Development of sectional blades with IndeModular technology

The current trend in the wind energy sector toward the construction of even bigger wind turbines is compelling manufacturers to face major technological challenges related to the manufacturing and transportation of large blades. INDEOL and the National Renewable Energy Centre of Spain (CENER) have developed IndeModular, a joint system that allows blades to be manufactured in several sections which will be assembled afterwards at the wind farm site.

The joint system is composed of several cell units which are disposed in the spar cap of the blades. Its design aims for easy integration of the joint system into current manufacturing processes. Furthermore, it has a high capacity for load transmission without penalizing blade aerodynamics. Integrating the joint system on the blade does not have a high impact, as the increase in weight of around 7% does not affect the dynamic behavior of the wind turbine. The joint system allows blade tips to be dismantled for repair or retrofit purposes, and it significantly reduces costs related to the logistics of manufacturing and assembly processes.

IndeModular has been validated by the certification body Germanischer Lloyd (GL) and it has been recently awarded the Eolo Innovation 2015 prize by the Spanish Wind Energy Association (AEE).

Wind energy has become one of the fastest growing renewable energies worldwide, encouraging the development of larger wind turbines with unitary capacities up to 8 MW. This is forcing wind turbine manufacturers to deal with the current limitations of large blades regarding manufacturing, transport and assembly.

Some manufacturers are developing their own joint systems for sectional blades, which are made up of several sections that are manufactured and transported separately to the wind farm site, where they will be finally assembled. Sectional blades facilitate logistics during the manufacturing and transport processes, allowing large blades to access wind farms with limited road dimensions, and avoiding manufacturing plants to be relocated or duplicated.

There are two main sectional blade families, according to the technology used for joining the blade sections together. First, blade sections could be connected by means of bolted joint systems; various threaded elements such as bolts, studs and nuts may be used and, therefore, bolted sectional blades are more versatile. On the other hand, blade sections could be bonded through the use of adhesive joints, which are often lighter. Nevertheless, they do require adhesive curing in a controlled environment, and therefore a complex infrastructure must be deployed at the wind farm site.

Consequently, blade assembly takes longer and any problem arising during the process may not be easily fixed. In addition, any blade that may need to be repaired at the manufacturing plant must be cut off in smaller sections for road transport.

The IndeModular joint system

IndeModular is a bolted joint system for sectional blades. It was created and developed by INDEOL and the technical team of CENER’s wind energy department. The system is located at the blade spar cap, which is the structural element that supports the main blade loads. It is based in cell units, each comprising one intermediate plate, four inserts and four studs, with their respective washers and nuts.

FIGURE 1 shows the different parts of one cell unit. The inserts, which are bonded to the spar cap, have a threaded longitudinal hole where the studs are fastened to. The studs pass through the intermediate plate, and the system is locked by means of nuts. The intermediate plate has been designed to accommodate both the cell unit parts and the tightening tool, and it has been optimized for cell unit compactness.

IndeModular differs from other solutions by the fact that long and short studs are alternately disposed, thereby reducing the distance “d” between adjacent inserts (**FIGURE 1**); therefore, the joint system can achieve a higher load density per cap width than

