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A Preliminary Analysis and Case Study of Transmission Constraints and Wind Energy in the West

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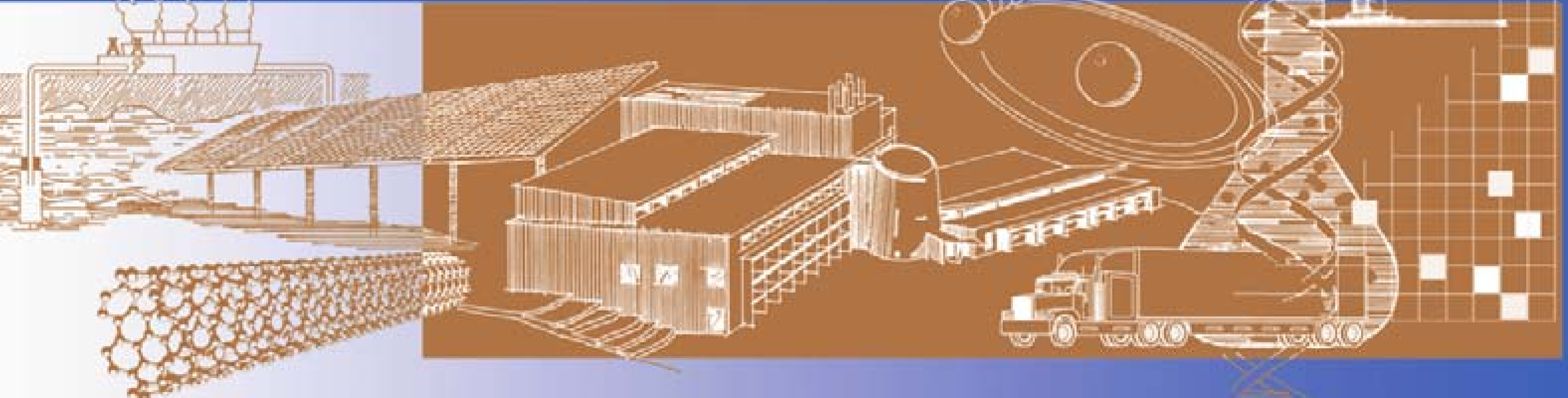

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Abstract

The Rocky Mountain region has been identified as possessing some of the most attractive wind resources in the western United States. Wind developers typically need long-term transmission service to finance their projects; however, most of the capacity on several key paths is reserved by existing firm contracts. Because non-firm contracts are only offered for periods up to 1 year, obtaining financing for the wind project is generally not possible when firm capacity is unavailable. However, sufficient capacity may exist on the constrained paths for new wind projects that can risk curtailment for a small number of hours of the year. This paper presents the results of a study sponsored by the National Renewable Energy Laboratory (NREL), a work group participant in the Rocky Mountain Area Transmission Study (RMATS). Using recent historical power flow data, case studies were conducted on the constrained paths between Wyoming-Colorado (TOT3) and Montana-Northwest, coinciding with areas of exceptional wind resources. The potential curtailment frequency for hypothetical 100-MW and 500-MW wind plants was calculated using hourly wind data. Although the high-level approach of the study cannot specifically define amounts of generation that can be added to these paths, it does present a new approach to identifying the potential for improved utilization of existing transmission assets. The results from the study also indicate that sufficient potential exists for innovative transmission products that can help bring more wind to load centers and increase the efficiency of the existing transmission network.

Introduction

Recent studies of historical power flow data have helped to identify the degree of congestion of constrained paths in the West. These analyses show that periods of heavy congestion above 75% of a path's rating on many of the paths have historically been confined to less than half of the hours in the year [1]. In contrast to the historical loading, firm transmission service contracts reserve much of the capacity on the transmission lines that make up the paths.

The shortage of firm transmission capacity over constrained paths is a significant obstacle to wind developers. The use of non-firm capacity is also problematic in that it involves levels of financial risk that are difficult to quantify. Transmission infrastructure upgrades are necessary to increase capacity over constrained paths; however, the time frame for planning and construction of transmission improvements is considerably greater than the construction time frame for wind projects. The optimal use of the existing transmission system could allow wind producers to obtain transmission service in a time frame consistent with wind project development, and at a known level of risk that is acceptable for project financing. The key to this approach is the ability to quantify the risk of curtailment due to periods of peak flow.

