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B2 OVERHEAD LINES
PS3 Environmental and Safety Aspects from OHL

2x400 kV Composite Pylon ready for use, Innovative and Compact – reducing the impact of OHTL considerably

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SUMMARY

The European electricity grid is undergoing major expansions to accommodate the switch to renewable sources and a more integrated European energy market. However, the wider incorporation of renewable energies requires uprate and/or upgrade reinforcement of existing overhead transmission lines (OHTLs) and the construction of new electricity corridors resulting in a significant expansion and modernization of the electrical grids.

This **transformation of the energy generation and transmission infrastructure is a major challenge for the high voltage grid**, which must be adapted accordingly. One of the major obstacles towards grid expansion consist of the public acceptance of OHTLs.

Transmission system operators (TSO**s**) are therefore making a significant **effort to find innovative OHTL solutions that can minimize the visual and environmental impacts** of new grid infrastructure **ensuring its smooth integration** into the local landscape. Public opposition to new OHTLs projects is linked with the negative visual impact of the traditional and widespread lattice towers in landscapes. The alternative method of underground cables is too costly for long stretches and is, in many areas, not feasible due to barriers related to underground geological structures.

TSOs and the OTHLs industry are facing important constrains related to conflicts in project acceptance. These constrains combined with lengthy permitting procedures, regularly result in delays in commissioning new infrastructures. Therefore, TSOs are increasingly looking for less intrusive, smaller, visually appealing systems that could raise public, environmental and landowners' acceptance, enabling TSOs to expand the electricity grid with minimal resistance.

In 2019 a European team of 5 partners were being awarded a Horizon 2020 program to prepare, test and validate the innovative composite pylon design that faces these challenges over a 24 -month period. The project started in 2019 and is finalized having **3 full scale demonstration pylons installed in Denmark**.

The 2x400 kV **Composite Pylon** is an **innovative project** that targets the missing link in transmission towers through a **compact, environmentally friendly, and pleasant solution**. It relies on the use of composite materials on pylon crossarms, enabling the integration of insulators and consequently the **reduction of the size of pylons**. The innovative part of the project is that three conductor configurations (1x400kV) are installed on one single composite crossarm. On conventinal towers using insulator crossarms each conductor configuration is installed on its own crossarm. The result is bigger towers. Since the Composite pylon works as an insulator itself **distances between conductors can be reduced** – thereby significantly reducing the size of the system (roughly ½ of a lattice tower).

A comprehensive test program is successfully finalized on all parts of the pylon. Recently a crucial milestone was achieved since the full crossarm was **successful electrical and mechanical tested** in laboratories in Germany and Czech Republic according to EU norms.

Today three full scale demonstration pylons are installed for visual inspections and mechanical tests in Denmark. In 2022 they can be visited and inspected as a validated proof of concept showcasing the power pylon of the future – ready to be energized!

www.compositepylon.com

KEYWORDS

Compositepylon, composite insulators, public acceptance, environmental impact, horizon 2020

Background

The EU electricity grid is undergoing major expansions to accommodate the switch to renewable sources and more decentralized energy production. However, the wider incorporation of renewable energies requires uprate and/or upgrade reinforcement of existing OHTLs and the construction of new electricity corridors resulting in a significant expansion and modernization of the electrical grids, in particular of the high-voltage transmission networks. The major barrier towards grid expansion consists, especially, of public acceptance of OHTLs, rather than technical or financial barriers. Public opposition to OHTLs is closely linked with the perceived, negative visual impact of the traditional and widespread lattice towers in landscapes. The lattice towers, which dominate the landscape today, were developed over 70 years ago without visual appearance consideration – and, recently, a growing opposition to new projects with the use of traditional towers has emerged.

Therefore the main drivers for the ECP project and for the Composite Pylon demand are (problem):
1. the need for expansion of the electricity transmission networks all over the world.
2. the landscape impact and public opposition to the traditional lattice towers.

The new Composite Pylon will enable innovative visual expressions and at the same time - through the integration of insulators in the pylon design - reduce the overall size of transmission towers. Moreover, as the pylons are expected to be smaller and compact, it will reduce the footprint associated to the manufacturing and transport to the installation sites. Furthermore, the use of mono-pile foundations lead to significant reduction in construction costs.

