# ELECTRIC INDUSTRY RESTRUCTURING, ANCILLARY SERVICES, AND THE POTENTIAL IMPACT ON WIND

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## INTRODUCTION

The new competitive electric power environment raises increased challenges for wind power. The DOE and EPRI wind programs have dealt extensively with the traditional vertically integrated utility planning and operating environment in which the host utility owns the generation (or purchases the power) and provides dispatch and transmission services. Under this traditional environment, 1794 MW of wind power, principally in California, have been successfully integrated into the U.S. electric power system. Another 4200 MW are installed elsewhere in the world. As issues have arisen, such as intermittency and voltage regulation, they have been successfully addressed with accepted power system procedures and practices (Putnam 1996 and Utility Wind Interest Group 1992).

However, FERC Order 888, *Promoting Wholesale Competition Through Open Access Non-Discriminatory Transmission Services by Public Utilities*, issued in April of 1996 and modified in March 1997 requires electric utilities to provide open access, non-discriminatory transmission service. The Commission's stated goal is "to remove impediments to competition in the wholesale bulk power marketplace and to bring more efficient, lower cost power to the Nation's electricity consumers." FERC is doing this by requiring transmission utilities to unbundle, and charge separately for, all of the ancillary services required to make the electric system operate. This unbundling requires cost and administrative consideration of operating, dispatch, and transmission issues that had previously not been a concern in the use of wind power and that had not been considered explicitly in rates. For an intermittent, non-dispatchable resource such as wind, this raises questions about which ancillary services wind plants will be able to sell, which they will be required to purchase, and what the economic impacts will be on individual wind projects.

This paper begins to look at issues of concern to wind in a restructured electric industry. The paper first briefly looks at the range of unbundled services and comments on their unique significance to wind. To illustrate the concerns that arise with restructuring, the paper then takes a more detailed look at a single service: regulation. Finally, the paper takes a brief look at technologies and strategies that could improve the competitive position of wind. Further details can be found in the report "Ancillary Services and Their Impact on Renewable Resources - Wind as an Example" which will be available this summer.

Restructuring and ancillary services do not address new physical phenomena or new physical interactions between wind resources and the electric system. What they do address is the way provision and consumption of services is determined and how providers and consumers of those services will be compensated or charged. In a restructured electric power industry it is necessary to think in terms of providers and consumers of services rather than in terms of generators and loads. A generator may be a provider of some services and a consumer of others. Ultimately, a sustainable market will require that individuals be compensated for what they actually provide and charged for what they actually consume, with both determined through performance monitoring.

A major issue for wind in the restructured marketplace is the magnitude, frequency, and trends of short term (1 to 10 minutes) power fluctuations. Data on this are lacking because 1) previous regulatory treatment recognized only energy and capacity payments, 2) fluctuations were not generally considered a problem in California, and 3) there have not been opportunities to examine the fluctuations in new projects. Thus, this paper is more illustrative than analytical and serves to alert the wind community of data requirements for analysis of ancillary services as well as the implications of ancillary serves themselves. Examples, when given, are illustrative only. While the data used is real, it is not representative of wind plants in general, any specific equipment configuration, or even of the site it was collected from. DOE, EPRI, NREL, and partners are collecting short-term power data as part of the Turbine Verification Program and are planning to support collection of similar data from other projects as partners become available.

## ANCILLARY SERVICES AND THEIR RELATIONSHIP TO WIND ENERGY

Ancillary services are those functions performed by the electrical generating, transmission, system-control, and distribution-system equipment and people that support the basic services of generating capacity, energy supply, and power delivery (Hirst and Kirby 1996a). The overall cost of ancillary services in the U.S. is 6 to 20% of total generation and transmission costs, equivalent to approximately $12 billion a year or 0.4 ¢/kWh (Kirby and Hirst 1996). Key ancillary services are listed in Table 1 grouped according to the FERC's requirements for provision and acceptance. FERC requires transmission providers to provide, and transmission customers to accept the first two services: 1) scheduling, system control, and dispatch, and 2) reactive supply and voltage control. Transmission providers are required to offer four more services: regulation, spinning reserve, supplemental reserve, and energy imbalance, but transmission customers are free to obtain these services from other sources. Transmission providers are not required to offer the remaining services; transmission customers are free to obtain these remaining services from third parties or provide them themselves.

