A Grid to Decarbonise Europe

CurrENT event
Brussels 6 March 2024

Event Summary

Welcome by Layla Sawyer, Secretary General of CurrENT

Layla Sawyer opened the event organised by CurrENT, SuperNode, KU Leuven and the University of Strathclyde, welcoming the participants, including those following online.

CurrENT, she said, is a growing group of innovative grid technology companies. Its members are developing and supplying both technologies that can be implemented very quickly to help us get the most out of the existing grid, as well new and innovative technologies that can help build the grids that we will need to support a fully decarbonized European economy.

Up until now we have been inching forward with the grids making incremental improvements as we go along. But that that is not going to cut it. We need to look at what we are going to need in 2050, and what the technology gaps are.

She quoted Einstein who said that "the definition of insanity is doing the same thing over and over and expecting different results". If we want different results, Ms. Sawyer said, we will have to do something differently. The speakers today will share something different, she said, introducing the speakers:

- **John Fitzgerald, CEO of SuperNode**, will tell us about what a 2050 grid model could look like, when you break free from ingrained and damaging assumptions.

- **Dirk van Hertem, professor at the KU Leuven,** is going to give us an overview of the current technologies that are available, and whether current technology can deliver on what we are going to need.

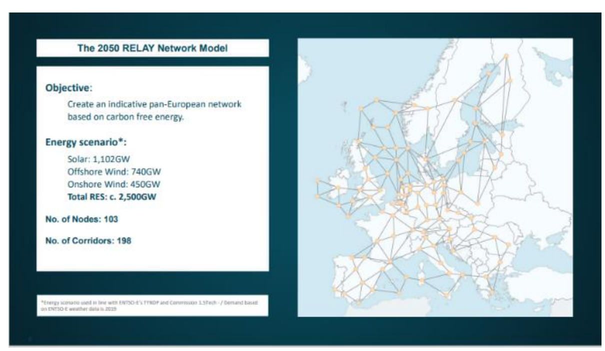
- **Professor Lie, University of Strathclyde**, will present a study that demonstrates the first ever feasible approach to a meshed DC overlay grid.

- **Dr. Eoin Hodge, chief engineer SuperNode** will talk the possibility of superconducting cable technology can fill some of the technology gap that has been identified.

- **Dr. Antje Orth, chief engineer Energinet**, and Convenor of ENTSO-E's Offshore Network Development Plan, will present ENTSO-E's report.

- **Eric Lecomte, European Commission, DG ENER** will talk about the Commission's Grid Action Plan and the Commission's Strategic Energy Technology Plan's Implementing Working Group on HVDC and DC Technologies.

John Fitzgerald, SuperNode CEO (JF)
John Fitzgerald started by saying that Europe's power system – the largest in the world – runs incredibly well. Unfortunately, it only runs on carbon. Politicians have therefore set targets to decarbonise our energy supply. This changes the game and the energy model we have developed over the past 100 years. The good news is that we can electrify with wind and solar at the needed scale and pace – and at low cost. We need to move from 25% to 75% of our energy coming from electricity. The biggest challenge is the grid supporting that enhanced power system. It has been developing very slowly.

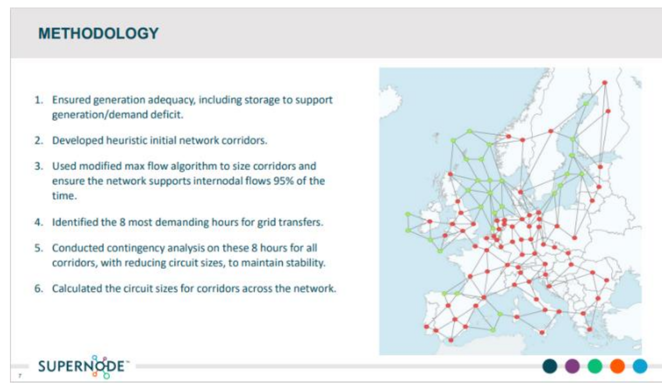


JF referred to a study by UCD last year showing that customers would get 40% cheaper electricity in Europe if we had more grids. It examined corridors of major flows of power between countries. That is not the same as a grid.