In many areas of the world, the public is increasingly opposing new lines due to the visual impact, fear of magnetic fields, environmental effects of the towers and more.

At the same time, operators and utilities are under pressure to deliver power continuously and efficiently - at a low cost - and to minimize the effects on the environment.

During the recent years, alternative tower designs, that would be more acceptable to the public and still deliver the needed power, have been proposed. However, most of these designs have been made from traditional materials, such as steel and concrete.

While these materials have proven their worth throughout many years, the expected benefits of composite towers could surpass the possibilities of steel and concrete.

Composite material has been used for many years on smaller voltages and has proven many benefits such as reduced maintenance, light-weight, low-cost material, that is easily acquired. This material is also non-conductive.

The obvious benefits sparked the idea of making a ground-breaking, new design: as the material is non-conductive, the cables can be attached directly to the cross-arms – this will save significant height on the pylon. By attaching the cable directly to the cross-arms, the movement of the insulators would also be eliminated. This would result in further size reductions.

The light-weight material also poses great benefits during the transportation and installation phase; parts – or whole pylons – can be flown directly to the site and installed, easily and efficiently.

Towards the end of 2019, a team of five international partners received funding from the European Union via the Fast Track to Innovation program (Horizon 2020), to produce and install 3 test pylons that will be able to carry 2x400 kV.

Figure 1 : Demonstrator of 400 kV European Composite Pylon

The project is named the **European Composite Pylon**, referring to the European partners involved and the funding source. The composite pylon will be able to be installed and used by operators and utilities around the globe.

For this reason, the consortium applied for funding from the European Union, to produce, test and install 3 composite pylons during the years 2019-2021.

The design – optimized according to european standards

The concept behind the European Composite Pylon is a compact power pylon, enabled by the combination of an innovative design system with an assembling of components (incl. composite crossarms, insulation elements, cables, fittings) especially designed and projected to ensure high voltage power transmission, using low density structures for minimal visual impact, as illustrated in Figure 2.

Figure 2 : Left: L13 2x400kV Lattice tower. Right: 2x400kV Composite pylon – same specifications

In the figure below (Figure 3), a traditional lattice tower is shown in red and a compact pylon in steel (*T-Pylon*) in yellow. **In green is the Composite Pylon** which is clearly smaller than previous designs and has a significantly smaller footprint when compared to the lattice. The main Composite Pylon's innovation lies in the integration of the insulators in the cross arms, where conductors are placed (using a cable clamp) on the cross-arms instead of hanging down from the structure. This means the pylon can be up to **20 m lower** than lattice towers.

