Engineering 6 (2020) 587–589

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

News & Highlights

Transmission Infrastructure Challenges Use of Renewable Energy

Mitch Leslie

Senior Technology Writer

By 2030, California plans to obtain 60% of its electrical power from renewable sources [1]. The state will be able to produce only about half that amount of power itself, however, and will need to import the rest [2]. In contrast, by 2030 the Upper Midwest portion of the United States will be generating more than twice as much renewable energy as it needs—so much that wind farms in the region will have to cut back their output by 61% [2].

The obvious solution to this imbalance—sending the spare Midwestern power to California—is not possible with the current US electrical grid. To meet renewable energy targets set by states and companies, the United States needs to build a large number of new electrical transmission lines to carry power within and between regions, according to a new report commissioned by Wires, a Washington, DC-based trade group that includes power companies, transmission line operators, and engineering firms [2].

China and the European Union (EU) face the same challenge as the United States as they try to integrate more renewable power into their energy mix—the large cities with the highest power demand are not necessarily close to the areas where renewable energy is cheapest and most abundant. They are following different strategies than the United States to modify their electricity grids to distribute this power.

In the United States, the prime zone for wind power is the midsection of the country, from Texas to the Canadian border [3], whereas the southwestern states have the most potential for solar power [4]. Because constructing new transmission lines is less expensive than building facilities for capturing renewable energy, consumers will get the cheapest electricity if these facilities are located in these prime areas, said James McCalley, professor of power system engineering at Iowa State University (Ames, IA, USA). "Ideally, you want to build where resources are of the highest quality and then move the power to areas of need."

The popular impression is that the US power grid is crumbling and outdated, but that view is wrong, said John Kassakian, professor of electrical engineering at the Massachusetts Institute of Technology. "It's clear that the grid as it stands is keeping the lights on everywhere." Regardless, the US grid does need substantial upgrades before it can optimally distribute large amounts of renewable power, said Gregory Reed, professor of engineering at the University of Pittsburgh. Once renewable energy facilities start providing gigawatts of power rather than the megawatts they typically generate today, "we don't have the grid infrastructure for that," Reed said.

One limitation is that instead of an integrated nationwide power grid, the United States relies on three mostly independent networks [5]. The Eastern Interconnection covers the majority of the eastern and central parts of the country. The Western Interconnection powers almost all of the country west of the Great Plains. A third grid serves much of Texas. Although electricity can move around within each network, only a few, low-capacity connections link the three systems, and they share almost no power, McCalley said. As a result, Nebraska wind power cannot reach Los Angeles, and solar power from Arizona cannot keep the lights on in New York.

Updating the US grid to optimally distribute renewable power "will require a major investment in high-voltage direct current transmission," said Reed. High-voltage direct current (HVDC) lines can carry up to eight times more power across the same right of way and lose less power per kilometer than do the alternating current (AC) lines that predominate in the United States [6,7]. They also cost less to construct, Reed said. However, because HVDC lines require expensive converter stations at each end to switch their power to and from AC [8], they are not cost-effective unless they are at least about 300 km long, Reed said. The United States currently has five HVDC lines, McCalley said, but only two carry power from renewable sources across long distances. One 500 kV line brings hydropower 1361 km from the Pacific Northwest to Southern California, and the second 450 kV line delivers hydropower 1480 km from Quebec to Massachusetts [9].

Numerous schemes for revamping the US electrical power grid and adding long-distance HVDC lines have been proposed [7]. One plan released in 2019 by China's Global Energy Interconnection Development and Cooperation Organization calls for ten new 800 kV ultra-HVDC lines in North America, as well as multiple new high-voltage AC lines, by 2035 [10]. A 2018 study by the US National Renewable Energy Laboratory evaluated three alternatives for building stronger links between the Eastern and Western Interconnections [11]. For example, one proposal would increase the capacity of the existing links between the interconnections. The second scenario would add three HVDC lines to connect the Midwest and South to the western states. And the third scenario envisions an HVDC "macrogrid" serving much of the country. The study found that all three options were superior to merely increasing the number of AC lines within each interconnection, with the savings outweighing costs by 13% to 26% [12,13]. If the United States adopted a carbon-pricing policy, the benefits would be even

https://doi.org/10.1016/j.eng.2020.04.006

larger. Boosting power exchange between the interconnections would also increase the reliability, resilience, and adaptability of the grid, said McCalley, who helped conduct the study.

Whether new HVDC lines will be built is uncertain, however. The United States does not have a national strategy for updating its grid to accommodate more renewable power, Reed said. And potential new lines face economic and political hurdles. Because obtaining permission is so difficult, "building new transmission is a real challenge," said Kassakian. Any proposed line requires approval from all of the states it will cross—and some states are fighting HVDC projects [14]. "States pretty much have a monopoly over siting lines," said Kassakian.