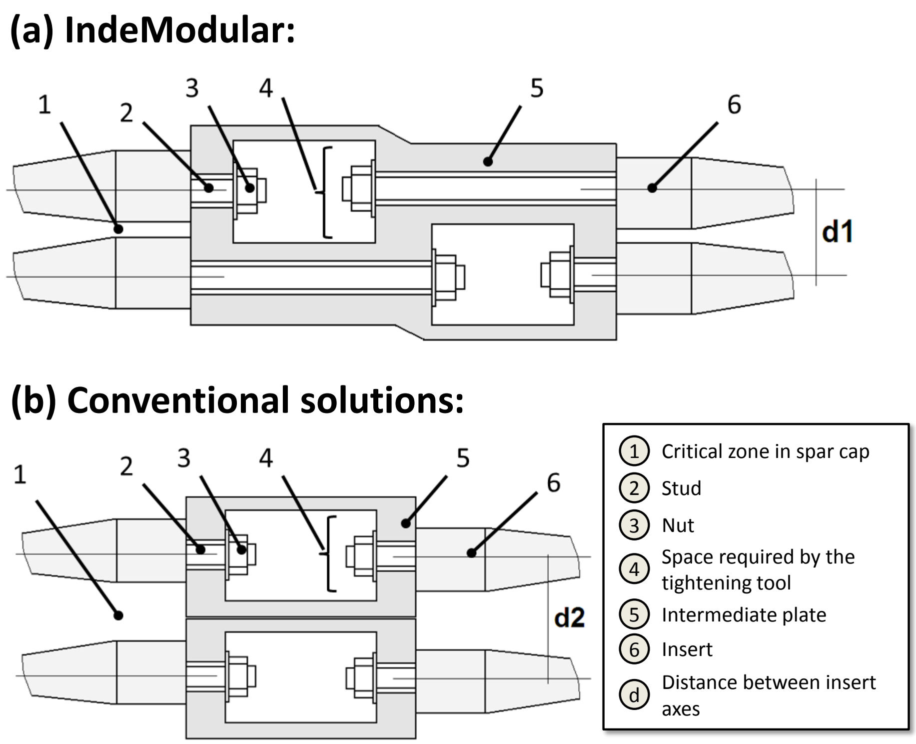

FIGURE 1: Configuration of two joint system solutions

conventional solutions. Moreover, the intermediate plate has a high fatigue resistance capacity as a result of its special geometry, which allows the cell unit to work mainly under compression loads.

Development of the joint system

INDEOL and CENER were challenged to develop a joint system that could be used in the structure of any commercial blade (such as spar box, single and double spar web), that would have little impact on the blade production rate, and would be innovative and patentable for its subsequent commercialization.

A flow chart of the followed methodology is shown in **FIGURE 2**. First, prior art was reviewed and various joint concepts were developed and evaluated during several brainstorming sessions. Then, the six joint systems with the greatest potential were shortlisted. At the same time, a wind turbine blade was selected as a reference for calculating design loads and for assessing the integration of the joint system; after analyzing the latest trends in both

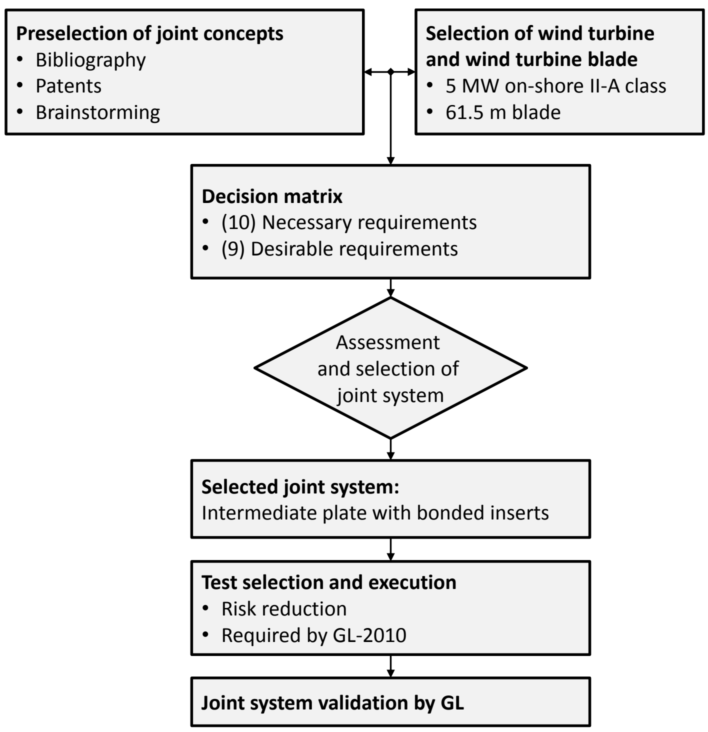

FIGURE 2: Development process of IndeModular joint system

the development of wind turbines and in the most usual locations for wind farm sites, a 61.5 meter blade on a 5 MW onshore class II-A wind turbine was finally chosen, since the joint system was likely to be used on blades longer than 40 meters.

