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Flexibility in Wind Power Interconnection Utilizing Scalable Power Flow Control

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SUMMARY

This paper explores how adding power flow devices incrementally to constrained transmission lines provides benefits to both wind generation developers and transmission owners. Capital is only spent when it is necessary, generation developers can be charged incrementally, in-service dates can be accelerated and congestion can be relieved providing economic benefits to the region.

KEYWORDS

Distributed Series Reactor, FACTS, D-FACTS, Power Flow Control

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Introduction

Utility scale wind deployments in the US have increased rapidly over the last decade and according to interconnection request data in various regions, additional deployments are expected. Renewable energy expansion subjects stakeholders, such as transmission owners (TOs) and generation developers, to uncertainty including schedule uncertainty, location uncertainty, financial uncertainty and operational uncertainty. These uncertainties are in addition to the greater uncertainty that TOs are facing compared to the era of vertically integrated utilities with coordinated transmission and generation planning. All of these factors impact the scope, timeline and cost of transmission expansion required to successfully interconnect and operate new wind generation customers. This paper reviews the challenges of wind interconnection from the TO's perspective and discusses the possibility of employing scalable power flow control solutions on the existing transmission system in order to minimize this uncertainty in all four dimensions while also reducing or eliminating transmission congestion on existing transmission lines. Scalable power flow control allows transmission utilities to interconnect new generation customers in a flexible manner, bring generation online sooner and allocate costs to customers incrementally. Further, it can provide a cost effective way to minimize congestion that can result in curtailing wind generators during critical load periods.

Consequences of Transmission Constraints

Utility-scale wind deployments in the US have increased rapidly over the last decade. Financial incentives, state and federal regulations, and climate change concerns continue to drive the construction of more renewable capacity, and the EPA's proposed clean power plan is adding an additional layer of uncertainty. Constraints on the transmission grid tend to be one of the main challenges to integrating utility scale wind generators. These constraints cause two main issues:

- Certain constraints must be resolved before a wind generator can be brought online initially, increasing the fixed cost of wind deployment.
- Constraints may cause congestion at certain times resulting in wind generators being curtailed (turned off) even when the wind is blowing, reducing generator revenue.
- The cost and time to address some transmission constraints may derail certain generation projects altogether.

Overview of Interconnection Process

When a wind developer determines where they intend to construct a new wind farm, they must work with the local regional transmission organization (RTO) or transmission owner (TO) to determine what impacts the proposed generation will have on the existing transmission system. This is typically referred to as entering the generation interconnection queue, and the process can take many years before a new wind generation customer is allowed to come online and begin producing power. During this time a number of studies are done, which are shown in Figure 1 below. This process, seen in Figure 1, includes a number of progressively more detailed versions of the following studies:

- Power flow analysis
- Fault current and stability studies
- Physical constructability studies
- Cost allocation studies

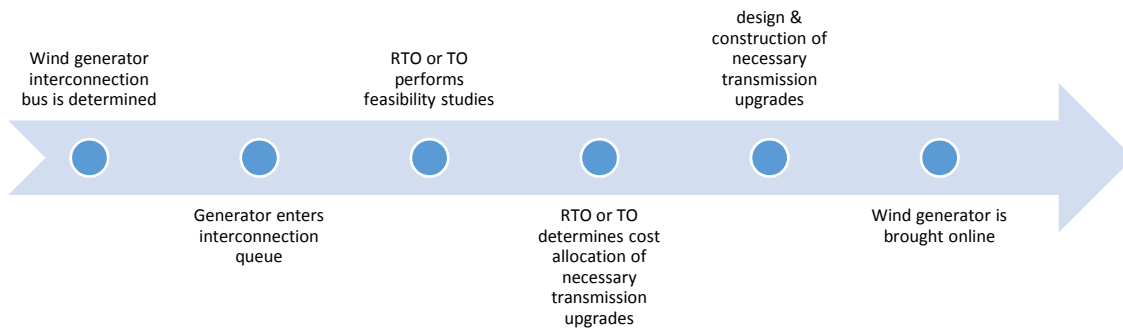


Figure 1 - typical interconnection process in the USA (details vary depending on region)

If the electrical studies determine that the transmission system requires upgrades in order to accommodate the new wind generator, the wind generator may be responsible for some or all of these costs, an example of which is demonstrated in Table 1 below. Further, the generator may have to wait to come online until the transmission projects are completed, which could be after the requested in-service date of the generation customer. Wind generators may be curtailed (turned off) due to transmission congestion even after the required upgrades are complete.