The process and criteria for generator interconnection studies is mandated by the Federal Energy Regulatory Commission's (FERC) Large Generator Interconnection Procedures (LGIP), and by the merged North American Electric Reliability Council (NERC) and Western Electricity Coordinating Council (WECC) Planning

Standards [2], [3]. However, the recognition of wind power as a non-dispatchable resource warrants the investigation of additional study methodologies that take into account the nature of wind energy. This proof-of-concept study attempts to identify the potential for a new approach to wind power transmission service and availability.

Rocky Mountain Area Transmission Study

In September 2003, Wyoming Governor Freudenthal and then-governor Leavitt of Utah announced an initiative to analyze potential transmission additions in the western states. The states include Colorado, Idaho, Wyoming, Utah, and Montana. The study of this subset of the Western Interconnection was called the Rocky Mountain Area Transmission Study (RMATS), and it involved many regional stakeholders. The primary goal of the study was to help "break the log jam of inactivity" around transmission planning and investment in the west and identify potential transmission upgrades to strengthen the electricity supply in the region [4]. A number of future generation scenarios were developed to represent potential futures in 2008 and 2013. These scenarios were analyzed with the help of a region-wide power systems dispatch model that recognized the key constrained transmission paths and performed economic dispatch based on locational marginal prices at the various transmission nodes and across the system. As a result of the study, a number of specific transmission upgrades were identified [5]. In Phase 2 (currently underway), the study will move toward more detailed financial and cost allocation so that the transmission expansion can begin to move forward. However, there are many uncertainties that could significantly alter the momentum achieved in Phase 1.

A Regulatory and Operational Impacts Work Group (ROIWG) that was part of the RMATS effort proposed an analysis of some key transmission constraints to determine the usage of those paths. Because path flows vary significantly throughout the year, the intent was to quantify the extent that these key paths were constrained, similar to work that was previously done by the Seams Steering Group-Western Interconnection (SSG-WI) [1]. Because the RMATS scenarios included significant wind generation, there was also an interest in quantifying the impact that these key transmission bottlenecks would have on the deliverability of wind generation to loads.

Tariff Impacts on Wind

Under the FERC Order 888, several types of transmission service are defined. Network service is available for generation resources that serve load within the control area. Alternatively, if the generator provides energy for loads outside of the control area, point-to-point transmission service must be acquired from the transmission provider. This service is classified as either firm or non-firm [6]. Firm transmission service grants transmission rights to the purchaser for every hour of the year. Non-firm transmission can be purchased for distinct time frames that range from very short-term (hourly or daily) up to 1 year. However, non-firm service is not guaranteed, so service can be interrupted under specific curtailment procedures and priorities.

Under Order 888, non-firm service was not specified for periods longer than 1 year. Although the FERC intended Order 888 to provide a framework that individual transmission operators could expand on, this has not happened. So although Order 888 did not expressly forbid non-firm service for more than 1 year, transmission providers did not offer it.

These transmission tariffs make it difficult, if not impossible, for wind generators to obtain point-to-point transmission service for the life of the wind project. Because wind project financiers want assurance that energy can be delivered to loads, the lack of firm transmission in most parts of the west means that only non-firm transmission is available. This makes it difficult for wind generators to obtain financing. First, non-firm transmission is sold "as available" with no cap on the number of hours per year on potential curtailment. Second, because non-firm could not be obtained for more than 1 year, financiers are understandably reluctant to loan the necessary financial capital to wind projects with a project life of 20 years or more, if they have no apparent way to deliver energy to loads.

Analysis of transmission path loadings by the SSG-WI indicated that even though firm capacity may not be available on many paths, a significant number of paths have available capacity for most of the year. Because wind is an intermittent resource, the ROIWG decided to investigate whether sufficient physical transmission capability exists on several key paths in the west to accommodate wind generation. The goal of this work was twofold: (1) to determine how much likely curtailment a wind generator would experience over key constrained paths, and (2) if sufficient transmission capability exists to deliver wind to load centers, which tariff mechanism(s) would help provide a sufficient risk cap for lenders evaluating wind projects.

