NEWS

720 KM: LONGEST UNDERSEA HVDC CABLE, SET TO JOIN NORWAY AND THE UK IN 2018

THE VIKING CONNECTION: A new high-voltage DC cable will connect Denmark to Norway.

STATNETT

NORWAY WANTS TO BE EUROPE'S BATTERY

A new HVDC line will let Europe store more wind energy in Norway's hydropower system

Norway's hydropower reservoirs make up nearly half of Europe's energy storage capacity. European grid operators need energy storage to cope with an ever-mounting, always-shifting torrent of wind power. See the connection? So does Norway. In December, engineers will energize a new subsea power cable that will begin to bridge the gap between need and opportunity, greatly expanding European power systems' access to Norway's hydropower-rich power grid.

The 240-kilometer cable across the Skagerrak Strait separating southern Norway and northern Denmark is Norway's first new power link to Denmark since 1993. Called Skagerrak 4, its high-voltage direct current (HVDC) converters—the electronic units at either end of the line that transform AC into high-voltage DC and vice versa—are also the building blocks for more ambitious cables from Norway to wind-power heavy- »

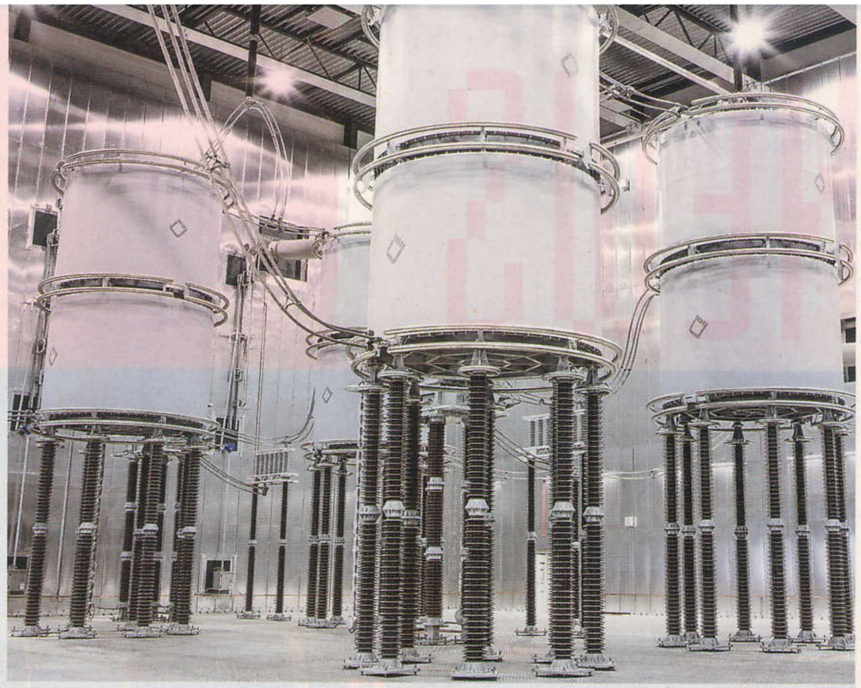
weights Germany and the United Kingdom. Construction on those is expected to commence during the coming year.

The existing Skagerrak interconnection, three HVDC cables with a combined 1,000 megawatts of capacity, is already showing the world just how well wind and hydropower complement each other. According to the Danish Energy Agency, such interconnectors are why Denmark can accommodate the world's highest levels of wind power, which met 41.2 percent of Danish demand in the first half of this year. At times wind power production even exceeds the country's domestic power demand.

"We store their surplus in the hydro reservoirs and then feed it back on a seasonal basis or a daily basis. This is a very strong business case," says Håkon Borgen, executive vice president at Statnett, Norway's state grid operator.

Norwegian hydropower turbines throttle down as Norway consumes Danish wind energy instead, leaving an equivalent amount of energy parked behind dams. And when the weather shifts and becalms the North Sea winds, the reservoirs and Skagerrak's cables feed that stored energy back to Denmark.

Borgen says the addition of the 700-MW Skagerrak 4 advances plans to plug the U.K. and Germany into Norway's batteries by pushing the most flexible form of HVDC technology–voltage source converters (VSCs)–to its highest voltage yet. VSCs' ability to stabilize the voltage of the AC grids on both sides of a cable makes the technology better suited than any existing alternative for handling intermittent flows of renewable energy, he says. Skagerrak 4's VSCs operate at 500 kilovolts each–30 percent higher than the previous record holder. Borgen says that voltage boost will be needed to reduce losses on longer runs such as the 720-km cables to the U.K., which will be the world's longest subsea power cables.



SMOOTH OPERATORS: Reactors on the Denmark side of a new HVDC link even out the flow of power stored in Norway. The country plans similar links to the United Kingdom and Germany.

ABB

ABB, of Zurich, which built Skagerrak 4's VSCs, says the tougher technology challenge was ensuring that the VSCs function well alongside the older HVDC lines. That's because current that Skagerrak 4 carries south across the strait must cycle back to Norway via the Skagerrak 3 cable, which uses the older, classic HVDC converters. This will be the world's first paired operation of cables using VSCs and classic HVDC converters.

Such a pairing gets interesting when operators want to reverse the flow of power–something that can happen up to 1,000 times per year at Skagerrak as winds and markets shift. VSCs normally reverse power flow by reversing a line's current, whereas classic HVDC converters must flip the line's voltage polarity.

So how to reverse power flow on both lines? ABB's solution is a 5- to 10-second process that uses coordinated actions by both converter types and eight high-speed switches that reconfigure the wiring of the VSCs, flipping their polarity so that the flow of power in Skagerrak 4 can change direction while its current keeps flowing south.