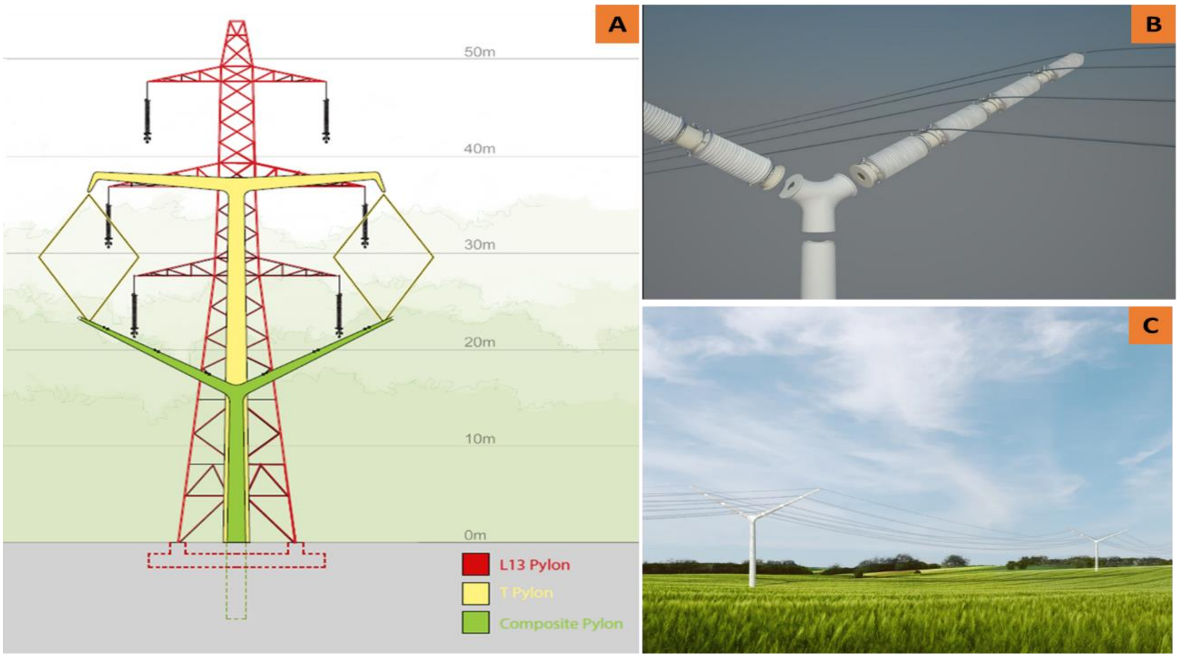

Figure 3 : A) Composite Pylon (green) compared with traditional lattice towers (red) and BYS's T-Pylon (yellow); B) Detail of Composite Pylon's elements; C) Representation of Composite Pylon's visual impact

The right-of-way (ROW) corridor along an transmission line depends on the insulating spacing between the individual phase conductors, the configuration of the conductors and the design of the pylon. In OHTLs with traditional vertical insulators, the insulators are suspended from just one point on the cross-arm. Windy conditions can therefore cause them to swing to either side, calling for larger space needed between the insulators to secure the minimum clearance required. In pylons with insulated cross-arms, the conductors are fixed to the cross-arm, so they cannot swing sideways as by using convential glass insulators. As a result, the minimum electrical requirement between the conductors is reduced remarkably. Using the electrical requirements in DK, we are able to **reduce the internal distance by 46%** (from 5 to 3.2 m).

The pylon and its central node are designed to withstand the load cases specified in the overhead lines code. In particular, the superstructure and its foundation can resist large bending and torsion that could possibly be induced by extreme environmental conditions, such as wind and ice loads.

The foundation is site specific to suit local ground conditions, but using a monopole foundation has proven its remarkable savings in time and excavation.

The design of the shaft is similar to the design of towers for wind turbines. Consequently, it has been possible for the manufacturer to take advantage of the experience from wind turbine towers to produce the shaft using automated processes in controlled factory conditions. This simplifies on site operations and reduces construction labor as well as environmental impact.

The electrical design is specified in EN50341§5 Electrical requirements, the standard used by all EU operators, also using the 50341-2-4 national annex for Germany since Germany is a well-accepted and generic annex.

Below you will find a high level list of specifications for the demonstration project:

- EN50341 / EN50341-2-4 (GER)
- Wind zone 2, Ice load zone E2
- 2x400 kV AC, 4.400 Amps
- Site altitude: 100 m
- Basic mean hourly wind speed: 25 m/sec (Wind Zone 2)
- Terrain category: II

- Max single span: 350 m
- Max weight span: 450 m
- Conductor: ACPR Lo-Sag 451 – AL1 / 64
- Earth Wire: ACSR 240/40
- Galloping acc. CIGRE TB 322
- Max everyday tension at 10 deg: 52 N/nm2
- Max operating temp: 80 deg
- Lightning acc. IEEE standard 1243:1997

Having the above specifications ready the pylon is optimized according to minimal electrical clearences (phase-phase, phase-earth). The final design is 30 m tall having a span of 350 m. This is approximatly 20 m lower than traditional lattice tower for 2x400 kV. For instance the UK L13 lattice tower having the same specifications is 56 m.

The shaft is produced in steel in one piece ready having a 3 layer of surface treatment offering a lifespan of 80 years without additional treatment.

The shaft is optimized for simple production using only the minimal use of steel all over. The diameter in the bottom is only 1.3 m ending up having a footprint of 1,59 m^2.