JF said, a new model – the Relay Network Model – was developed by SuperNode and UCD to provide answers to critical questions about the nature of our future power grid for decarbonisation. What we tried to do was to ask: What does a system without carbon look like? What kind of grid do we need? How big a grid do we need? What would the optimal circuit size within those corridors be? It's easy to say we need a 30 GW corridor from the North Sea to Belgium, but what are the appropriate circuit sizes for that corridor?

Once we have answered that, we can ask ourselves: Is the technology we have available today adequate? JF then moved on to present the assumptions and findings of the Relay Model – a technology agnostic network model to keep the lights on without carbon.

The model ensures generation adequacy, including storage to support generation/demand deficit. It used a modified max flow algorithm to size corridors and ensure the network supports internodal flows 95% of the time. The model identified the 8 most demanding hours for grid transfers, conducted contingency analysis of these on all corridors, gradually reducing circuit sizes – a proxy for resources and footprint – while maintaining security of supply and stability.



The circuit size was limited to 12 GW (the largest operating in the world today) and the Largest Single Infeed (LSI), i.e. the largest loss the system can withstand the loss of, was assumed to be 3 GW and 2 GW in Ireland, GB and Scandinavia. The model has 103 nodes and 198 corridors. It uses 2019 weather data and generation is adapted from the European Commission's 1,5 TECH Scenario, with a total of 2,500 GW of installed renewable energy generating capacity, including 1,100 GW solar PV, 450 GW onshore wind and 740 GW of offshore wind.

We identified the largest circuit size that can maintain stability for each corridor. You want the largest because each circuit cost money – it needs consent, right-of-way, landfall, installation and materials. The model found that the optimal average circuit size would be 6 GW, ranging from an average of 4.5 GW in Scandinavia to an average of 6.5 GW in Western Europe and 7 GW offshore.

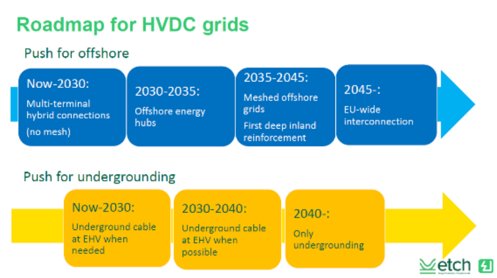
1,900,000 GWkm of transfer capacity would be needed to keep the lights on without emitting CO2, while satisfying the N-1 criteria. The cost and quantities of raw materials for infrastructure can be reduced substantially with appropriately sized circuits. While this is not a cost model, circuit-kilometers are a proxy for cost. The larger the circuits the lower the cost, as long as security of supply is maintained.

The conclusion of the Relay Network Model run was that an average circuit size of 6 GW minimizes circuit kilometers and satisfies N-1 stability criteria. With an optimal average circuit size of 6 GW, there is a significant gap between the transfer capacity of conventional power transmission technology and what is needed. We need much bigger circuit size technology than what we have today. 2 to 2.5 GW is the limit of the underground technology we have today.

This work complements the work that has been done by ENTSO-E with the ONDPs.

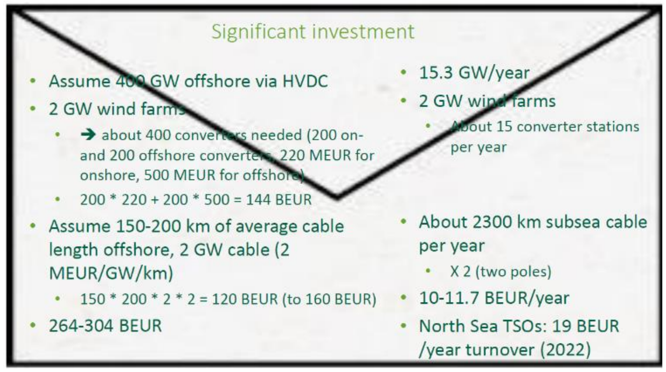
Professor Dirk van Hertem, KU Leuven.
Professor Dirk van Hertem (DvH) started by saying that a lot of innovation is necessary, but we already have a lot as well. I want to show that the steps we have to take are of a different scale than anything we have seen before. Electricity use will need to grow substantially. Today electricity is only 25% of our energy demand is electricity – the rest is largely fossil fuels – so electricity's share needs to grow. Electrification will be more efficient, so we will have less primary energy use and more electrification. We need wires for that.