FERC did nothing in the definitions to address methods to quantify either the services or the prices. FERC will allow market-based pricing if the transmission provider can demonstrate that it does not possess market power and will require cost-based pricing otherwise. But, it is not clear how to unambiguously determine the cost-based price for a separate service, such as supplemental operating reserve, where a single piece of equipment helps provide several services. Determining the market-based price requires knowledge of both the supply and demand in the rest of the market, along with the current spot price for energy.

Table 2 examines these services from the perspective of wind power. The individual characteristics of each wind plant, the equipment employed, the wind resource itself, the electric grid it is connected to, and the electric markets it has access to, will determine the importance of each service to that wind plant. Generators will buy or sell ancillary services, depending on their capabilities and the burdens they place on the electrical system. Plant designers, owners, and operators will need to evaluate their own situation, but Table 2 gives a good starting point to consider interactions between wind plants and electric markets in general.

Wind plants will want to pay close attention to services related to balancing generation and load (regulation, operating reserves, load following, energy imbalance, and backup supply). Older line connected induction generator based plants could have problems with the voltage control service depending upon the specific wording of the service rules. Services such as system control, real loss replacement, and black start will likely not pose problems for wind plants that are different from the problems other generators face.[1] Two services, voltage control and network stability, may provide opportunities for new plants that are connected to the grid through solid-state converters to sell services to the grid if they are located where the service is required.

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[1]The relatively small size of many wind plants coupled with frequent schedule changes could result in high charges for system control, depending on how the control area prices this service.

Table 1. KEY ANCILLARY SERVICES AND THEIR DEFINITIONS

| Service | Description |
|---|---|
| **Services FERC requires transmission providers to offer and customers to take from the transmission provider** | |
| Scheduling, system control, & dispatch | The control-area operator functions that schedule generation and transactions before the fact and that control some generation in real-time to maintain generation/load balance |
| Reactive supply and voltage control | The injection or absorption of reactive power from generators to maintain transmission-system voltages within required ranges |
| **Services FERC requires transmission providers to offer but which customers can take from the transmission provider, third parties, or self-provide** | |
| Regulation and frequency response | The use of generation equipped with governors and automatic-generation control (AGC) to maintain minute-to-minute generation/load balance within the control area to meet NERC control performance standards |
| Operating reserve - spinning | The provision of generating capacity (usually with governors and AGC) that is synchronized to the grid and is unloaded that can respond immediately to correct for generation/load imbalances caused by generation and transmission outages and that is fully available within 10 minutes |
| Operating reserve - supplemental | The provision of generating capacity and curtailable load used to correct for generation/load imbalances caused by generation and transmission outages and that is fully available within 10 minutes |
| Energy imbalance | The use of generation to correct for hourly mismatches between actual and scheduled transactions between suppliers and their customers |
| **Services that FERC recognizes but does not require transmission providers to offer** | |
| Load following | The use of generation to meet the hour-to-hour and daily variations in system load |
| Backup supply | Generating capacity that can be made fully available within one hour, used to back up operating reserves and for commercial purposes (as opposed to being required for reliability) |
| Real losses | The use of generating equipment to compensate for the transmission-system losses from generators to loads |
| Dynamic scheduling | Real-time metering, telemetering, and computer software and hardware to electronically transfer some or all of a generator's output or a customer's load from one control area to another |
| Black-start | The ability of a generating unit to go from a shutdown condition to an operating condition without assistance from the electrical grid |
| Network stability | Maintenance and use of special equipment (e.g., power system stabilizers and dynamic braking resistors) to maintain a secure transmission system |

Dynamic scheduling is not an ancillary service in the sense the others are; it is not a service the grid requires to maintain reliability. Dynamic scheduling provides the ability to electronically transfer the full regulating, reliability, and commercial burden (or benefit) of a generator or load from one control area to another by telemetering MW production or consumption information to both control areas every 2-8 seconds. Wind plants may wish to use dynamic scheduling to access more favorable markets or to combine resources to obtain a more favorable performance profile, (Hirst and Kirby, 1997).