The fittings are designed for triple bundle (400 mm. center/center) on the demonstration pylons but can be tailored to any other configuration such as duplex, quadro etc.

All parts of the tower is designed to optimized production, minimizing material use and time use in installation.

Today’s lattice pylons are made from galvanised steel and are painted and/or galvanized to help protect the structure from corrosion during its anticipated life span of circa eighty years. If rust does occur on the lattice design, it is possible to take the affected piece of steel out and bolt in a new one, and trained linespersons can drive onto site to climb the structure with the necessary safety and work equipment.

The Composite Pylon, however, is different. With less than ten large parts, the line owner does not expect to replace any parts unless they are mechanically damaged. To help blend the pylon into the landscapes the line owner is investigating the merits of applying different surface coatings for an 80-year life. The operator does not expect the steel parts of the composite pylon to require routine maintenance as is required by today’s lattice pylons.

Mechanical and electrical type test of the crossarm

The crossarm was designed following the overhead line standard EN 50341-2-4. Additionally mechanical requirements from IEC 61462 standard for hollow core insulators was considered and insulation coordination was carried out in accordance with IEC 60071-1 and IEC TS 60815-3. The crossarm was designed using analytical calculations and FEM simulations. To create the required material models, sample tests were carried out. To validate the design a mechanical and an electrical type test were performed both shown in Figure 4.

For the mechanical type test, load case J from EN 50341-2-4 was tested. This load case take into account unbalanced ice loads. Therefore, not only bending loads, but also torsional loads act on the crossarm and pylon due to the one-sided forces in direction of the conductor cables. The loads acting on the crossarm and pylon result on the one hand from the boundary conditions of the load case and on the other hand from the weight loads of the conductor and earth cables, the dead weight of the crossarm itself and additional snow and ice loads acting on he crossarm.

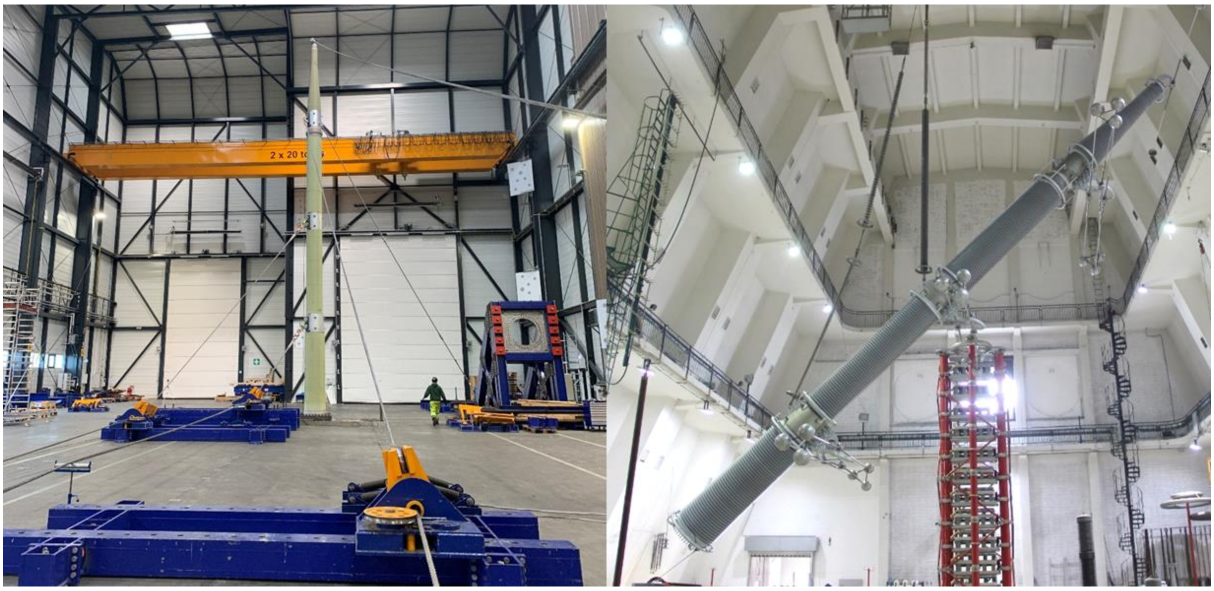

Figure 4 : Test setup for mechanical (right) and electrical (left) type test of full-scale crossarm