If we look at offshore wind alone, putting up to 450 GW of offshore wind in the sea is not normal business. We need to have a DC grid to connect all these lines, as we did with the AC and bring it over land to the load centres. He presented a roadmap for offshore with a meshed grid starting in the mid-2030s and EU-wide interconnection from 2045. He believed Europe would gradually move towards more and more undergrounding of cables.



Interconnection and DC grids are going to be expensive. However, he said, referencing ENTSO-E, for every €1.3 bn invested you reduce generation cost by €4 bn per year. Studies in the US found that a Macrogrid expansion to support a zero-carbon system would cost €350 bn but return €1 trn in economic benefits. So, the ratio is similar: you get two to three times more back than you invest.

DvH presented a back of the envelope calculation showing investments in grids of app. €300 bn to connect 400 GW of offshore wind using HVDC. This would include approximately 200 onshore and 200 offshore converters and €120 – 160 bn worth of cables. If we had started implementation 1 January 2024, we would need to install 15 GW of offshore wind per year until 2050 – we have 30 GW of total installed capacity today. We need 15 converter stations per year, about the same as total global annual production today. Using current 525 kV cable technology, we need 2,300 km subsea cable), requiring 8 extra extruders making roughly 1 km per day.



This requires €10-12 bn per year of investments and the North Sea TSOs have an annual turnover of €19 bn per year. So, for the next 27 years the TSO must invest an amount equal to half their turnover in new technology, just for offshore. This is not trivial.

He mentioned that interoperability is absolutely crucial and suggested that a more open control paradigm would be more suitable for planning the grid of tomorrow.

Today, we can expect up to 3 GW Loss of Load in Europe, what if you lose 6 GW? We may have to think about how we design our reserves. What we found was that there is an optimum, with a possibility of going with bigger connections but they are required to have more advanced protection. We need to address those design criteria early on. Otherwise, we get stuck with a sub-optimal set-up. Energy islands are very interesting from a control and operation perspective, but there is some way to go before we have all the answers, DvH added.

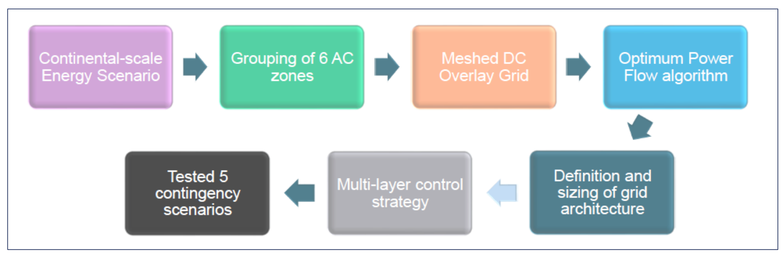
He imagined that converting to the weather-based system needed to decarbonise would require developing a sort of traffic light system in the transmission system. We also need to ask ourselves if governments are willing, for example, to accept that for some hours we will be relying exclusively on Scottish or Irish energy supply.

Some say we should have one TSO to rule them all – a super TSO. That does not sound very appealing to system operators and maybe it is not necessary. But we do need a more dynamic grid operation with shared responsibilities. I call that a “grid of grids” and I think we will see it rather quickly.
Are we ready to build HVDC grids? Yes, but: we need to address interoperability, protection, and ratings / capacity. How do 50 GW corridors work. Today’s technology

