Reducing Variable Generation Curtailment Through Flexible Transmission Expansion and Operation in the United States

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Overview

Over the past two decades, variable resource renewable generation (VG) capacity, made up of largely wind and solar technologies, has grown rapidly in the United States. From 2001 to 2016, the share of generation from wind and solar technologies grew from a mere 1.8% to almost 7% of total U.S. electricity generation, and this trend in growth is expected to continue (Cole et al. 2016; EIA 2017). As the penetration of VG technologies increases, the potential for curtailment, or the intentional reduction in generation from VG capacity when generation exceeds load, can substantially increase (Denholm and Margolis 2016; Denholm, Clark, and O'Connell 2016). Curtailment may result from insufficient transmission capacity to export surplus power, inability to store surplus energy, or inability to turn down committed thermal units (Bird, Cochran, and Wang 2014; Fink et al. 2009). Curtailment decreases the value of the plants and can drive suboptimal deployment of resources from the perspective of a societal system planner. Therefore, mitigating curtailments of VG is a key factor in improving the economic value of renewable projects, especially as electricity demand is increasingly served by VG.

A key driver of curtailment is the lack of available transmission (Bird, Cochran, and Wang 2014; Fink et al. 2009). Such shortages occur both on a *planning* level, when new transmission line construction lags behind renewable capacity expansion (Fink et al. 2009), and on an *operating* level, when there is transmission congestion during certain periods. In this study, we examine the relationship between VG deployment, VG curtailment, and transmission expansion. We use the Regional Energy Deployment System (ReEDS) capacity expansion model to evaluate how different levels of VG deployment, transmission expansion, and inter-regional cooperation (represented through hurdle rates) impact VG curtailment and the overall capacity and generation mix. In addition, we quantify the electricity system costs of the various configurations of transmission expansion explored across the scenarios.

Methods

In this study we implement the National Renewable Energy Laboratory (NREL) ReEDS model, a linear optimization model that determines the capacity expansion of both traditional and renewable technologies from present to 2050 (Eurek et al. 2016). The model applies a linearized AC power flow approximation based on the fast decoupled load flow method for transmission representation, and considers the co-optimization of both renewable energy capacity and transmission expansion based on system cost-effectiveness.

Using ReEDS, we simulate and analyze a suite of future power system expansion scenarios to investigate the role of transmission in reducing VG curtailments. The Reference scenario assumes a business-as-usual power system evolution considering default physical, technological, and policy constraints. The High Variable Generation (HiVG) base scenario prescribes the level of national VG to be 10% of total generation in 2020, 25% in 2030, 40% in 2040, and 55% in 2050, where VG technologies are defined as utility-scale PV, distributed PV, concentrating solar power without storage, and land-based and offshore wind.

To demonstrate both the effects of both physical transmission constraints as well as operational challenges (limited interregional coordination), we first consider two transmission expansion futures: one that allows transmission capacity construction and one that prohibits any new transmission expansion. For each of these two transmission configurations, we implement four levels of hurdle rates ($0, $5, $10, and $15/MWh) for transferring power across 18 ReEDS regional transmission organization (RTO) regions. Here hurdle rates represent the bilateral trading transaction costs, wheeling charges, and other transmission-related limitations between balancing areas. The different levels of hurdle rates represent different levels of "friction" between regions.

Results

For the scenarios where transmission capacity expansion is allowed, higher levels of VG penetration drive additional transmission expansion. The cumulative transmission capacity is always higher under the HiVG scenario than the corresponding Reference scenario. Also, higher hurdle rates result in less transmission expansion and lower transmission utilization rate.

The curtailment rate generally increases as VG penetration increases. However, somewhat surprisingly, the results suggest that curtailment levels are quite similar under different transmission expansions and hurdle rates for the given VG penetration (Figure 1). One of the reasons for limited impact on overall curtailment is that the ReEDS model changes its capacity and generation mix as transmission gets more constrained. As transmission gets more constrained, natural gas combined cycle (NG-CC) capacity and solar capacity are increasingly relied upon, but wind and natural gas combined turbine (NG-CT) capacity are reduced. The reduction in coal generation lowers the minimum generation level of the coal plants (i.e., more plants are turned off for longer periods), which in turn increases the flexibility of the system and allows the additional PV to be integrated without increases to the overall curtailment rate.

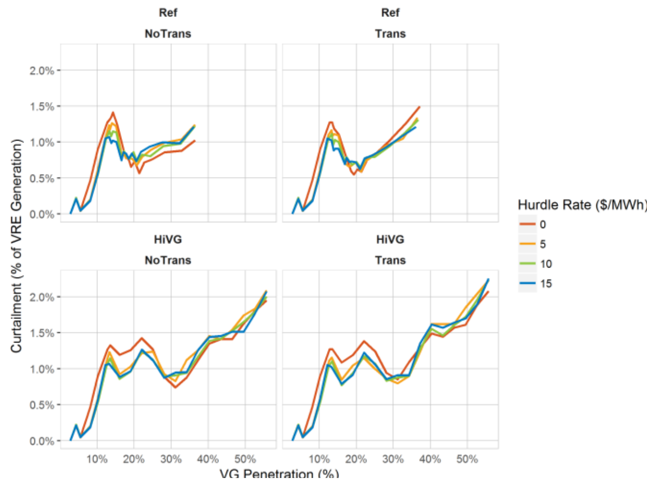

Figure 1. National curtailment level vs. VG penetration for difference scenarios.

Although the changes in capacity and generation mix allow the system to maintain nearly the same curtailment levels as we layer on transmission constraints, such solutions are more costly to achieve. Total system cost increases as the hurdle rate grows. For example, under the HiVG scenarios when transmission is allowed, the total system costs are $20, $28, and $34 billion (2016$) higher with $5/MWh, $10/MWh, and $15/MWh hurdle rates, respectively, than the no hurdle-rate scenario.

Conclusions

In this study, we explored how different levels of transmission expansion and interregional cooperation impact VG curtailments, and how the generation mix can respond in order to minimize curtailment. Our results show that VG curtailment increase as VG penetration grows, although overall curtailment levels remain relatively low. Curtailments under different transmission assumptions are very similar, mainly because the model builds more flexible conventional plants and chooses VG locations that are closer to load centers rather than more remote sites. Under more restricted transmission system, natural gas combined cycle and solar capacity increase while wind and coal capacities decrease. Such changes in capacity and generation mix allow the system to increase grid flexibility and local generation, which counterbalances the transmission availability constraints and thus mitigates VG curtailment levels.

Although an adjusted generation mix can help mitigate curtailments when transmission is not available, such integration requires higher cost local generation and results in higher total system costs. Additional regional cooperation among balancing areas, RTOs, or other organizations has the potential to increase the system efficiency and reduce economic losses that created by limitations in the ability to reduce curtailment through exports.

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