A decision matrix was developed in order to evaluate the six preselected joint systems; this matrix included ten necessary requirements (such as patentability, minimum increase in weight and cost, minimum impact on blade manufacturing process, easy integration into commercial blades, easy access from the outside of the blade for assembly and disassembly of the joint system) and nine desirable requirements (reduced number of interfaces where failure might occur, manufacturing and assembly tolerances, easy inspection and disassembly not resulting in structural damage, among others). The different systems were evaluated and two possible solutions were shortlisted. Finally, after an in-depth assessment of both solutions, the joint concept consisting in an intermediate plate with bonded inserts was finally selected.

Analytical calculation tools were used in order to complete a preliminary design of the joint systems, where materials of common use in the wind energy industry were selected. Then, a complete testing programme was designed in order to consider both tests required by the GL-2010 [1] standard and risk reduction tests [2] that would guarantee viability and reliability of the joint system.

Risk reduction tests

First, some tests were carried out in order to select the most convenient adhesive for bonding the inserts to the spar cap. Then, adhesive processability was evaluated; next, mechanical performance under static and fatigue loads at room temperature was confirmed to be good. Finally, it was selected the most suitable surface treatment for the inserts. Afterwards, some tests were performed on a 1:2.5 scale prototype in order to verify that the stud load factor of both the design and the finite element model did match; these tests also helped to establish the stud tightening process.

Finally, several full-scale risk reduction tests were performed:

- Fatigue tests on studs with two different thread types. After an assessment on their mechanical behavior and the detail category of their S-N curve, the stud thread type was selected.
- Tightening tests in order to verify that the intermediate plate could accommodate the tightening tool, as well as to ensure that the resistant capacity of the tightening tool could withstand the required tightening torque.
- Hole drilling tests in the composite material to verify that the manufacturing tolerances did meet the design requirements. These tests also helped to optimize the drilling process, to determine the minimum distances between holes, and to validate the tightening tool. **FIGURE 3** shows hole inspection after completion of one drilling test.

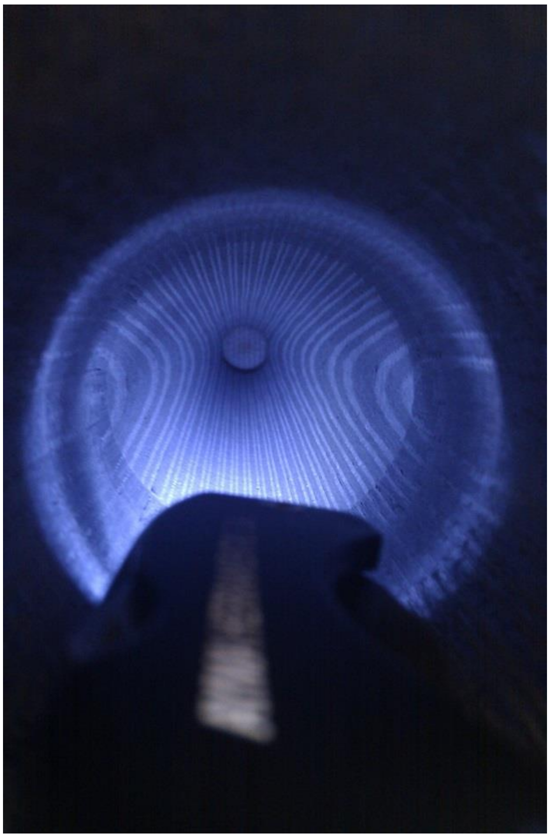

FIGURE 3: Hole dimensional inspection after drilling test on composite material

Validation of the joint system

After conclusion of the risk reduction tests, it was completed the final design of the joint system, which was optimized by means of structural calculation based on GL-2010 [1] standard and finite element detailed analysis [3]. Finally, the joint system was validated through completion of the tests required by the standard; both bench-scale and full-scale testing was performed in order to obtain the allowables of the bonded interface and the joint system, respectively.