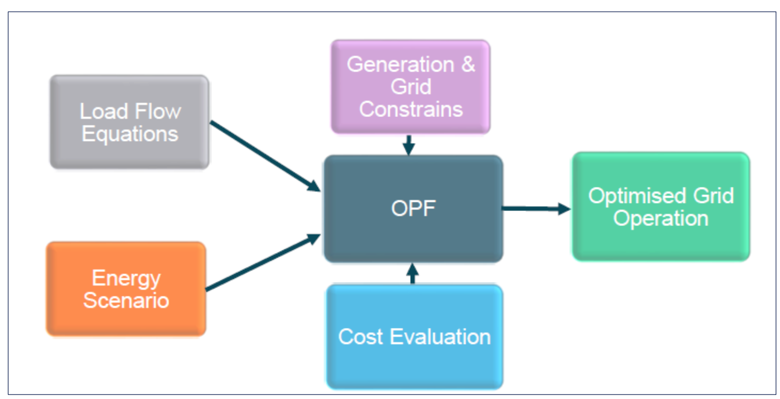
can be improved, in terms of efficiency, rating, better standards, and cost. The supply chains today are a big issue.

Meshing was valuable for AC, and I don't see an AC solution to the offshore grid. We can discuss how much meshing is needed. In the end it's a question of cost and efficiency.

Professor Lie Xu, University of Strathclyde
Professor Lie Xu (LX) presented the results of a new study that demonstrates the first ever feasible approach to a meshed continental scale DC overlay grid on top of the AC grid, undertaken by the University of Strathclyde, KU Leuven and SuperNode. The objective was to demonstrate the architecture, operation, and control of such a grid.



The study is technology agnostic and investigates how an overlay DC grid could connect with the AC grid and how the two systems interact and integrate. We took a continental scale decarbonisation energy scenario for and grouped them into 6 AC zones.



We then envisaged a DC overlay grid on top of this and ran an "optimal Power Flow Algorithm" (OPF) from KU Leuven from which we designed and sized the grid architecture. After considering the different energy scenarios we came up with a contral strategy in order to operate the system on a steady state under different contingency events. Finally we developed a model to test five different scenarios.

The OPF calculates optimised settings for generation, converters and power flow in the AC/DC netowrks and defines the sizes of the circuits.

Professor Lie then ran through two of the scenarios; i) The loss of a converter on the DC grid, resulting in a transient loss of 3 GW power and ii) A fault on a DC line transmitting 4 GW.

Professor Lie concluded by stating that the research demonstrated the first feasible approach to the development, operation, protection, and control of a continental-scale DC Overlay Grid. The control strategy was effective and demonstrate that power flow can be balanced in normal operation while system stability was maintained in all contingency scenarios,

Finally, the work demonstrates that a continental-scale renewable-based power system with adequate infrastructure can be achieved through increased system flexibility enabled by a meshed DC Overlay Grid.

The results are available in this White Paper, accompanying the research.

Dr. Eoin Hodge, SuperNode

Eoin Hodge (EH) set out to talk about technology that can deliver bulk power transfer. The focus was on superconducting transmission technology: How can they contribute to a decarbonised energy system, how do they function, what are its advantages, and what is the current status of superconducting power cables?

EH sees three overall challenges to transmission in the coming decades: i) Capacity – we need a bigger grid, ii) Range – we need to move power over longer distances, iii) Operability – we need to get the new DC overlay system to work with the existing AC system.

If we are to decarbonise, we need a grid that can move approximately three times more power around. We simply do not have the infrastructure to do that. This requires investment and grid technology development that can move much higher capacities than technology available today.

So which transmission technologies can satisfy the need for greater capacity, longer range and interoperability, EH asked?

The obvious one is **overhead transmission**. He showed a 12 GW circuit currently operating in China. It's 1,200 kV and 3,000 km long, moving hydro power from the Northwest of China to Beijing and Shanghai where the demand is. The pylons are 200 metres high, which will not be accepted in Europe.

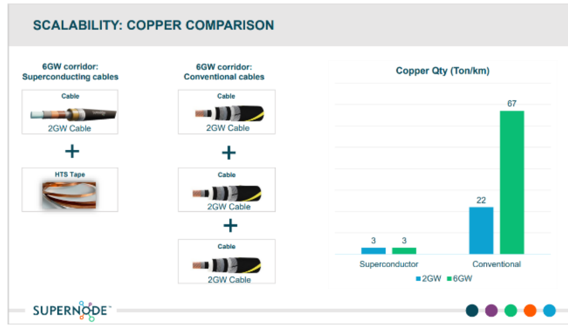
AC transmission cables are everywhere in our system, typically at distribution level. They are technically not capable of long-distance bulk power transfer without reactive compensation.