Table 2. ANCILLARY SERVICE CONCERNS FOR WIND

| Service | Of special concern to wind? | Will wind buy or sell the service? | Mitigating Strategies and Technologies[a] | Time Frame |
|---|---|---|---|---|
| System control | No | Buy | Dynamic scheduling | |
| Voltage control | Possibly for older plants | Newer plants may sell service | Solid state power system interface | Seconds |
| Regulation | Yes | Buy | Inter- and intra-plant aggregation (diversity), array control, dynamic scheduling, re-optimization, financial/physical hybrid, short-term energy storage | 1-2 min |
| Spinning reserve | Yes | Buy | Short-term (10-20 min) forecast, dynamic scheduling, aggregation, hybrid, re-optimization, array control | Seconds to 10 min |
| Supplemental reserve | Yes | Buy | Short-term forecast (20 min - 1 hr), dynamic scheduling, aggregation, hybrid, re-optimization, array control | <10 min |
| Energy imbalance | Maybe | Buy | Short-term forecast (1 hr), aggregation, hybrid, re-optimization, array control, dynamic scheduling | Hourly |
| Load following | Yes | Buy | Short-term forecast (1 - 3 hr), re-optimization, dynamic scheduling, hybrid, array control | Hours |
| Backup supply | Yes | Buy | Forecast, dynamic scheduling, hybrid, array control | >30 Min |
| Real losses | No | Buy | | Hourly |
| Dynamic scheduling[a] | Yes | Buy | May help wind reach better energy and services markets | Seconds |
| Black-start | No | Buy | | |
| Network stability | No | Newer plants might sell service | Solid state power system interface, machine design, analysis demonstrating benefit | Cycles |

[a]Dynamic scheduling is both a service and a possible mitigating technology since it can be used to move generation from one control area to another or to aggregate non-contiguous resources.

## SERVICE QUANTIFICATION AND PRICING

Though the ancillary services are now fairly well defined and FERC has established which services must be offered by transmission providers, methods for measuring and pricing services have not been determined. Most tariffs filed to date simply allocate the overall system requirement for each service to all customers based upon energy consumption. That is, they set a ¢/kWh price for each service based upon basic energy consumption. This is simple and straightforward. It is also wrong, and in our opinion will not last.

As deregulation progresses, competitive pressures will likely force an allocation based upon actual service consumption and compensation based upon actual service provision. Taking the regulation service as an example, Figure 1 shows the variation in load for an aluminum smelter and a steel mill over an hour. The aluminum smelter will eventually realize that it is imposing a much smaller regulation burden on the system than the steel mill and it will negotiate a reduced rate for regulation. If the host control area will not offer a reduced rate the aluminum smelter will seek service from someone that will. Though this example, chosen for its clarity, is of two loads the principle holds equally for non-regulating generation.