Analysis of Potential Benefit of New Transmission Tariffs

Our analysis represents a first-cut estimate of the transmission capability that could potentially become available to intermittent generators under alternative tariffs. The project goal was to analyze three key constrained paths in the west that were consistent with wind scenarios developed for RMATS. Wyoming wind resources are among the best in the United States. The RMATS wind scenarios were based, in part, on Wyoming wind energy delivered to the Colorado Front Range (including the Denver area), and west to Utah and the Northwest. Another key wind energy source is Montana, and wind energy was modeled to be delivered to the Northwest. To accomplish these large-scale exports of wind energy, three key transmission paths would be required. West of Naughton (WY) provides a path from southwest Wyoming to the west; TOT3 is the constrained path from Wyoming into the Colorado Front Range, and the path from Montana to the Northwest involves a series of individual transmission lines. Figure 1 shows the Montana-Northwest path; Figure 2 shows the West of Naughton path, and Figure 3 shows TOT3.

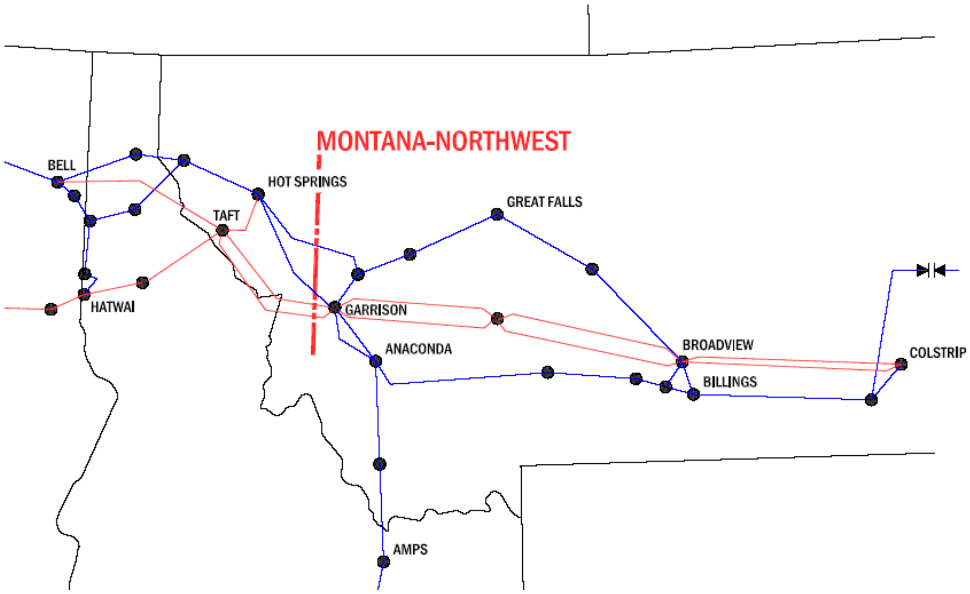

Figure 1 - Montana-Northwest Transmission Path

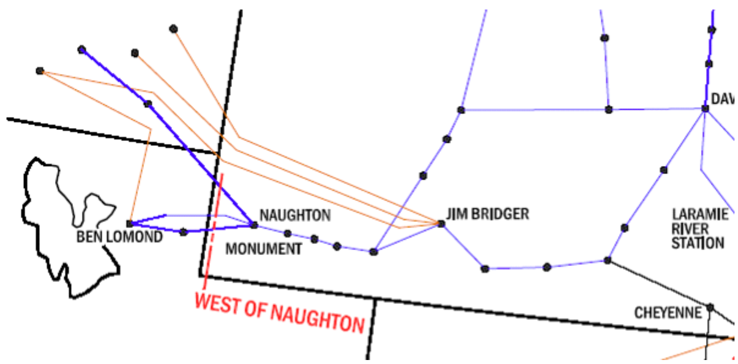

Figure 2 - West of Naughton Transmission Path[1]

[1] Lower-voltage transmission and adjoining infrastructure are not shown in the figures.

