

Automation and robotics transform wind tower manufacturing

Much of the discussion around wind energy focuses on blades, nacelles and installation vessels. Yet one of the most critical challenges of the energy transition lies far from the wind farm itself, but it is in the fabrication halls where towers and offshore foundations are built. Here, kilometres of weld seams determine the structural integrity of turbines expected to operate for decades. As wind energy scales up, manufacturers are discovering that the real constraint is not only turbine design, but the ability to automate production of these massive steel structures.

Wind tower and foundation manufacturing is undergoing rapid industrialisation. Fabrication processes that once relied heavily on manual welding and conventional workshop methods are evolving into automated, digitally controlled production systems capable of delivering both scale and consistency.

This transformation is driven by two converging pressures. On the one hand, global wind energy targets require manufacturing capacity to expand significantly during the coming decade. On the other hand, the structures themselves are becoming more demanding: thicker materials, larger diameters and more complex offshore foundations.

Among all production processes, welding sits at the centre of this transition. The ability to weld large steel structures efficiently and consistently is becoming a defining capability for tower and foundation manufacturers.

Growing structures, growing complexity

Wind towers are typically fabricated from rolled steel plates welded into cylindrical sections. These sections are then assembled into tower segments that can reach tens of metres in length and weigh hundreds of tonnes.

While the underlying concept has remained relatively stable, the scale has changed dramatically. A decade ago, onshore tower diameters commonly ranged between three and four metres. Today, diameters exceeding five metres are becoming standard, with offshore foundations often pushing up to 13 metres. For future floating foundations, even larger diameters of up to 15 metres are already being considered.

Larger structures bring exponential increases in weld volume. Each tower contains kilometres of weld seams, including longitudinal seams, circumferential welds and flange connections. These welds must maintain

structural integrity throughout decades of cyclic loading caused by wind, turbine operation and environmental conditions.

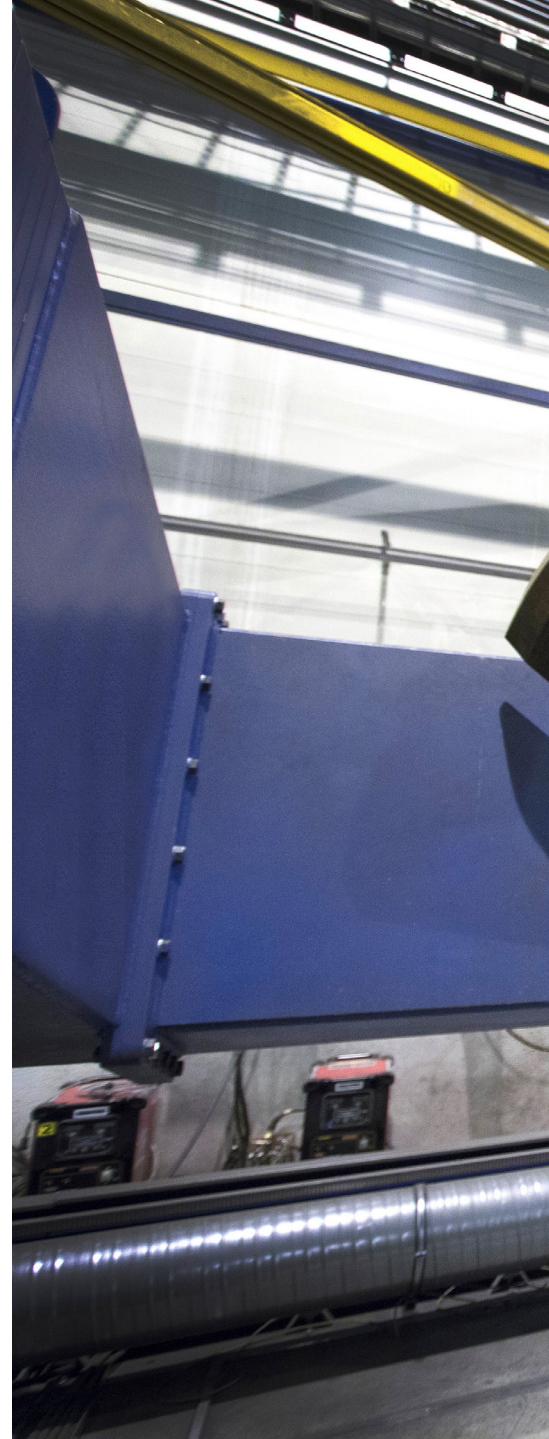
Even minor inconsistencies in welding quality can influence fatigue performance over the long term. At the same time, manufacturers must increase production capacity to keep pace with rising global demand for wind energy installations.