Required Upgrades	Total Upgrade Cost	Cost Allocated to Wind Generator X (based on load flow)	Cost Allocated to Wind Generator Y (based on load flow)	Cost Allocated to Wind Generator Z (based on load flow)
Line #1755: Rebuild 18 miles of 115 kV	\$9,000,000	\$2,500,000	\$3,500,000	\$3,000,000
Line #1834: Rebuild 9.5 miles of 161kV	\$4,800,000	\$500,000	\$1,000,000	\$3,300,000
Substation 34: replace three 115kV breakers.	\$2,000,000	\$2,000,000	0	0

Table 1 - GI upgrade cost allocation example (for a hypothetical project)

There are a large number of proposed wind generators in several RTO markets. Between CAISO, MISO, PJM and SPP regions there is over 34,000 MW of wind generation currently in the generation interconnection queues.

	CAISO [4]	MISO [5]	PJM [6]	SPP [7]
Wind in Queue as of June 2015 (MW)	3,600	11,900	12,700	6,500

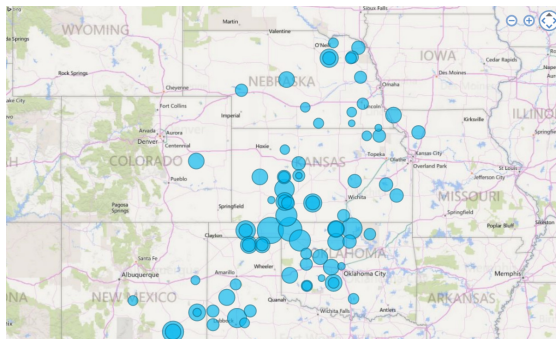


Figure 2 - wind generators in the SPP interconnection queue. Circle size is proportional to nameplate capacity [7].

Project Type	Current Cost Estimate
Balanced Portfolio	\$65,342,060.00
Economic	\$15,780,573.00
Generation Interconnection	\$124,563,559.00
High Priority	\$1,313,191,074.00
Regional Reliability	\$2,333,921,972.00
Regional Reliability - Non OATT	\$7,107,090.00
TO - Sponsored	\$61,304,438.00
Transmission Service	\$104,965,855.00
Zonal Reliability	\$109,245,734.00
Total	\$4,135,422,355.00

Figure 3 - estimated costs for approved projects in SPP region by need type [2].

Overview of Cost Allocation Procedures

Capital costs for necessary transmission upgrades are usually funded directly by the wind generation developer rather than being added to the rate base of the transmission owners. The cost and scope of work can vary widely depending on the size of the proposed wind farm and the state of the surrounding transmission system. Some proposed wind farms may only require modest substation upgrades, while others require miles of existing transmission lines to be rebuilt over a number of years. For example, a recent feasibility study in the SPP region revealed that approximately 68 miles of transmission lines would have to be rebuilt at a cost of \$38 million in order to interconnect just 172 MW of proposed wind generation [1]. This is a cost of \$220/kW. Historically, wind interconnection costs have ranged from nearly \$0/kW to more than \$1500/kW [3].

Benefits of Power Flow Control

Scalable power flow control technology enables each power line to dynamically control and transfer more or less power based on the real-time needs of the grid. By turning the lines themselves into dispatchable assets, that can be dialed up or down like a power plant, and grid operators can transfer much more power using the existing infrastructure they already have. In addition, power flow control allows grid operators to trade more power with their neighbors, spreading the variability across a wide area. And by adding distributed power flow control strategically to their grids, grid operators can dramatically lower the investment required to accommodate much higher penetration of renewable energy and shorten the time it takes to bring a renewable energy project online. The scalability is rooted in the fact that distributed power flow controller can be added incrementally as it is needed, allowing grid owners to better time transmission upgrades to when they are needed. An example is shown below in Figure 4. The photo shows the PowerLine Guardian™, a distributed power flow product developed by Smart Wires Inc., installed on a high voltage transmission line.



