This left some curvature, which was minimized by putting the pipes under a load in the order of 1000 N.

Fig. 8: Pipe couplings (every 100 m) in Lindø trial

The array cable could be installed, with effort: water push-pulling with pushing force 8000 N, water pressure 8 bar, additional winch pulling 4000 N and the bend at the end taken away. The semi-conducting (containing graphite) sheath, extruded over the cable´s outer jacket (for fault localization; when the cable is surrounded by sea water, such a sheath is not needed anymore) caused a high coefficient of friction between cable and pipe (measured 0.19, lubricated, much higher than the value of 0.09 measured for standard PE sheath of the export cable).

The export cable was much easier to install, without the need for winch pulling assistance. The cable could also be floated, with pushing force 4000 N and pressure 4 bar. As it is claimed that floating can be done in very tortuous trajectories (only limited by tight bends), each new test more curves and loops were added at the end of the trajectory. In test number 6 the total number of bends (bend radius 5 m) was 1x90° plus 5x180°, plus 2 full loops of 360°. This did not change the installation performance.

Fig. 9: Pipe windings and loops in Lindø trial

It was also tried to install the cable with a vulcanized joint into the pipe. This makes the cable locally 5 mm larger in diameter, so it could not pass the seals in the current WATUCAB equipment. This was solved by opening and closing the equipment (in the future the equipment can be adapted to make this process easier). The vulcanized joint did not influence the installation performance.

Fig. 10: Cable vulcanized joint

THYBORØN TRIAL

Fig. 11: Overview semi-offshore trial

In the summer of 2013 a trial was done in Thyborøn, DK, with a 82 mm array cable like the one of the Lindø trial, now with normal PE jacket. The duct was also the same as in Lindø, only a bit more thick-walled (inner diameter 102.2 mm) and longer (the entire length delivered on 1 Jumbo drum). Installation was done from the quay side of the local harbour (10 m deep), in order to simulate installation from and to an offshore wind turbine, including the functioning of the bend restrictors. Instead of a point-to-point connection, the pipe was installed in a loop, returning next to the point of departure. To allow freely passing of ships, the loop could not be made longer than 680 m (usual distance between wind turbines). The loop was intended to be 20 m wide, in order to get a bend radius of 10 m (this was not the case, see Intelligent Pigging). The bend restrictors were developed with bend radius of minimum 2.5 m (middle of bend restrictor, relaxing to larger radius at the ends of the bend restrictor; again different values found with Intelligent Pigging).

Fig. 12: Pipe supply on Jumbo drum

Fig. 13: Sailing out the pipe from the Jumbo drum

Pipe installation

The pipe was sailed out using a small boat. Halfway it was anchored by ropes before the boat returned (to make the loop) to its starting position (only relevant for this test).

Both pipe ends were pulled into the bend restrictors by a rope. They were then lowered until touching the seabed. Later it was found that the bend restrictors were 1 m too high, detected by Intelligent Pigging, confirmed by divers. This was solved by lowering the bend restrictors further.

To sink down the pipe, it was filled with brine (26% NaCl, density 1.2 g/cm^3). First a pulling pig (same as used with water push-pull technique) was inserted in the pipe, to ensure that no air voids are locked in. Measuring the water flow (in this trial 161 l/min, equivalent to 20 m/min), it was possible to monitor the position of the pig, which was in agreement with visual observation of the sinking pipe. The same brine was also used for the cable installation, except for one test, where seawater was used (the cable weight was still enough to keep the pipe down).