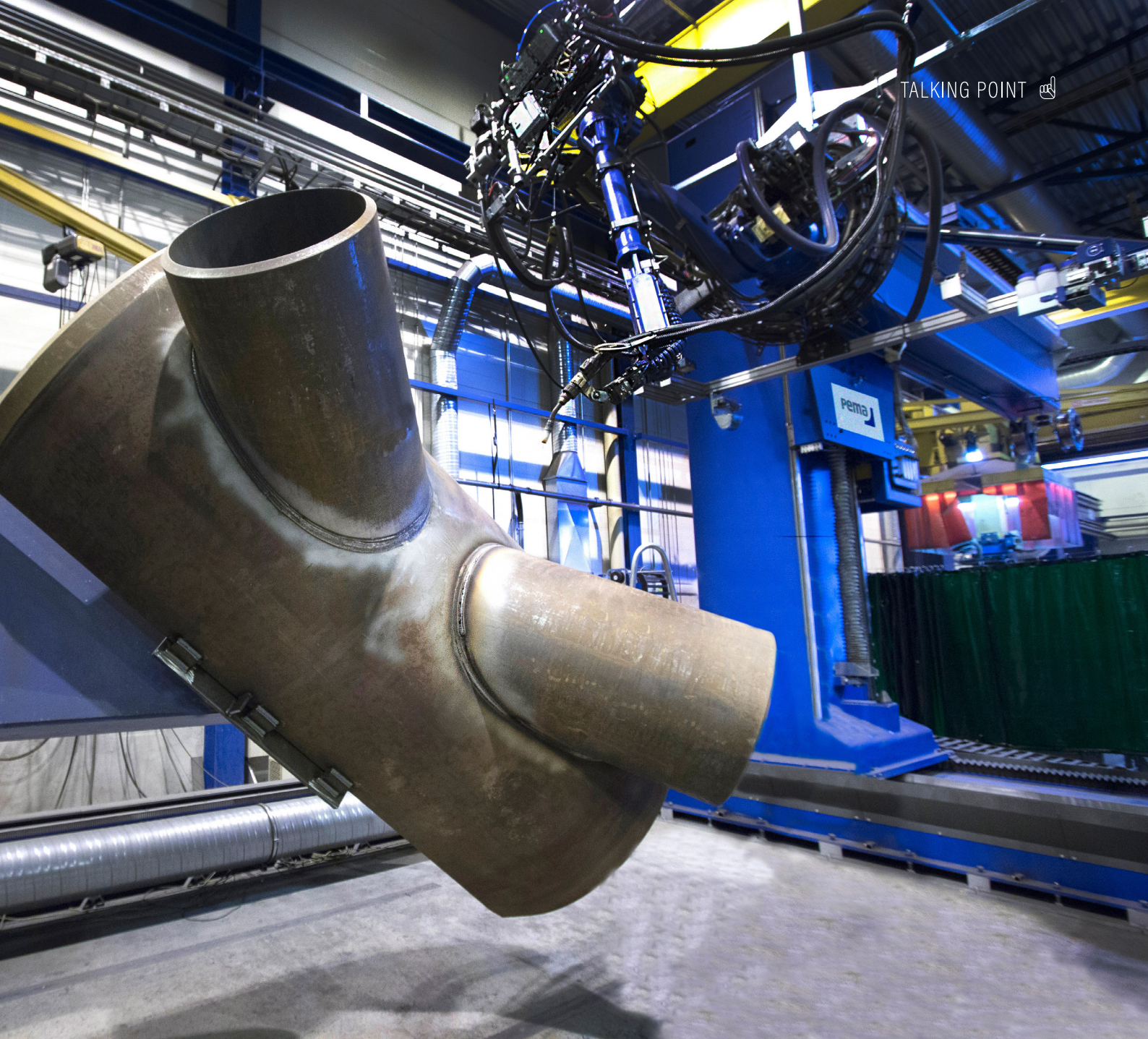
This combination of structural demands and production pressure is accelerating the shift towards automated welding solutions.