Figure 4- Power Flow Control Devices Installed on High Voltage Line

Example Study

Smart Wires performed a study in collaboration with a major utility relating to wind congestion and future wind generator integration. The utility and RTO were experiencing heavy congestion on a 138 kV transmission line for both N-0 and N-1 conditions during periods of heavy wind, as shown in Figure 5 below. Congestion due to this line was estimated at roughly \$15 million to \$20 million per year, and the constraint was also limiting the ability to bring more wind generation customers online in this area in the future. Smart Wires studied whether deploying scalable power flow control technology on the overloaded line could eliminate the overload, address the congestion and allow more wind generators to connect to the system.

Study Overview

- A transmission line overloads for both N-0 and N-1 under windy conditions during the summer, winter and even certain light load conditions.
- The current mitigation to this congestion is to dispatch an expensive fossil fuel plant to eliminate the overload, with an even more expensive shadow price during redispatch.
- If the RTO does not dispatch the fossil fuel plant then wind generation would need to be curtailed.

Figure 5 below shows the system today under N-1 conditions. The red line is the constrained line and overloads to 111% in pre-contingency conditions. Even when the wind generation is lower and line does not overload under N-0 conditions, the N-1 contingency will cause an overload and the fossil fuel plant is committed pre-contingency. During the summer months it is estimated that this line is constrained more than 50% of the time in the day-ahead market.

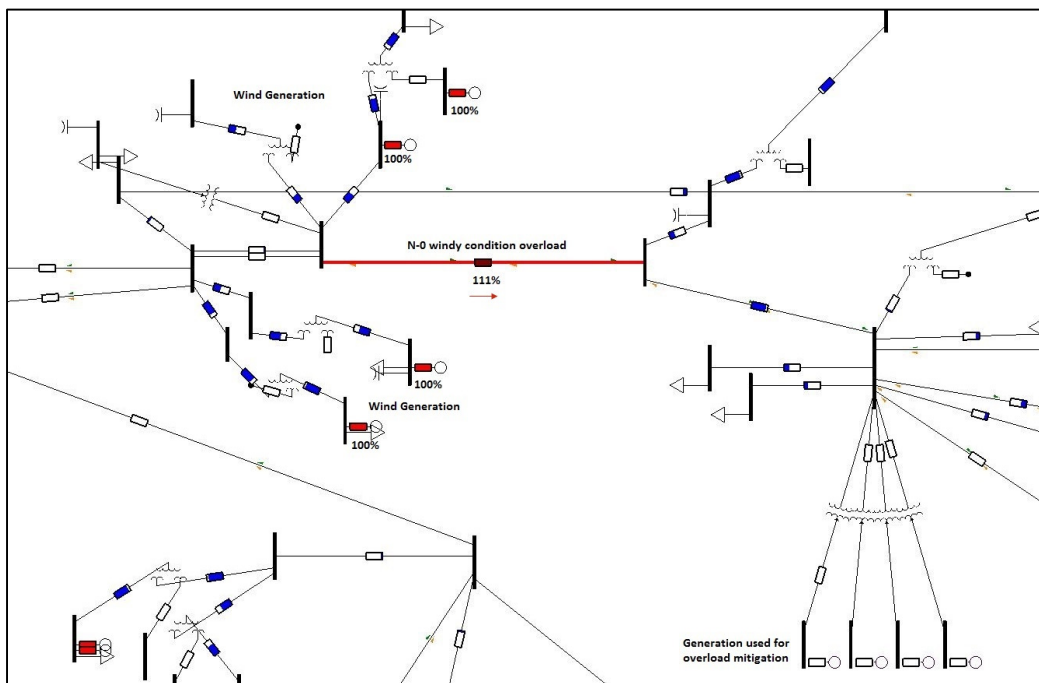


Figure 5 - Power Flow Diagram Under N-0 Windy Conditions, Without Power Flow Control