The full-scale crossarm was tested in vertical position. The forces were applied via cables at four different load application points. 20 strain gauges as well as angle of rotation and displacement sensors were used to record the strains and deformations of the crossarm during the test. Four load levels ranging from 0.5 to 2.31 times the maximum operating load were applied one after the other and held for a defined time. The test procedure was performed in accordance with IEC 61462. The crossarm was not destroyed during the tests, only minor, permissible damage occurred at loads above the maximum operating load.

The electrical design of the crossarm was also successfully validated via a type test. The type test included wet switching impulse as well as dry lightning impulse tests between the individual phases and between the phases and the grounded ends of the crossarm. The tests were performed on a full-scale crossarm including all fittings and aluminum rods as conductor cable mock-ups. The crossarm was suspended at an angle of 45 ° in the test hall. All dry ligthning impulse tests for 400 kV rating with peak value of 850 kV and 1175 kV lightning impulse were passed sucessfully. The same also applies to wet switching impulse test for 400 kV rating with switching peak value 850 kV between phases and 950 kV between phase and earth. Limitation for higher ratings were in each case only the distance between the conductor mock-ups. Flashes occurred therefore only at the spheres at the ends of the conductor mock-ups. Conversely, this means that for higher ratings only the distance between conductor cables have to be increased.

Production

During the design phase in 2019 and 2020 a prototype for pylon part and the center knot have been developed.

For testing 2 different type of T-knot was produced, see Figure 5 and Figure 6. Production have been done according EN 1090-2 EXC 3. Material S355J2G3 with 3.1 certificate.

Figure 5 : Left: Center knot type 1. Middle: Center knot type 2, Right: T-knot welded to the shaft

Production is carried out from plate material, with process of cutting, rolling, machining and welding.

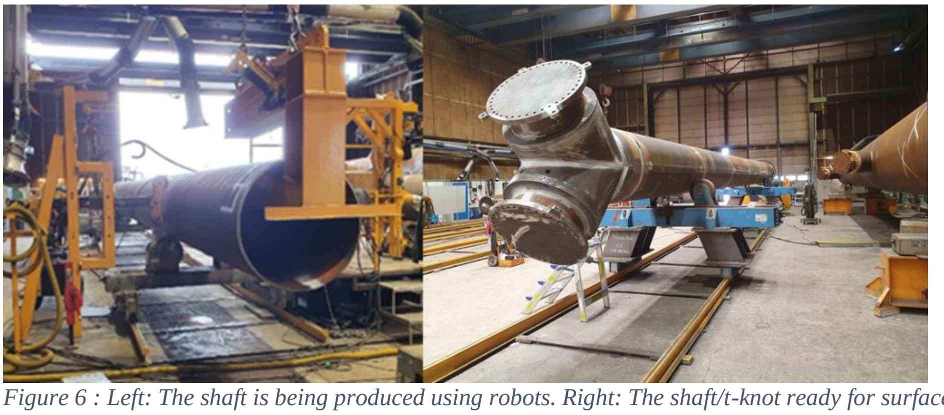

Figure 6 : Left: The shaft is being produced using robots. Right: The shaft/t-knot ready for surface treatment

Access to the inside of the pylon is closed, Means no surface treatment inside is needed. System for outside treatment will typically be made from a duplex system according ISO 12944 C5 VH, depending on wanted lifetime.

Installation

Since operations at installation site is costly, the entire proces is optimized.
The shaft including T-note arrive in one piece at the intallation site. Also the crossarms arrives including fittings. The entire pylon is assembled on the ground. Finally the entire pylon including fittigs is being erected using two cranes.

The entire process is simple and easy. 3 towers can be installed every day according to the site condition and the weather.

Figure 7 : Left: Preparing of installation. Middle: Cranes ready for erection. Right: Pylon installed.