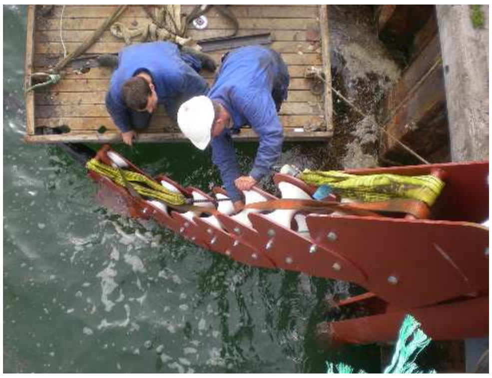

Fig. 14: Installation of pipe in bend restrictors

Fig. 15: Pipe sinking

Survey

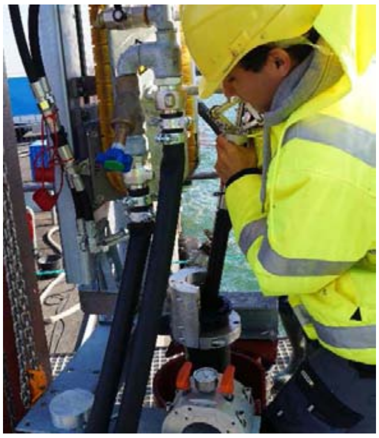

Fig. 16: Inserting Intelligent Pig

Fig. 17: Intelligent Pigging curvature profile example

After the pipe was sunk down and stable in place (not trenched for this test) Intelligent Pigging was done. The Intelligent Pig was attached to the pulling pig and then pumped through the pipe, again with brine. Three surveys were done, starting with 193 l/min flow (24 m/min) and just before the end (accurate to control) reduced to 80 l/min (10 m/min). Each survey took about 33 minutes. Several profiles were obtained, like depth and curvature profile (latter shown). A surprisingly high degree of correlation between the surveys was achieved. The depth profile showed a still sloped section 1-2 m down at the risers, the bend restrictor bend radii were a bit less than 2.5 m (explained by undulations in the pipe itself, superimposed on bending in the bend restrictor) and the U-turn made a sharper bend than the intended 10 m bend radius

Cable installation

The installation of the array cable, now with normal PE jacket, went easily. Installation with water push-pulling (with pig) was done 3 times (pushing 6000 N and water pressure 6 bar), one time using just seawater, resulting in only a slightly higher pushing force, indicating that the tight bends at the bend restrictors were dominant). Also 2 times floating (without pig) was done (pushing 5500 N and water pressure 6 bar). An employee of the cable producer visited the site and was confused because he thought installations were done already, while the cable looked brand new (but it was installed already 5 times!). The installation of the cable could be stopped and then started again, without extra pushing force or water pressure needed. Every new installation even went a bit easier. But also each time lubricant was added to the water (on the other hand also a lot of water was flown through).

STOP-AND-GO TESTS

Fig. 18: test trajectory for stop-and-go tests

When the cable and brine density are tuned to each other, extremely long floating lengths are to be expected. And for single phase cables vulcanized joints make it possible to really install them into the pipe (installation with one such joint already done in the Lindø trial). This would even allow to installing export cables from the shore in many cases! As the time to make a vulcanized joint is 2 days, it shall be possible to start up floating after each stop.

Measurements have been done on the coefficient of friction (COF) for power cables in PE ducts aged in (North)sea water. After 3 years of aging no change in the COF was found.

In the winter of 2014 “stop-and-go” tests were done in Kalundborg, DK. A 200 m long 125/102.2 mm pipe was laid straight on the ground (tensioned to keep it straight when heated up by sunshine). A 65 mm solid 1x630 mm^2 Al 72 kV export cable was installed into the duct with brine (density 1.2 g/cm^3) with lubricant added. The cable started moving when the pressure drop over the flowing brine reached 0.8-1.5 bar and stopped again at 0.4-1.0 bar. The cable could be pulled through the duct with 40 kgf start up and then at constant speed with 35-38 kgf. The test was repeated, first every hour, then reduced to once / 2 days (production time vulcanized joint) until a total of 12 days. There was no increase in pressure or pulling force after 12 days within measuring accuracy (partly caused by relatively large end effects). The test became more stable, even dropped to 22 kgf at the end, pressure 1.4 bar. At every new test lubricant was added.