We have seen a lot of progress technically with DC cables over the last 10-15 years, culminating with 22 GW HVDC Tennet projects, EH said. These will take us a long way towards 2030 in Europe, but beyond that it's getting constrained. The supply chain can't keep up and the systems are very expensive. One solution is to go higher in voltage, which the cables may be able to. However, when you scale voltage, the whole system scales in voltage and size, making the electrical system even more expensive.

When we need more power – more capacity – we go higher in voltage and get into cost and supply chain problems. We need to break the link between voltage and power and superconductors can do that, EH said. Superconductors can achieve the higher capacities needed at lower voltages.

He explained that superconductors are materials experiencing no electrical resistance when cooled. We generally use liquid nitrogen to cool them down to minus 200°C. Nitrogen is very cheap, abundant and a very well understood cryogen. You can leverage the lack of electrical resistance and losses to have a very power dense cable allowing you to reduce voltage and increase power capacity.

EH presented five different superconducting cables that have been built and operated over the past ten years. What's common about them is that they resolve challenges around urban congestion, e.g. in Essen, Chicago and Munich.



EH explained that a 2 GW copper cable weighs about 40 ton per km whereas a superconducting cable weighs 17 ton per km. A copper cable would need more than eight times as much copper per km compared to superconducting cables. The conductor itself constitutes a fraction of the material, which makes it very scalable.

He explained that superconducting power cables are already a mature technology, when applied for urban congestion. What SuperNode (SN) is doing is developing the next generation of superconducting cables, scaling it for power capacity, for distance and for volume manufacturing. SN is developing new polymer cryostat materials to replace the expensive corrugated steel in first generation superconductors; it's developing new advanced thermal insulation and a novel outer cryostat technology that allows for volume manufacturing. Technology Readiness Level (TRL) 5 was achieved last year and TRL6 qualification will be achieved in 2025.

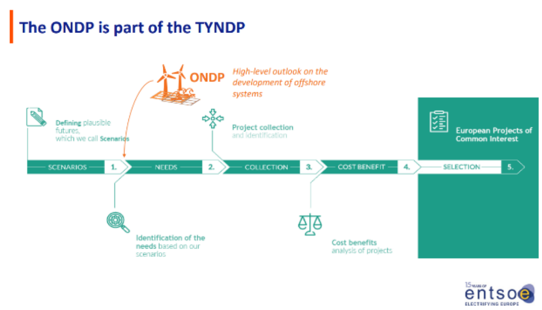
Later this year, a terrestrial demonstration project will be connected to the grid at a European TSO innovation centre. A marine demonstration of the technology is scheduled for 2026, which will be a world-first for superconducting cable systems. A commercial project is expected to be ready towards the end of the decade.

EH concluded that we need high-capacity meshed grids to deliver decarbonization. It needs to be DC, but there is a technology gap in DC. We something that can deliver with higher capacity and scale. Superconducting cable systems can do that.

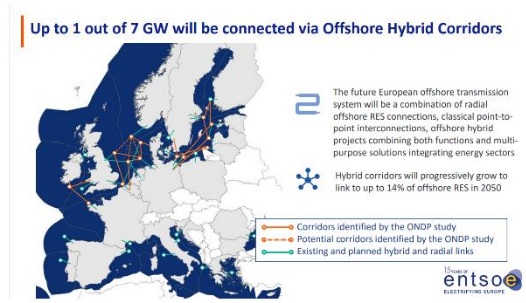
Dr. Antje Orths, Energinet / ENTSO-E

Antje Orths (AO) presented results from ENTSO-E's Offshore Network Development Plans, published in January 2024 in accordance with legal obligations under the revised TEN-E regulation. It translates the EU Member States' capacity targets into infrastructure equipment needs and their costs. Member States deliver the targets, ENTSO-E delivers the infrastructure needs, and the next step is that the Commission publishes guidelines on how to share the cost. After that the guidelines will be applied to the ONDP to see who pays what.