The construction of power pylons has traditionally been a time-consuming process on site, bolting the lattice structure together. However, with modern manufacturing processes and sections not bigger than a truck, it is possible to transport a full pylon on a single truck – ready for installation.
In remote areas where access is not possible by truck it is possible to reduce the sections for helicopter transport.

Any overhead line foundation solution must be robust enough to last the lifetime of the pylon, be capable of quick installation, and minimise land use.
Foundations for offshore windmills are typically made with monopiles driven into the seabed. Similarly, foundations for pylons on land can be provided by a hollow steel tubular section hammered into the ground.

A monopile foundation footprint is very small (Ø1.5 m/Ø1.8 m) compared to a concrete plate foundation. The environmental impact - noise, possible site contamination, and temporary works - is subsequently smaller, and due to very limited excavation, ground water problems are practically eliminated.

For installation, a steel monopile is delivered to the chosen site, where a crane uprights and places it in the driving position on the ground's surface. The installation of the monopile foundation is shown in Figure 8.

Figure 8 : Left: Hammer stating the installation. Middle: Hammerhead. Right: During installation

The hammer can achieve full foundation installation in under an hour, depending on ground conditions.

Using this solution, total installation time including set-up of a full strength monopile foundation can be done in one day, compared to the approximately 28 days it would take for the traditionally concrete solution to reach the requisite strength for pylon erection.

Conclusion

Since 2019 the design has been designed, optimized, tested – electrically and mechanically, produced and installed at Valmont SM in Rødekro, Denmark – close to the border between Denmark and Germany.

The future plan is to install minimum five fully operational pylons including conductors somewhere in Europe. If possible, the pylons will be installed in an energized grid in collaboration with an operator.

The result is that any operator will be able to enquire a turnkey project (design and build) tailored to their individual specifications including the following benefits:

	Composite Pylon's advantages, when compared with current approaches
Compact design	Composite Pylon's height (30m) is almost half the size of a conventional lattice tower (54m). A reduction in the size means less visibility on the horizon, less right of way, less material use, and easier production and handling. With compact towers, it is also possible to minimize the right-of-way, which is a top priority in densely populated areas.
Longer lifespan with reduced maintenance	Fewer parts mean less maintenance, and the pylons can undergo maintenance from a Mobile Elevating Work Platforms (MEWP), designed to give safe access. On the contrary, lattice towers must be re-galvanized or replaced every 40 years, increasing maintenance expenses over the total lifespan.
Aesthetically pleasant and flexible design	Every function of the single pylon is incorporated into a consistent overall design, resulting in a pylon that is able to deviate according to the specific route and corridor that is usually strongly affected by land rights issues and natural barriers.
Reduced footprint - Minimal	Lattice towers consist of four legs that take up 64 m^2 (suspension tower) and up to 81 m^2 (angle tower). By using monopile, the footprint can be reduced to 1,6 m^2 (Ø1,4/Suspension tower) and 5,3 m^2 (Ø2,6/Angle tower).
50% time savings in installation and stringing	Having fewer parts installation of the tower and the stringing proces are much faster than traditionally. On the test site the company saved 50% time using tradtional tooling and gear.
Reduced weight	Having a compact tower the total weight is below 20T compared to traditionally lattice towers having a weight of approximatly 25-30 t.
Easy transport	The entire pylon can be transported on two trucks including all parts required. All segments can even be designed to be transported by helicopter if required for remote areas.
No unauthorized access	The design cannot be climbed – and steel cannot be removed from the structure – this means our designs cannot be vandalised.
Full digital system	The pylon offers several opportunities to provide real time monitoring of grid and pylon performance by including sensors. A composite hollow insulator is able to transmit the corresponding signals along the insulator. The result is a system that gives day to day status of weather, conductor temperature, partial discharge, leakage current and many more.

To release the full potential of the new design and generate the expected high impact in the sector, the team aims to complete the full maturation of the new transmission system and release a turnkey solution into the market, and secure **business growth** in Europe, **environmental benefits** and **accelerate the transformation into renewables**.

Figure 9 : Demonstrator of 400 kV European Composite Pylon

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