The certification body Germanischer Lloyd (GL) supervised the validation of the IndeModular joint system: for that purpose, GL personnel monitored the tests and reviewed the required reports and calculations.

The mechanical validation test consisted in extreme and fatigue load testing. The prototype, which comprised two cell units, was consecutively subjected to extreme tensile and compression loads, fatigue cyclic loading and tensile loading to failure [4]. The validated loads per cell unit are shown in **TABLE 1**.

LOAD TYPE		VALIDATED LOAD
Extreme	Tension	+ 824 kN
	Compression	-1.033 kN
Dynamic	R=-1, N=2E6 cycles	± 213 kN

TABLE 1: Validated loads per cell unit

Integration of the IndeModular system on a sectional blade

It was carried out an exercise consisting in the integration of the validated joint system on a 5 MW onshore class II-A wind turbine 61.5 m blade. Considering load and blade data, the joint section was located at 30 meters from the root, and it was determined the number of cell units the joint system should be composed of.

FIGURE 4 shows the system arrangement at the joint section, where 16 cell units were disposed for load transmission through the spar cap (8 cell units per cap). In order to achieve continuity at the joint section, some metallic plates were fastened at the webs and a fairing was disposed between the blade shells. **FIGURE 4** does not represent the fairing so that the other parts of the joint system can be shown.

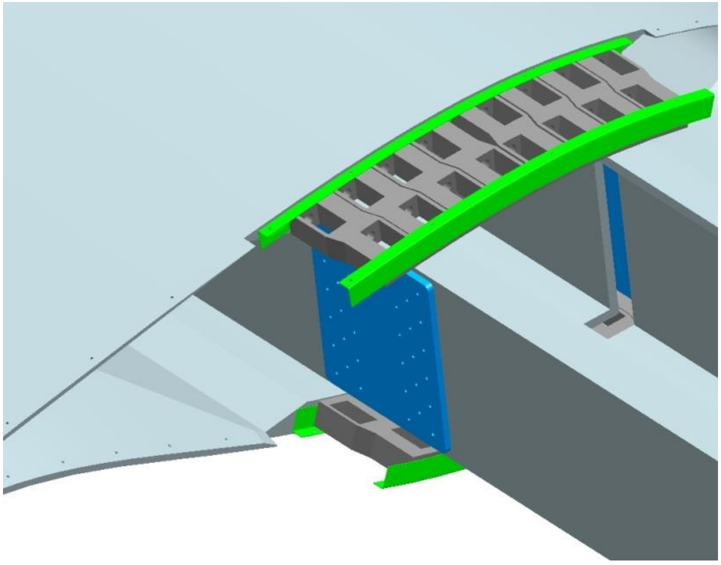

FIGURE 4: Integration of IndeModular in a sectional blade

The integration exercise revealed that the sectional blade weighted a 7% more than the monolithic blade. It was also determined that the additional weight at the joint section did not affect the dynamic performance of the wind turbine and, therefore, no resonant effects arose.

In addition, the integration exercise showed that the increase in manufacturing costs remained below 10%; hence, the blade final cost, which results from considering not only manufacturing costs, but also transport costs to the wind farm site, reduces progressively as blade length increases. This trend may be noticed in **FIGURE 5**, which has been prepared on the basis of NREL's WindPACT project conclusions [5], updating them with current data of various commercial wind turbine blades.