Moreover, not everyone is convinced that all these new lines are needed. Alexandra von Meier, an adjunct professor of electrical engineering and computer science at the University of California, Berkeley, said that alternative approaches such as increasing local electrical storage and better controlling demand could allow greater use of renewable energy without requiring large numbers of new lines. "I am in favor of building transmission lines if and when they are clearly needed," she said, "but before we do that, we should consider other solutions and be sure to understand the tradeoffs."

Unlike the United States, China has aggressively expanded its HVDC transmission capacity, and now has 22 ultra-high voltage—exceeding 800 kV—lines, more than any other country [15,16]. Plans call for construction of at least 11 more ultra-high voltage lines [15]; the enormous voltage capacity allows transmission over longer distances because the lines lose less power [15]. In 2019, China unveiled the longest, highest-voltage line in the world; this ultra-HVDC link can carry 1100 kV and runs 3293 km between Xinjiang in the northwest part of China and Anhui in the eastern part of China (Fig. 1) [17]. Another key part of China's grid modernization is a network of ultra-high-voltage AC lines that distribute the power delivered by ultra-HVDC lines [16].

China's upgraded transmission system enables it to use its renewable resources more efficiently. For example, in 2017, Xinjiang had to curtail, or hold back from the grid, more than 20% of its solar generation and 25% of its wind power [17]. The new 1100 kV line allows more of this electricity to reach parts of the country that need it. However, the line will only carry about 50% renewable power, with the rest coming from coal-fired plants [17].

China's grid modernization does have some limitations. It has been expensive—the Xinjiang-to-Anhui line cost more than 40.7 billion CNY (about 5.8 billion USD) [15]. And questions remain about how well the HVDC and high-voltage AC portions of the system will mesh (Fig. 2) [15].

Fig. 1. China has aggressively expanded its high-voltage transmission capacity in the past two decades. Seen here is part of the newly operational ultra-HVDC 1100 kV transmission line. It is the longest, highest voltage line in the world, linking Xinjiang in the northwest part of China to Anhui in the eastern part of China, spanning a distance of 3293 km. Credit: People's Network–Hubei Channel, 28 September 2019.

Fig. 2. This is one of the two giant transformers for the new 1100 kV transmission line that runs 3293 km between Xinjiang and Anhui in China. Located at the terminus of the line, it is 37.5 m long and weighs more than 816 t. With > 99% efficiency, the transformer converts the ultra-high-voltage line's direct current into AC that is distributed to cities. Credit: Siemens (press release).

The EU strategy for incorporating renewables into the grid focuses on increasing integration between the power systems of its individual members. Like the United States, the EU includes disparate states (nations, in this case) with different power mixes and strategies. For example, Germany currently gets 46% of its electricity from renewable sources [18], Sweden > 50% [19], and Luxembourg ~10% [20]. The EU's current targets call for member nations to be able to send 10% of their generating capacity across their borders by 2020 and 15% by 2030 [21]. Such transfers are supposed to better match supply to demand and shift renewable energy to where it is needed.

EU member countries are also planning or building new HVDC lines to redistribute renewable energy. In 2019, for instance, Germany approved the first leg of a high-voltage line to bring North Sea wind power to the southern part of the country [22]. An HVDC cable that would run under the North Sea from Norway to Scotland in the United Kingdom also received approval in 2019 [23]. But unlike China, Europe has not seen a boom in high-voltage lines, said Reed. "Their electricity grid was pretty well built up already," very much like the US grid, he said.

References

[1] Domonoske C. California sets goal of 100 percent clean electric power by 2045 [Internet]. Washington, DC: National Public Radio; 2018 Sep 10 [cited 2020 Mar 22]. Available from: https://www.npr.org/2018/09/10/646373423/california-sets-goal-of-100-percent-renewable-electric-power-by-2045.

[2] Informing the transmission discussion [Internet]. Atlanta: ScottMadden Management Consultants; [cited 2020 Mar 22]. Available from: https://www.scottmadden.com/insight/informing-the-transmission-discussion/.

[3] Nusca A. Top 10 states for wind power in the United States [Internet]. ZDNet; 2010 Feb 22 [cited 2020 Mar 22]. Available from: https://www.zdnet.com/article/top-10-states-for-wind-power-in-the-united-states/.

[4] Sengupta M, Xie Y, Lopez A, Habte A, Maclaurin G, Shelby J. The national solar radiation data base (NSRDB). Renew Sustain Energy Rev 2018;89:51–60.

[5] US electric system is made up of interconnections and balancing authorities [Internet]. Washington, DC: United States Energy Information Administration; 2016 Jul 20 [cited 2020 Mar 22]. Available from: https://www.eia.gov/todayinenergy/detail.php?id=27152.

[6] Sneed A. A comeback for electricity tech once championed by Thomas Edison [Internet]. Scientific American; 2017 Jun 1 [cited 2020 Mar 22]. Available from: https://www.scientificamerican.com/article/a-comeback-for-electricity-tech-once-championed-by-thomas-edison/.