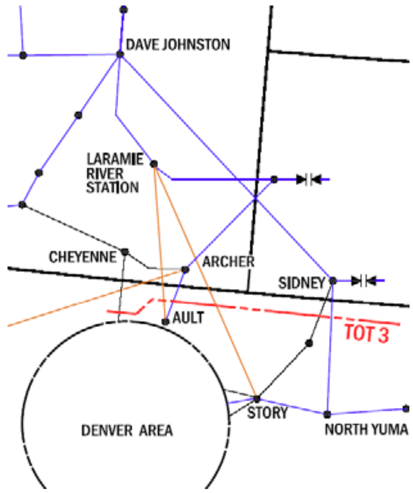

Figure 3 - TOT3 Transmission Path

Transmission Data

Transmission data were obtained for the 3-year period of 2001-2003 from two sources. TOT3 and Montana-Northwest data were obtained from the WECC. Data for West of Naughton came from PacifiCorp. The flow data consisted of hourly average values in megawatts for the path limit, the scheduled flow, and the actual flow.

The West of Naughton path has undergone significant upgrades in recent years. Path operation has been significantly impacted by the installation of a phase-shifting transformer to control power flow and by new generation to the east of the path. The path has also experienced the effect of load growth in the area. Because of these system changes, the available data cannot accurately represent West of Naughton capacity.

Complexity of the Montana-Northwest path, as well as data errors, minimized the potential for meaningful analysis of this path. The available data were not sufficiently detailed to address the serial nature of Montana-Northwest. Additionally, significant portions of the data were missing due to recording equipment malfunctions or failure to report the data to the WECC. Because of the data quality and other issues, we proceeded only with the TOT3 analysis.

Wind Data

For the analysis we used 3 years of wind data, matched with transmission-loading data from the same period. Platte River Power Authority[2] provided wind speed and production data. Because the RMATS study looks at future scenarios, we calculated hourly wind power output to simulate large wind power plants, 100 MW and 500 MW, using current wind turbine technology characteristics. In some cases, missing wind speed at the

[2] Thanks to Paul Warila for his invaluable assistance.

reference anemometer was re-calculated based on alternative anemometers at the same location but different heights. The recalculated data were then compared with power production data for the older wind turbine technology at the site to ensure reasonability.

The use of a modern 1.5-MW turbine at an assumed hub-height of 80 meters represents current technology. For the RMATS study period, additional advancements to turbine technology are anticipated. There is also a great deal of interest in taller towers, placing hub heights at 100 meters or perhaps even higher. These factors will increase wind turbine performance and energy delivery and will increase capacity factors. For this study, we estimated a capacity factor of 43%, based on the wind resource data and technology characteristics. Figure 4 shows the wind frequency distribution based on the 100-MW wind plant scenario. To calculate the 500-MW wind scenario, we simply scaled up by a factor of five.

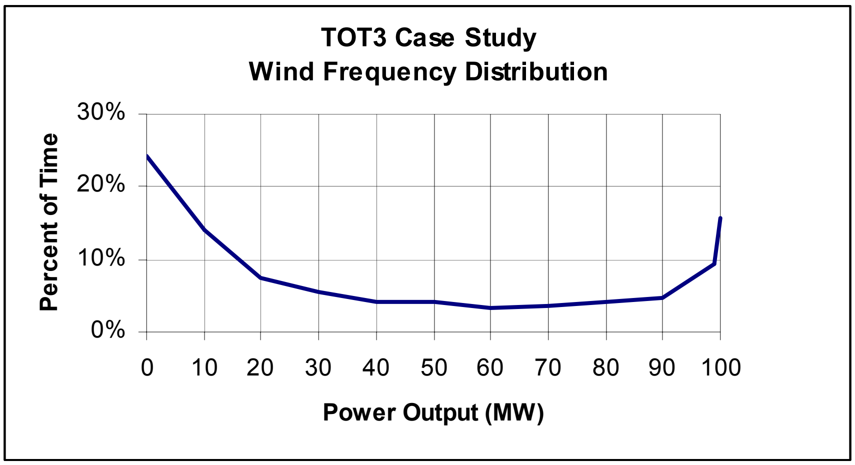

Figure 4 - Wind Frequency Distribution

The figure illustrates that the wind plant is idle (0 MW) 24% of the time. Full output in the range of 90 MW to 100 MW is achieved approximately 30% of the time combined. A traditional interconnection study for conventional generation assumes full output of the generator and worst-case transmission loading. Because wind power production is less than the nameplate capacity 46% of the time in this scenario, the transmission access requirements of wind power are less than for a conventional generator.