A future planned transmission line would help but not completely eliminate these issues. Smart Wires performed a study to determine if power flow control could minimize or eliminate the congestion on the 138 kV transmission line and facilitate the integration of future wind generation in the area, while simultaneously eliminating the need to dispatch the fossil fuel plant based on this congestion. The study results, shown in Figure 6, suggest that power flow control solves this problem and accomplishes the following:

- Completely eliminates the N-0 overload
- Completely eliminates the N-1 overload
- Eliminates the need to dispatch the fossil fuel plant
- Establishes a way to incrementally add up to 425 MW of additional wind at this bus without rebuilding the line while ensuring neither the existing or new wind capacity is curtailed.

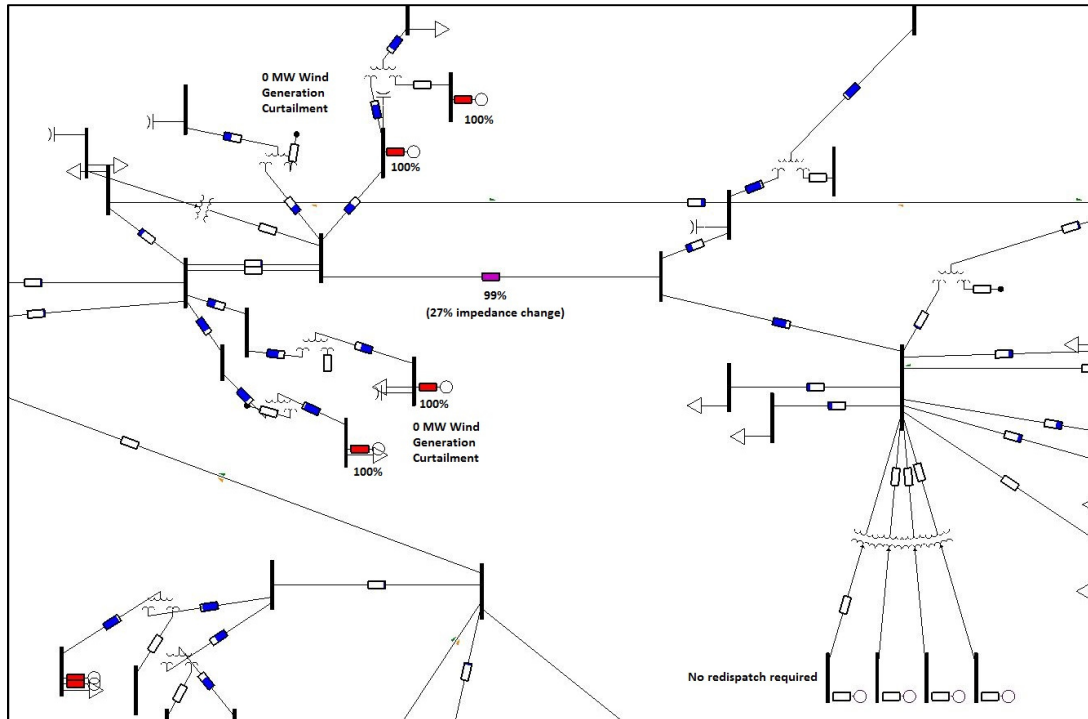


Figure 6 - Power Flow Diagram Under N-0 Windy Conditions, With Power Flow Control

Conclusion

Adding power flow devices incrementally provides several benefits to both proposed wind generation customers and the local transmission owners. Capital is only spent when it is necessary since the line can be upgraded as new wind generators are brought online rather than all at once. Each wind generator can be charged for its portion of the power flow devices needed to resolve transmission issues, rather than funding a fraction of a large, potentially lumpy transmission upgrade. The impedance change can be dispatched between 0% and 27% depending on how much impedance change is needed for a particular situation. The in-service date of proposed wind generators may be accelerated if they no longer need to wait for a long-lead transmission project to be constructed.

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