[7] Temple J. How to get Wyoming wind to California and cut 80% of US carbon emissions [Internet]. Boston: MIT Technology Review; 2017 Dec 28 [cited 2020 Mar 22]. Available from: https://www.technologyreview.com/s/609766/how-to-get-wyoming-wind-to-california-and-cut-80-of-us-carbon-emissions/.

[8] Larson A. Benefits of high-voltage direct current transmission systems [Internet]. Power; 2018 Jul 31 [cited 2020 Mar 22]. Available from: https://

www.powermag.com/benefits-of-high-voltage-direct-current-transmission-systems/.
[9] Assessing HVDC transmission for impacts of non-dispatchable generation [Internet]. Washington, DC: United States Energy Information Administration; 2018 Jun [cited 2020 Mar 22]. Available from: https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf.
[10] Fairley P. China's grid architect proposes a "Made in China" upgrade to North America's power system [Internet]. New York: IEEE Spectrum; 2019 Sep 12 [cited 2020 Mar 22]. Available from: https://spectrum.ieee.org/energywise/energy/renewables/chinas-grid-architect-offers-made-in-china-upgrade-to-north-americas-power-system.
[11] Interconnections seams study [Internet]. Golden: National Renewable Energy Laboratory; 2018 Jul 26 [cited 2020 Mar 22]. Available from: https://www.terrawatts.com/seams-transgridx-2018.pdf.
[12] Roberts D. We've been talking about a national grid for years. It might be time to do it [Internet]. Vox; 2018 Aug 3 [cited 2020 Mar 22]. Available from: https://www.vox.com/energy-and-environment/2018/8/3/17638246/national-energy-grid-renewables-transmission.
[13] It's time to tie the US electric grid together, says NREL study [Internet]. New York: IEEE Spectrum; 2018 Aug 8 [cited 2020 Mar 22]. Available from: https://spectrum.ieee.org/energywise/energy/the-smarter-grid/after-almost-100-years-of-talk-time-might-be-right-to-strengthen-the-interconnect.
[14] Tomich J. Battle reignites over $2.5B midwest transmission line [Internet]. Washington, DC: E&E News; 2019 Dec 19 [cited 2020 Mar 22]. Available from: https://www.eenews.net/stories/1061847775.
[15] Fairley P. China's ambitious plan to build the world's biggest supergrid [Internet]. New York: IEEE Spectrum; 2019 Feb 21 [cited 2020 Mar 22]. Available from: https://spectrum.ieee.org/energy/the-smarter-grid/chinas-ambitious-plan-to-build-the-worlds-biggest-supergrid.
[16] Temple J. China's giant transmission grid could be the key to cutting climate emissions [Internet]. Boston: MIT Technology Review; 2018 Nov 8 [cited 2020 Mar 22]. Available from: https://www.technologyreview.com/s/612390/chinas-giant-transmission-grid-could-be-the-key-to-cutting-climate-emissions/.
[17] Fairley P. China's state grid corp crushes power transmission records [Internet]. New York: IEEE Spectrum; 2019 Jan 10 [cited 2020 Mar 2]. Available from: https://spectrum.ieee.org/energywise/energy/the-smarter-grid/chinas-state-grid-corp-crushes-power-transmission-records.
[18] Renewable energy's share of German power mix rose to 46% last year: research group [Internet]. London: Reuters; 2020 Jan 3 [cited 2020 Mar 22]. Available from: https://www.reuters.com/article/us-germany-power-outputmix/renewable-energys-share-of-german-power-mix-rose-to-46-last-year-research-group-idUSKBN1Z21K1.
[19] Meyer D. More renewables than fossil fuels: as the UK reaches an energy milestone, here's how far others have gotten [Internet]. Fortune; 2019 Oct 15 [cited 2020 Mar 22]. Available from: https://fortune.com/2019/10/15/uk-renewable-energy-40-percent-fossil-fuel/.
[20] Oglesby K, Jacquemot P. 10% of electricity in Luxembourg from renewable sources [Internet]. Luxembourg Times; 2019 Oct 16 [cited 2020 Mar 22]. Available from: https://luxtimes.lu/luxembourg/38764-10-of-electricity-in-luxembourg-from-renewable-sources.
[21] Electricity interconnection targets [Internet]. Brussels: European Commission [updated 2020 Mar 17; cited 2020 Mar 22]. Available from: https://ec.europa.eu/energy/topics/infrastructure/electricity-interconnection-targets_en.
[22] German energy regulator approves first part of ultranet power line [Internet]. London: Reuters; 2019 Jan 21 [cited 2020 Mar 22]. Available from: https://www.reuters.com/article/germany-powerline-ultranet/german-energy-regulator-approves-first-part-of-ultranet-power-line-idUSL8N1ZL2OE.
[23] McPhee D. Scotland to Norway supercable granted marine licenses [Internet]. Energy Voice; 2019 Feb 15 [cited 2020 Mar 22]. Available from: https://www.energyvoice.com/otherenergy/192855/scotland-to-norway-supercable-granted-marine-licences/.