Capacity Calculations

The available capacity of TOT3 was calculated based on the flow data obtained from the WECC. To evaluate the path capacity, three indicators were used: the Operating Transfer Capability (OTC), the Unused Transfer Capability (UTC), and the Available Transfer Capability (ATC).

Operating Transfer Capability

The OTC is the transfer limit of the path. The published OTC value for each path in the west is determined seasonally according to WECC guidelines and is approved by the WECC OTC Policy Committee [7]. The flow data give the real-time OTC of a constrained path. The physical power flow on a path may not exceed the real-time OTC.

Unused Transfer Capability

The UTC was defined as the physically unused capacity of the path. It was calculated based on the hourly values of OTC and actual path flow with the equation:

$$UTC = OTC - (MW\ flow)$$

UTC is not a standard term used by the power industry. The term was defined for the purposes of the study to show the difference between physical capacity and the availability of non-firm contracts.

Available Transfer Capability

The ATC determines the amount of capacity that is available for posting on the Open Access Same-time Information System (OASIS). The ATC is determined according to WECC guidelines [8]. The ATC calculation consists of several additional variables that are not present in our UTC equation. Transmission providers are required by NERC/FERC to make their ATC calculation methodology available on their respective OASIS nodes.

The aggregate ATC was estimated for the purposes of the study based on the path flow data. It is important to note that ATC postings on the OASIS are for physical transmission line paths. The aggregate ATC calculated for the study cannot be fully realized at any one interconnection. Based on the level of detail of the data, an uncertainty factor was applied to the UTC to make a reasonable estimate of the ATC. The following equation was used to estimate the hourly ATC (hATC):

$$hATC = (uncertainty\ factor)\ (UTC)$$
$$where\ (uncertainty\ factor) = 0.6$$

The uncertainty factor of 0.6 was chosen based primarily on the experience of the path operator for the Western Area Colorado Missouri (WACM) area. The WACM operator is the Western Area Power Administration, Rocky Mountain Region. Approximately 60% of the hourly unused capacity can be reliably offered as ATC. Reasons for reducing the unused capacity include anticipated loop flow, uncertainty as to whether existing firm contract rights will be exercised within the next hour, reserve margins, and reliability margins.

Whether 0.6 was the appropriate value for the uncertainty factor elicited significant discussion within the ROIWG. Transmission operators withhold some transmission capacity to allow for unforeseen operating conditions. Because of the dynamic behavior of power system flows, all physically unused capacity would not be made available as ATC. It is therefore likely that a one-size-fits-all approach to calculating ATC will not work and that the results of our study should be interpreted accordingly.

Curtailment Analysis

Our analysis assumes that all of the power output from the wind plant is contracted to flow across the TOT3 cut plane. Although physical power flow may involve transmission lines that are not part of TOT3, we explicitly evaluated curtailment based on the available capacity of TOT3. Curtailment of the theoretical wind plants was calculated by comparing the wind power output data series with the TOT3 available capacity (ATC) data series. If the wind generation was greater than the ATC of the path for a given hour, we considered the amount of power exceeding the capacity to be curtailed. For example, if the available capacity of the path was 300 MW for a given hour, and the wind power output was 400 MW for that hour, then a curtailment of 100 MW was recorded for that hour. Curtailment was then quantified in terms of the total energy curtailed in megawatt-hours (MWh). Figure 5 illustrates the correlation of the data with several days of power profiles. The hourly ATC in the graph is the difference between the OTC and the recorded power flow across the path. Curtailment of the 500-MW wind plant occurred on July 5 due to the output exceeding the ATC at three separate times during the day.