Conclusion: waiting for almost 12 days (6 joints, or 7 cable lengths) did not result in higher start-up pressures or pull-out forces than at the start, within measurement accuracy. It looks like the pull-out force is even decreasing (same behaviour seen in Lindø and Thybøron trials).

THERMAL PROPERTIES

The current rating of a non-armoured cable in a water filled pipe does not differ a lot from that of an armoured cable. In [7] the effect of convective cooling is studied, which exceeds that of conduction. In [8] it is stated that cables in ducts when completely filled with a pumpable material, with thermal resistivity not exceeding that of the surrounding soil (water is not far away from most soils), may be treated as directly buried cables. The assistance of convection helps. In most models the heat resistance of the water in the pipe is so low that often the temperature of cable outer surface and pipe inner surface are taken equal. The system even makes possible active cooling by a forced water flow, during long periods of high power.

WHAT IS POSSIBLE?

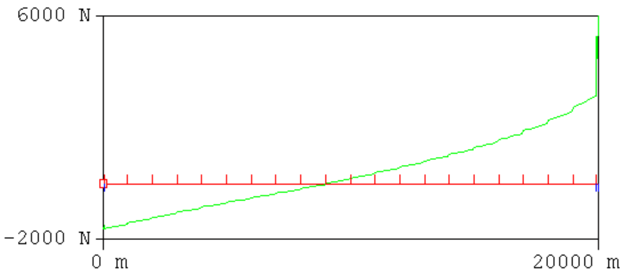

Fig. 19: JetPlanner plot pushforce vs installed length for export cable floated with brine of density 1.2 g/cm^3

To get an idea what is possible with floating, the 60 mm export cable with mass of 3.9 kg/m (estimated stiffness 2200 Nm^2) is taken as a JetPlanner [2,4] calculation example. Tight bends and undulations (no problem when with long period) must be minimized to reach the maximum. At both ends a 90° bend of radius 2.5 m (bend restrictor) is assumed, and every 1000 m a 30° bend of radius 15 m for connection of pipe sections. For floating with seawater, a length of 9 km is calculated for pushing force 9000 N and water pressure 10 bar. When (saturated NaCl) brine of density 1.2 g/cm^3 is used a length of 20 km is calculated, although the cable gets stuck in the bend at the end. But, applying a small pushing force there of 1600 N this bend is passed. When brine of density 1.38 g/cm^3 is used (1.57 g/cm^3 can be reached with K_2CO_3) a 100% match is obtained, and much longer lengths can be reached. The limit (100 km?) is determined by tight bends and undulations, to be suppressed as much as possible.

Even array cables can be installed from shore, using the FreeFloating technique, where sections of cable are delivered like “pneumatic mail” (water instead of air) [4,5].

CONCLUSIONS

The system of floating non-armoured HV cables into pre-installed PE pipes to connect offshore wind turbines has been studied in two trials. The pipes are first sailed out and then sunk by filling them with brine. The pipe solution also offers simultaneous laying and trenching of the pipe. The pipe solution offers the ability to remove/replace the cable at a later stage. With Intelligent Pigging the trajectory can be determined before or after trenching in seabed which ultimately may eliminate need for and thereby reduce cost for as built and inspection surveys significantly. Costs savings are further achieved because of the lower price of non-armoured cable, reduced AC-losses and reduced risk of pipe kinking (no preferred torsional direction) and thus eliminated risk to kink the cable (should the pipe kink, it is much easier to repair). Telescopic riser and flexible bending restrictor will allow the cable in pipe to follow the seabed in case of erosion around the mono-pile. Impact tests were performed which showed that non-armoured cables in pipes are better protected against mechanical impact than armoured cables, because of the free space in the pipe. Extremely long cable lengths (> 10 km) can be installed, including vulcanized joints that can pass the pipe. Even installation from shore becomes feasible!

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