Automation as a foundation for consistency

Automation in welding is often framed as a response to labour shortages. While workforce availability is indeed a growing challenge in heavy fabrication industries, the more fundamental driver in wind tower manufacturing is consistency.

Manual welding inevitably introduces variations in parameters such as heat input, penetration





Robotic welding systems combined with scanning technologies enable automated welding of complex jacket node joints used in offshore wind foundations

and bead geometry. Even experienced welders produce subtle differences across long weld seams. When multiplied across kilometres of welds in a single tower, these variations can become significant.

Automated welding systems allow manufacturers to control key parameters such as travel speed, wire feed rate and arc characteristics with far greater precision. Sensors and process monitoring systems provide continuous feedback, ensuring welding conditions to remain stable throughout the process.

Automation also enables the use of high-deposition welding techniques such as tandem arc or triple arc long stick-out (LSO) submerged arc welding. These processes significantly increase production output while maintaining high quality, minimised weld defect rates and consistent weld profiles.

For manufacturers working with massive steel components, thick materials and multi-layer

weld seams, these capabilities provide both productivity improvements and better process reliability.

Managing variation in large diameter welding

While automation improves consistency, tower and foundation manufacturing must still cope with significant variation between different turbine designs.

Tower diameters, plate thicknesses and weld groove geometries change frequently as turbine manufacturers optimise their designs. Production systems must therefore be capable of handling different joint configurations without extensive manual adjustment.

Even relatively small differences in groove geometry can influence welding performance. If welding parameters do not match the actual joint geometry, problems such as insufficient penetration or inefficient deposition rates may occur.

To address this challenge, modern welding systems increasingly combine digital process control with integrated laser scanning technologies.

Scanning systems measure the real geometry of a weld groove before and during welding. The collected data is analysed within the production software, allowing welding paths and parameters to be automatically adjusted to match the actual joint conditions.

Systems such as PEMA WeldControl with integrated scan technology demonstrate how adaptive welding control can support large-scale tower and foundation manufacturing. By analysing the groove geometry and adjusting welding parameters accordingly, the system helps maintain stable weld quality even when working with varying tower diameters or joint configurations.

This reduces the need for manual parameter adjustments and supports more predictable production performance across different tower and foundation designs.

Robotic welding for complex offshore jacket structures

While towers and foundations present their own challenges, offshore wind jacket foundations introduce an additional level of complexity.

In deeper waters, jacket foundations are frequently used instead of monopiles. A jacket structure typically consists of three or four main legs connected by diagonal and horizontal bracings to a transition piece located in the centre of the structure.

These tubular frameworks provide the stiffness and structural stability required to support turbines in deeper offshore environments. However, they also create some of the most demanding welding joints in wind energy fabrication.

The nodes where legs and bracing members intersect involve complex groove geometries, varying joint angles, volumes and thick materials. Compared with the relatively uniform weld seams found in cylindrical towers and monopiles, these joints are significantly more difficult to automate.

Historically, welding such structures has relied heavily on manual processes. As offshore wind capacity expands rapidly,

manufacturers are increasingly exploring robotic solutions capable of handling these complex geometries.

Adaptive robotic welding systems combine multi-axis robotics with integrated scanning technologies. Before welding begins, the system scans the real geometry of the joint and analyses the data within the control software.

Instead of relying on predefined robot paths alone, the welding trajectory is adjusted to match the actual geometry of the workpiece. Solutions such as PEMA WeldControl illustrate how this approach can be applied to variable-geometry joints commonly found in offshore jacket nodes.