She then explained how the ONDPs fit into the ten-year Network Development Plan (TYNDP) framework of ENTSO-E. At the moment, the ONDP is separated from the TYNDP Needs Assessment, but in time it will be an integral part of it. The question the ONDP



answers is: "What does it take to integrate 496 GW in 2050 (382 GW in 2040) of offshore RES into the Decentralised Energy Scenario 2040/2050-environment?". The TYNDP model was used. In this first edition, only investments in transmission infrastructure are used to optimize, other parameters are locked. The TYNDP Scenarios can invest in a number of generation and infrastructure technologies. We assumed standard 2 GW links.



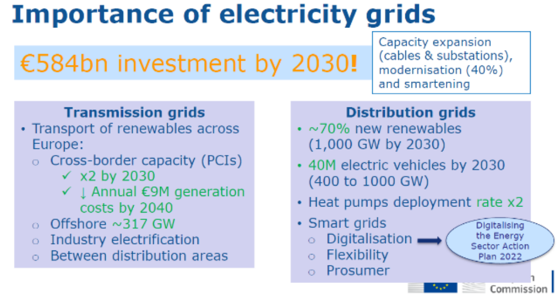
AO said that installed offshore renewables today is only 7% of what is needed by 2050 and that annual installation of generating capacity and infrastructure need to happen nine times faster than the past 10 years. The remainder of this decade, and throughout the next decade, 22 GW offshore renewables must be installed per year. Most would be radial projects. Hybrid projects connecting two countries or bidding zones and offshore renewables will link 14% of the renewable's capacity in 2050, according to the ONDP.

AO said that the ONDP distinguishes between scenarios, depending on the future availability or absence of DC circuit breaker technology. If we have DC breakers available, we will see more interlinks. If we don't have one, we get infrastructure but without interlinking, many of the benefits are lost and the price of offshore assets triple.

ENTSO-E will now integrate the ONDP into the TYDP 2024, incl. offshore reinforcements, to be released in the autumn of 2024.

Eric Lecomte, European Commission, DG ENER

Eric Lecomte (EL) confirmed the European Commission's expectation that electricity demand will need to multiply. He presented the latest Projects if Common Interest (PCIs) and Projects of Mutual Interest (PMIs) and said that the intention of the EU Grid Action Plan, a non-legislative communication from the Commission published in November 2023, is to accelerate the implementation of the PCIs. The Grid Action Plan addresses six areas:



i) **Network Planning**: The planning at transmission level is to be improved with the TYNDP and the ONDP, he said. Also, distribution level planning must be improved.

ii) **Regulatory incentives**: We must address the day-to-day requests for connection, but also anticipate a more global holistic view of future needs. EC and ACER will provide guidance on anticipating investments. The EC will also provide guidance on cost sharing – not only applying to countries with a seashore.

iii) **Smart and efficient grids**; We must enhance the grid capacity transparency, so developers know where to connect. We need to uptake smarter grids and new innovative technologies at distribution and transmission level. We also increasingly must incorporate OPEX costs in tariffs. ACER will provide recommendations.

iv) **Financing**: Massive investments are needed from TSOs. This may put them in a financial situation affecting their credit rating, reducing their capacity to fund projects. The EC will engage in investor dialogues to overcome these financing obstacles.

v) **Permitting**: Even if you have the money, the projects must still be accepted by the public. Permits go with environmental studies and the EC will provide guidance on environmental aspects.

vi) **Supply chain**. Will industry be able to deliver the equipment needed, EL asked? One way is more standardized specifications. Also, common technical requirements for connection of generation and demand are needed. Finally, the Net Zero Industry Act has not yet been adopted, but agreement has been reached. It specifically identifies grids as a critical technology to enable the Net-Zero transition.

EL also shared work done under the framework of the European Commission's SET Plan Working Group on HVDC and DC technologies and a new LVDC Implementation Plan launched last year.

Panel

The presentations were followed by a panel debate moderated by Christian Kjaer, Chair of CurrENT. Panelists were Antje Orths, Energinet; Eric Lecomte, European Commission; Lie Xu, Strathclyde University; Dirk van Hertem, KU Leuven; John Fitzgerald, SuperNode.