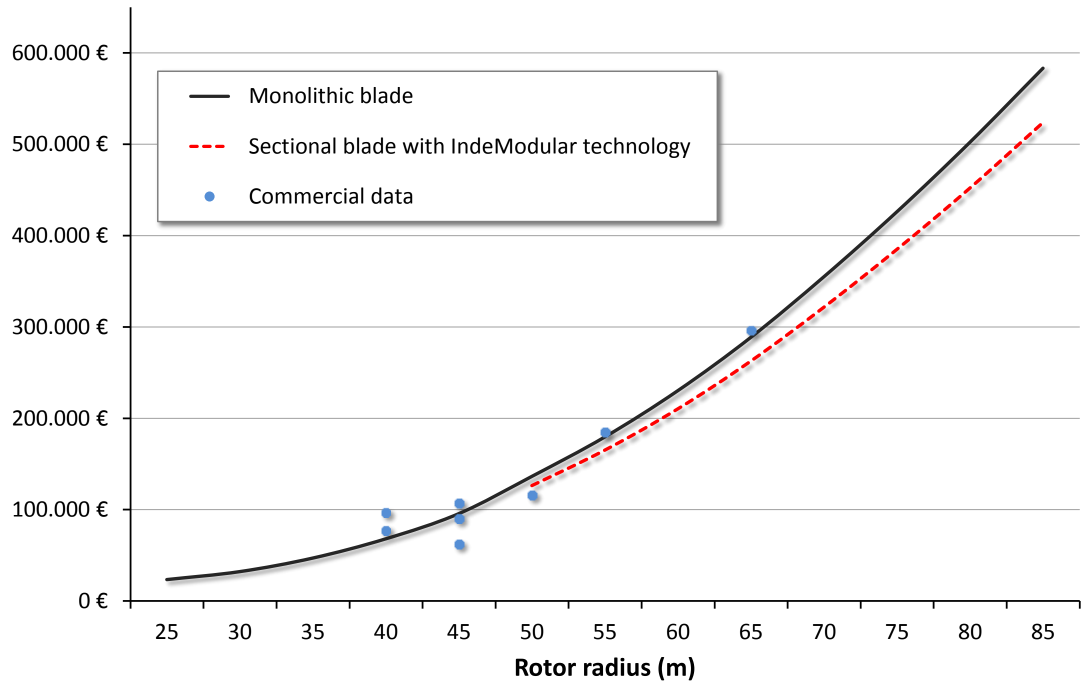

FIGURE 5: Blade cost at the wind farm site

Conclusions

The IndeModular joint system is a cost-competitive solution for the new multi-megawatt wind turbine blades, dealing with the technical challenges related to their manufacturing and transport. It helps blade manufacturers to develop families of blades that differ only in their blade tips; in addition, blade tips can be easily replaced for blade repair or retrofitting with minimal impact on wind turbine production, as assembly and disassembly of blade tips can be easily performed. Blade aerodynamics is not affected and, due to its modular design, the joint system can be integrated into any different blade lengths and architectures (e.g. spar box, single and double spar webs).

The IndeModular joint system is patent-protected in Spain, where the patent was granted with preliminary examination [6]. Furthermore, the patent application has been filed in several foreign countries, including the rest of the European countries, China, Brazil and United States, among others. Recently, the Spanish Wind Energy Association (AEE) has awarded the Eolo Innovation 2015 prize to IndeModular, recognizing "its newness to facilitate transport and assembly of the large blades of the new generation of wind turbines" [7].

References

[1] G. Lloyd, "Guideline for the certification of wind turbines, Edition 2010".

[2] J. Sanz and J. M. Maruri, "The IndeModular blade joint system," *Windtech International,* vol. 9, no. 3, pp. 37-39, 2013.

[3] E. Saenz, I. Nuin, R. Montejo and J. Sanz, "Development and validation of a new joint system for sectional blades," *Wind Energy,* vol. 18, no. 3, pp. 419-428, 2015.

[4] R. Montejo, E. Saenz, I. Nuin and J. Sanz, "Desarrollo y validación de un sistema de unión para palas segmentadas," *Eolus,* no. 64, May-June, pp. 6-9, 2013.

[5] Sandia National Laboratories, "Cost study for large wind turbine blades: WindPACT blade system design studies," May 2003.

[6] R. Montejo, C. Amézqueta, F. Lahuerta, I. Nuin, J. Guelbenzu, M. Sanz, M. Del Río, A. Fariñas and E. Sáenz, "System for joining component portions of wind turbine blades". Patent ES 2.392.523 (B2), 13 May 2011.

[7] Spanish Wind Energy Association, 25 May 2015. [Online]. Available: http://www.aeeolica.org/es/new/aee-otorga-los-premios-eolo-de-innovacion-y-de-fotografia-a-cenerindeol-y-a-vicente-guill/.