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Marginal curtailment of wind and solar PV: transmission constraints, pricing and access regimes for efficient investment

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At COP28 in 2023 more than 115 countries promised to triple renewable energy capacity by 2030 - requiring a massive increase in the proportion of electricity generated by Variable Renewable Electricity (VRE, wind and solar PV). VRE has a high ratio of peak: average output, 3 - 4:1 for wind, 4-10:1 for PV. For VRE to contribute a high share of annual output, peak generation will inevitably exceed demand (including for storage and export) for a significant fraction of the year.

The challenge facing liberalised electricity markets is to adapt pricing, dispatch and even access rules to address VRE surplus supply. Liberalised markets in Europe adopted market designs that coped reasonably well with the conventional power stations for which transmission systems were designed. Markets set prices on the fiction of firm access and no internal constraints, leaving it to the System Operator to ensure final balancing of supply and demand. This was defensible with the initially adequate reserves and robust transmission system. Countries with severe internal constraints like Norway and Italy chose zonal pricing. Great Britain is consulting on Locational Marginal Pricing (LMP) and zonal pricing. Few countries recognised the importance of guiding the location of new generation with zonal transmission charges. Most EU countries have zero transmission charges for generation.

High VRE penetration casts doubt on almost all these design features. VRE resources are differently located and will likely face local transmission constraints more frequently than well-connected conventional generation. VRE lacks inertia. At some level of instantaneous share, VRE must be curtailed to keep adequate spinning turbines synchronised. VRE’S high peak: average ratio will inevitably require curtailment. Newbery demonstrated that marginal curtailment is typically 3+ times average curtailment. In current European markets entry decisions are driven at best by average curtailment. The marginal contribution of the last MW will be more heavily curtailed than the average, and so will deliver fewer useful MWh for the same cost. When inertia is the problem new VRE entry anywhere on the system risks being excessive.

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This paper addresses the more immediate problem of curtailment caused by the transmission constraints, whether existing market designs and access regimes (i.e. who gets curtailed and how much) give inefficient VRE entry signals, and if so what changes to these rules can resolve the problem. Whereas it is hard to devise price signals for inertia, pricing interconnector constraints is already standard. When constrained the resulting price difference will be the scarcity value of the constraint. This paper asks whether pricing internal constraints is sufficient, and, if nodal pricing has been ruled out, whether there are alternative solutions that could also work.

The paper concludes first, that most current VRE support policies exacerbate the efficient dispatch of VRE. Network charging arrangements frequently fail to provide good locational guidance and with firm access (i.e. the right to compensation if curtailed) over-encourages excessive entry into export-constrained zones. These design flaws call for immediate reform. However, while the concept of average curtailment is well recognized the concept of marginal curtailment has been underappreciated and brings new challenges to market and access design. Even under ideal conditions in which merchant entry is commercially viable with no contracts distorting dispatch decisions there are problems with most current market designs. Merchant VRE entry incentives are excessive in most liberalized European electricity markets with zonal pricing, zero transmission charges and firm access.

Modest changes to the access regime for new VRE entrants granting them non-firm access and priority dispatch (last in, first curtailed) largely solves the problem while not disturbing revenue streams to incumbents. In Queensland's Renewable Energy Zones, if exit capacity is optimized and VRE pays the marginal transmission capacity charge, then entry signals would be efficient even under current state-wide pricing. Indeed, priority access would both be unnecessary and give inefficient signals. If Australia adopted LMP, then if VRE continues to be charged for transmission, efficient entry signals would require pro-rata allocation of Transmission Congestion Revenue contracts. A simpler solution would be to remove the transmission charge and allocated all congestion revenue to the transmission owner.

The main conclusion is that transmission charging, access regimes and market pricing rules all interact to determine the efficiency of entry signals facing new VRE investors. While this article has shown that LMP requires natural adjustments to the access regime for VRE, it is not an argument against LMP. On the contrary, the main attraction of LMP is its ability to give efficient real-time dispatch signals for flexible dispatchable generation. Discussions about the case for LMP note that contracts for supporting VRE would probably need modification, and this article has shown that a move to LMP could require revisiting existing charging and access rules.