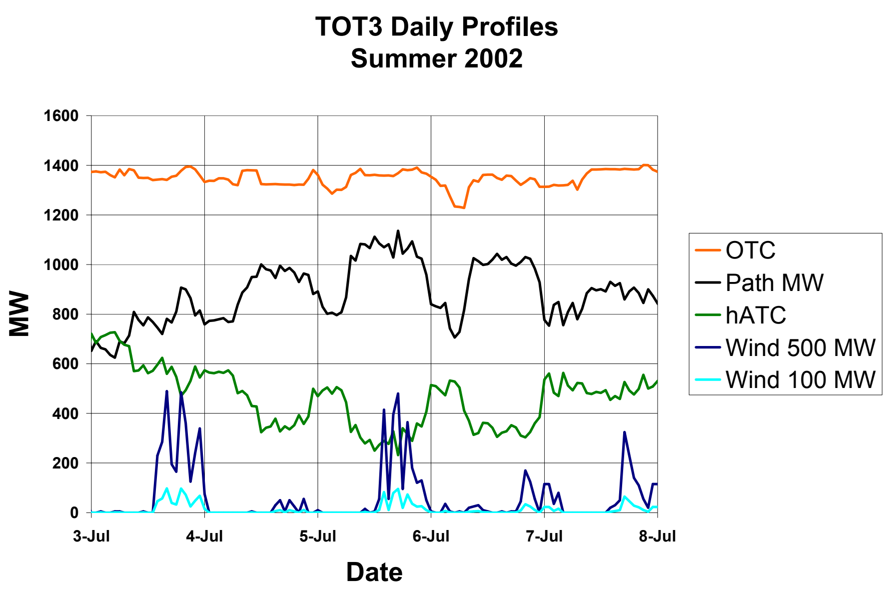

Figure 5 - Power Profiles

Cumulative frequency distribution was calculated to determine the characteristics of the path's available capacity and the wind power output. The cumulative distribution plot in Figure 6 shows the percent of time that a minimum level of ATC was available. Heavy loading of TOT3 is evident in this figure. The published path rating as of June 2004 is

1605 MW north to south [9]. Figure 6 shows that there is rarely more than 500 MW of ATC on TOT3 over the course of a year. As can be seen in the figure, path ATC was greater than 500 MW only 4% of the time. This heavy loading was the predominant cause of curtailment. In contrast, approximately 250 MW of cumulative ATC was available 80% of the time for the three years studied.