The process interrupts the circuit by which current flows from one cable to the other. But Lars-Erik Juhlin, an HVDC expert at ABB, says there is no meaningful loss or surge in power to the AC grids.

The key, explains Juhlin, is the excellent electrical conductivity of seawater. When the power-reversal scheme interrupts the circuit, the converters use subsea electrodes at either shore to feed the return currents across the strait through the water. Sending current through seawater can corrode subsea infrastructure such as natural gas pipelines, but here, the dose makes the poison. "They can accept even 2,000 amps for up to 2 hours. So for a short pulse, it's no problem," says Juhlin.

Statnett's follow-on interconnection projects could move quickly because they will just be longer versions of Skagerrak 4. The first, a pair of 500-kV VSC cables between Norway and Germany, was nearing final regulatory approvals when *IEEE Spectrum* went to press in October. Statnett and its European grid partner, Dutch-German firm Tennet, foresee charging up the 1,400-MW NordLink in 2018. The pair of Norway-U.K. cables, a joint effort of Statnett and London-based National Grid, is slated to start by 2020.

There should be many more cables to come if European countries make good on official goals to eliminate carbon emissions from power generation by 2050. The German government's Advisory Council on the Environment, for example, concluded in its influential 2011 report that an optimal zero-carbon power system for Germany would need more than 40 gigawatts of interconnection to Norway. That system, the council projected, would deliver power at a very affordable 6 to 7 euro cents per kilowatt-hour. Without Norwegian storage, power costs would rise to 9 to 12 euro cents per kilowatt-hour.

Ånund Killingtveit, a professor of hydraulic and environmental engineering at the Norwegian University of Science and Technology, says Norwegian hydropower is up to at least part of the task. Killingtveit led a five-year, US $5.7 million research program on hydropower balancing, which showed that existing hydropower reservoirs could "fairly easily" move about 25 GW of energy in and out of storage without damaging the environment—five times as much as they currently manage. The key, he says, is installing pumps to shift water from one reservoir to a higher one nearby, thus actively storing power rather than just deferring production.

If there is a limit to Norway's energy storage potential, it may ultimately be the country's own grid. Statnett has begun a 10-year, $8 billion to $10 billion grid upgrade, but it factors in only 3.5 GW of additional power from the three cable projects. The question may be how many power lines the Norwegians will accept to smooth Europe's departure from fossil fuel power. —PETER FAIRLEY

NEWS

TWIST AND SHOUT

Spiraling radio beams send data at 32 gigabits per second

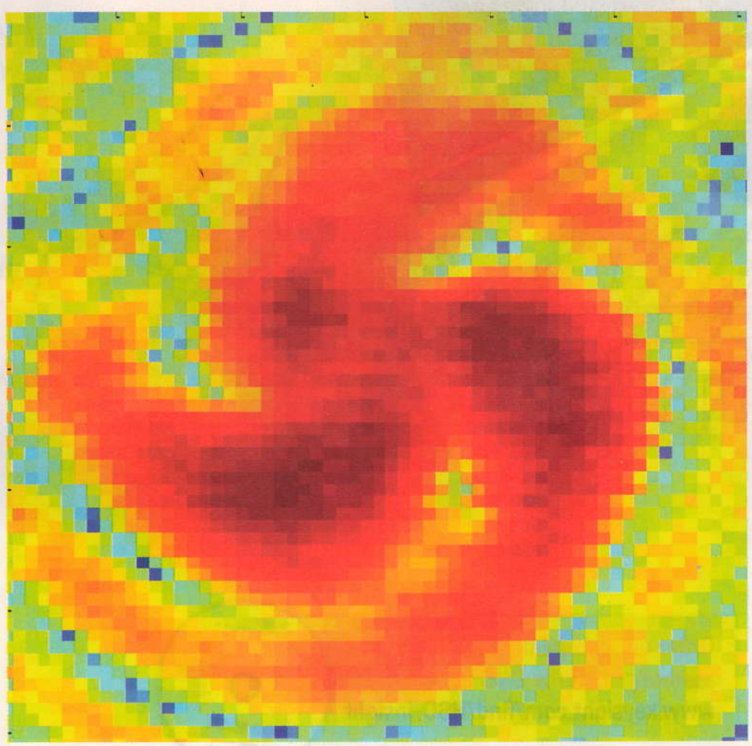
A team led by engineers at the University of Southern California has sent multiple channels of data over a single frequency by twisting them together into a beam resembling a piece of fusilli pasta. By combining several polarized beams carrying information into a single spiraled beam, the team was able to send up to 32 gigabits per second across 2.5 meters of open air, a rate around 30 times as fast as an LTE wireless connection.

The high data rate was made possible through a technique known as orbital angular momentum (OAM) multiplexing, says USC electrical engineering professor Alan Willner, who partnered with researchers from the University of Glasgow and Tel Aviv University on the experiment.

A property of electromagnetic waves first identified in the 1990s, OAM can be harnessed to let multiple channels of information ride along a single frequency. "I could have a wave that twists slowly and one that twists a little faster, and those waves are now orthogonal to one another," Willner says. "If you put them together and send them spatially co-located through the same medium, you have doubled your capacity."

Willner and others have previously demonstrated the twisting technique with beams of light, reaching data transmission speeds of 2.56 terabits per second through the air in 2012 and 1.6 Tb/s over optical fiber in 2013.

ROTATING RADIO: Waves of the same frequency won't interfere with one another if they are given different degrees of orbital angular momentum.



YAN YAN, GUODONG XIE, AND ALAN WILLNER