Another important capability is the efficient execution of multi-pass welding sequences.

Once the welding procedure has been defined within the system controller, the operator selects the appropriate programme and the system manages welding parameters, torch positioning and pass sequences automatically.

Because individual welds in jacket structures can take several hours to complete, automation significantly reduces the need for continuous manual intervention. In many cases, one operator can supervise multiple

welding robots simultaneously, increasing productivity while maintaining consistent weld quality.

From individual machines to connected production fleets

Digitalisation is also changing how manufacturing operations are managed at the factory level.

Modern automated welding systems generate large amounts of operational data, including welding parameters, production times and equipment utilisation. Historically, much of this information remained isolated within individual machines.

Today, manufacturers are increasingly connecting production equipment into larger digital ecosystems.

These machine ecosystems enable manufacturers to monitor multiple welding systems across an entire facility or across several factories. By collecting and analysing operational data from multiple machines, manufacturers gain improved visibility into production performance.

This brings several operational advantages.

Production managers can benchmark productivity across different welding stations,



Scanning technologies allow welding systems to measure groove geometry and automatically adapt welding parameters



Modern wind towers contain kilometres of weld seams, requiring highly consistent welding processes during fabrication

identify bottlenecks and analyse equipment utilisation. Maintenance strategies can also become more proactive when performance trends are monitored continuously.

In addition, process data supports ongoing optimisation. By analysing how welding parameters influence productivity and quality outcomes, manufacturers can refine their production processes and improve overall efficiency.

For large wind tower fabrication facilities operating dozens of welding stations simultaneously, fleet-level visibility is becoming an increasingly valuable management tool.

Scaling manufacturing for the energy transition

The wind industry is expected to expand rapidly during the coming decade. Many forecasts suggest that annual wind installations must

increase significantly to meet global climate and energy security targets.

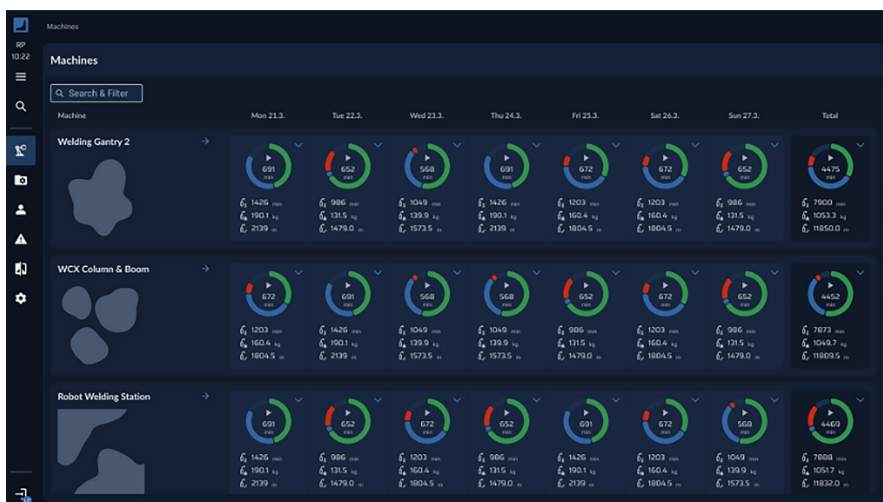
This growth will require more manufacturing capacity, but it will also demand more efficient production systems.

Automation, robotics and digital production management are becoming essential enablers of the wind industry's industrial scale-up. These technologies allow manufacturers to produce increasingly large structures while maintaining consistent weld quality and improving productivity.

At the same time, automation contributes to improved workplace safety, reduced physical strain for operators and better utilisation of factory floor space.

As turbines continue to grow and offshore projects move into more demanding environments, the manufacturing technologies behind them must evolve accordingly.

The industrialisation of welding processes, supported by automation, adaptive robotics and data driven production systems, is becoming a central part of how the wind energy sector will scale to meet the energy demands of the future.



Fleet-level monitoring platforms allow manufacturers to analyse welding performance across multiple production systems

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