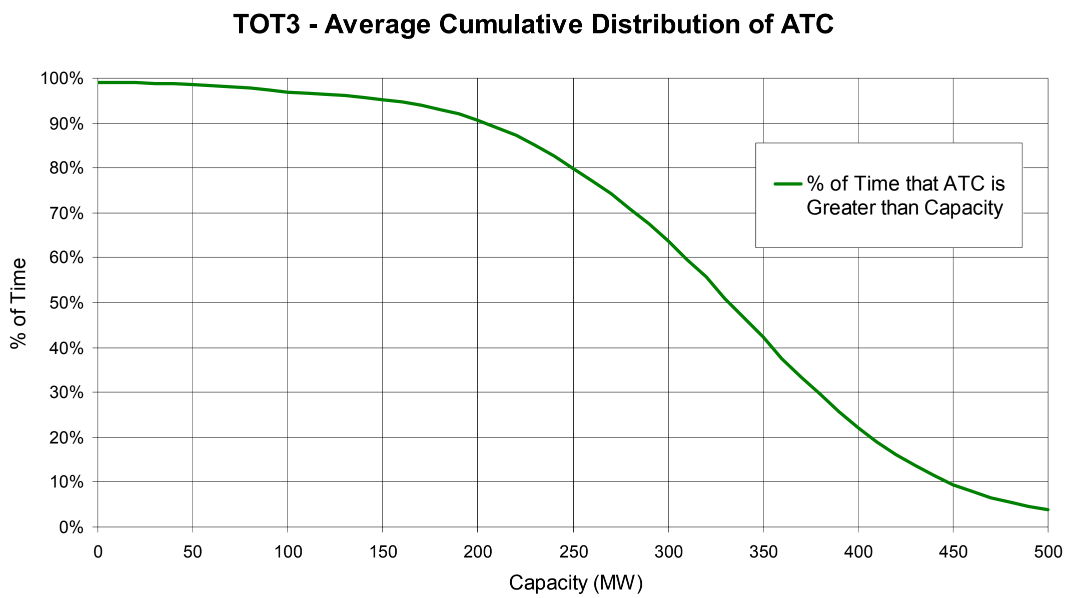

Figure 6

The curtailed energy was quantified in terms of percent of total output. Wind plants typically exhibit a capacity factor of approximately 30% of the combined turbine capacity. The significance of curtailment is put into perspective by normalizing it to the total output. Figure 7 presents the curtailment of the 100-MW and 500-MW wind plants. Two comparisons are made in this graph. The effect on curtailment of the UTC versus the ATC is displayed. Additionally, a constant-output benchmark case is shown in order to gauge the performance of the wind series. The generation of the constant-output plant was set at the same level as the wind plant. The constant-output generator is similar to a dispatchable resource such as a coal or gas plant; however, factors such as capacity factor or outages were not taken into account for the constant-output plant.

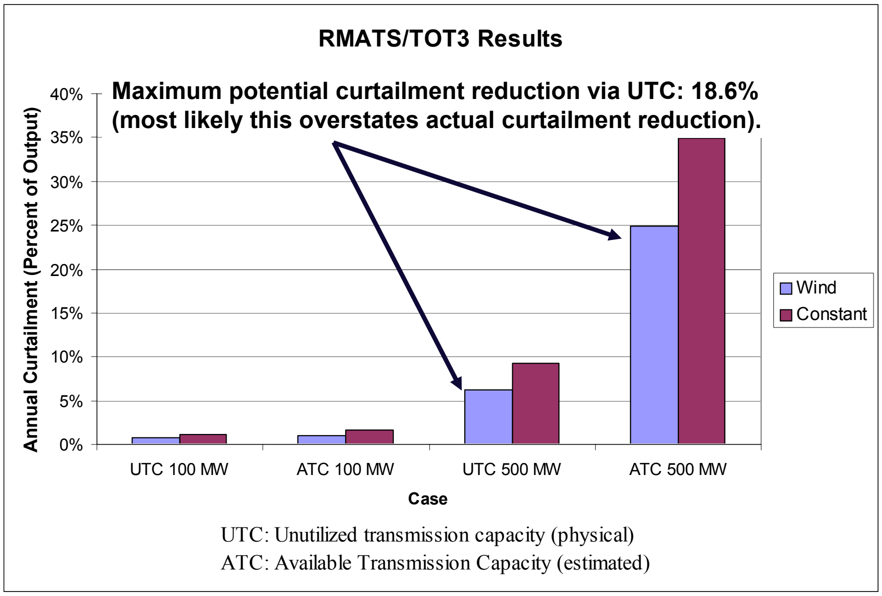

Figure 7

There was very little discernable difference for the 100-MW wind plant. This is due to the low level of curtailment frequency at or below 100 MW, as evidenced by the cumulative distribution of ATC. The previous plot of Figure 6 indicates that 100 MW of ATC is available 97% of the time.

Notable differences become evident for the 500-MW plant. Figure 7 illustrates the results. A 100-MW constant-output generator would be curtailed 1.2% of its annual energy output if all UTC could be utilized and would be curtailed 1.6% if only ATC could be utilized. A 100-MW wind plant would be curtailed 1.0% of its energy based on ATC and 0.8% if all UTC could be utilized. In both cases, the ability to obtain additional UTC beyond the posted ATC does not have a significant impact on either generator, and in all cases, curtailment risk is quite small.

The curtailment risk for both types of units changes significantly for 500 MW of generating capacity. A constant-output 500-MW generator would have energy curtailment of 9.2% annually based on UTC, and 34.9% based on ATC. For wind, the UTC curtailment would be 6.3%, and the ATC curtailment would be 24.9%. Clearly both types of generation would significantly benefit if additional transmission capability could be made available beyond what is posted as ATC.

Limitations of the Method, Data, and Approach

Preliminary results of our analysis were presented to the ROIWG in June 2004 at meetings in Denver, Colorado and Portland, Oregon. Representatives from several transmission owners attended the meetings to provide feedback to the path analysis and the conceptual tariff reforms. The work group discussions identified several issues that affect the accuracy and interpretation of the study. The study results indicate that ATC along constrained paths could be made available with the introduction of a conditional firm or long-term non-firm tariff, although the resolution of the data was not sufficient to draw specific conclusions on the amount of ATC. There were several technical and operational concerns which we believe are key to putting the results in perspective.

The study evaluates transmission capacity of TOT3 using a high-level approach. This approach makes several approximations that have the effect of presenting some unused capacity that may not be available for marketing in practice. The curtailment estimates we calculated are lower bounds, and depend on physical operating characteristics and practices across the path, as well as contractual and institutional issues. The path flow data for TOT3 was obtained as an aggregate of the six transmission lines that define the path. It was therefore necessary to assume that the available capacity of a constrained path could also be aggregated, both contractually and physically. New generation wishing to utilize capacity of TOT3 must be injected at interconnection points north of the path, and flow through physical lines which are geographically diverse and have different electrical characteristics. Capacity along the contract path of choice may not be available even if other lines in the path have capacity. The six transmission lines that make up TOT3 are owned by four different entities. ATC of the path is allocated among these entities in proportion of the percent of ownership. The ATC allocated to each owner is then applied to the infrastructure owned by each entity as appropriate.

Another key assumption is that the addition of new generation will not affect the transfer capability of the constrained path. The dispatch levels of existing generation north and south of TOT3 can have an effect on the path's OTC. Additional generation resources utilizing TOT3 may negatively impact the operation of TOT3 and ultimately the ATC. Further analysis would be necessary to assess these impacts.

Work group participants in Denver also recognized that variables such as unscheduled power flow on TOT3 and seasonal weather patterns can vary significantly from one year to the next. The historical data represents a relatively short time frame that cannot encapsulate all of the factors affecting operational practice that might occur in the future.

Although a more detailed study would be required to accurately determine the additional transmission capacity that might be available under new tariff arrangements, that was beyond the scope of this study. What we can conclude from this effort is that, in spite of the limitations of this study, there appears to be sufficient unused capability to motivate transmission owners to pursue these options and to perform the more detailed studies that would be required to more rigorously quantify this unused capability.

Proposed Transmission Tariffs: BPA, WAPA

Motivated in part by the results of the TOT3 analysis, the ROIWG developed two rough prototype transmission tariffs. The first was based on discussion at the Portland meeting of the ROIWG with transmission providers in the Northwest, including PacifiCorp and Bonneville Power Authority (BPA). This tariff approach was called conditional firm. The main characteristic of the conditional firm tariff involved a cap on the number of hours that the generator would be curtailed. A number of details emerged that would need further study. A significant effort by the Renewable Northwest Project (RNP) and BPA resulted in a workshop in Portland, March 16-17, cosponsored by BPA and the FERC. At the time of this writing BPA is undertaking internal discussions to help determine appropriate curtailment priority and other related issues. A new conditional firm tariff product from BPA may be forthcoming.

The second generic tariff was based on Western Area Power Administration's (WAPA) non-firm transmission tariff. The ROIWG analyzed the existing tariff to determine the extent of changes that might be required to specify a longer period for the tariff; up to ten years. WAPA is considering a long-term non-firm tariff, and such a tariff may be forthcoming. It is unclear whether wind developers and financiers would be able to utilize such a tariff, however, because there is no cap on curtailment over the 10-year period.

Further information can be found at www.ferc.gov/legal/ferc-regs/land-docs/11-04-wind-report.pdf [10].

Conclusions

Based on our results, there appears to be sufficient transmission capability on TOT3 to warrant the use of new innovative transmission tariffs. Although these new tariffs, if implemented, would benefit wind generators, they would also benefit other types of generation and would increase the utilization of the transmission grid. New tariffs would also increase revenues for transmission owners in proportion to the amount of additional capability. Although we were not able to analyze other paths, prior work by SSG-WI indicates that additional transmission may be available elsewhere in the west. Further analysis of those paths with sufficient data would provide further information.

Our work has highlighted a couple of issues. First, calculation of ATC is subject to uncertainties. When ATC is estimated for future years, these uncertainties increase. It is not possible, for example, to know the extent to which loop flow will have an impact on ATC. Other flow conditions, operating practice, load growth, and potential generation and transmission outages all can influence ATC and UTC. However, we believe that this method for evaluating potential UTC is useful, and provides enough information to move forward with new transmission tariffs that can help improve the utilization of the transmission system and help incorporate new renewable sources of energy into the western energy supply.

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