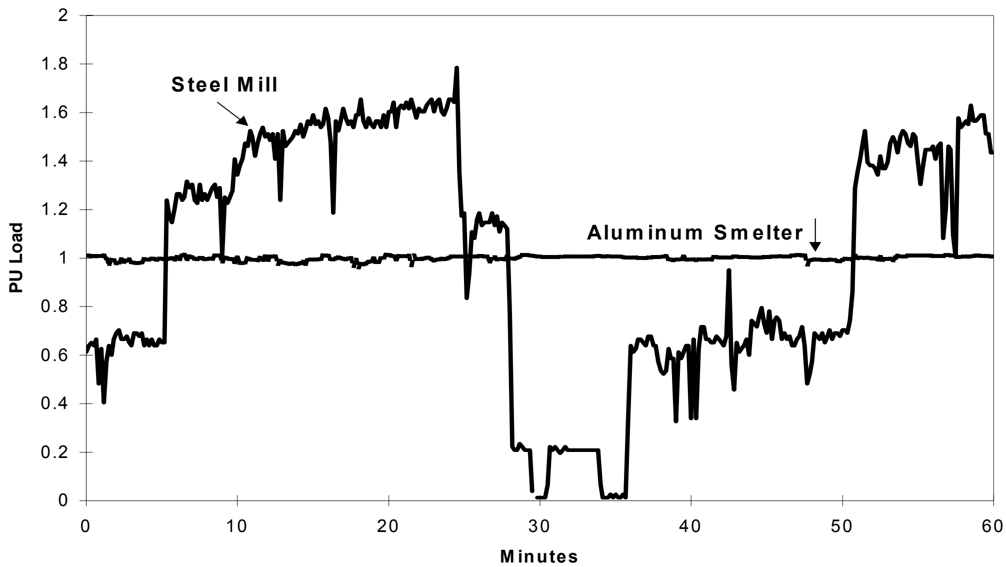


**Figure 1** VARIATION IN STEEL MILL AND ALUMINUM SMELTER LOADS FOR 1 HOUR MEASURED AT 10-SECOND INTERVALS

Some proposals call for compensating generators that provide regulation service simply based upon the capacity they dedicate to regulation. But, generators exhibit differences in performance when supplying regulation service. Examining two similar fossil-fired steam plants in a Midwestern control area, Hirst and Kirby (1996b) found that while one followed automatic generator control (AGC) signals well the other actually contributed 31 MW to the area control error over the hour studied. There are more pronounced differences between types of generating units with hydro units generally performing better than thermal units. Owners of better performing generators will want to receive more compensation for the service they provide than that given to poorer performing units. In addition to the two options generally available to loads for obtaining more equitable treatment (lobbying the rule-making organizations and using dynamic scheduling to reach other markets) generators are able to choose which services they sell. When a generator chooses to sell into the regulation market it removes a portion of its generating capacity from the basic energy market and from the reserve markets. To the extent that one of these markets does not provide appropriate compensation the generation will be moved to the other markets.

For these reasons, we think that charging customers for ancillary services based upon their energy consumption and compensating generators based simply upon the capacity they dedicate to the ancillary service is not sustainable. FERC has already provided sufficient flexibility that market forces will drive compensation to reflect performance. Prices paid for each ancillary service will likely vary dramatically in time and location.

REGULATION AND FREQUENCY RESPONSE

Due to the variability of the wind resource, regulation and frequency response will be an ancillary service of special concern. A more detailed examination of regulation also serves as an example of the types of interactions between wind plants and the power system that will be important when examining other ancillary services. But first we must define what is meant by regulation. Figure 2 decomposes a hypothetical transaction into its components: base, ramp, and fluctuations. The base portion can be accommodated through block transactions while the ramp can be accommodated through manual scheduling and control. Fluctuations, however, require AGC and faster response from the generators that are to provide the required aggregate generation/load balance. Regulation and frequency response is the ancillary service that responds to these fluctuations. Analysis of system fluctuations and the generation response showed that the important characteristic is the standard deviation measured at the 1- to 2-minute level (Hirst and Kirby 1996b).

Three characteristics are of interest when evaluating regulation; the magnitude and speed of fluctuations and their correlation with other fluctuations. The lack of short-term correlation among individual loads or non-regulating generators means that aggregation greatly reduces the regulation requirement for the overall system. The regulation requirement for N transactions with equal but uncorrelated fluctuations is only $\sqrt{N}$ times the regulation requirement of a single transaction.

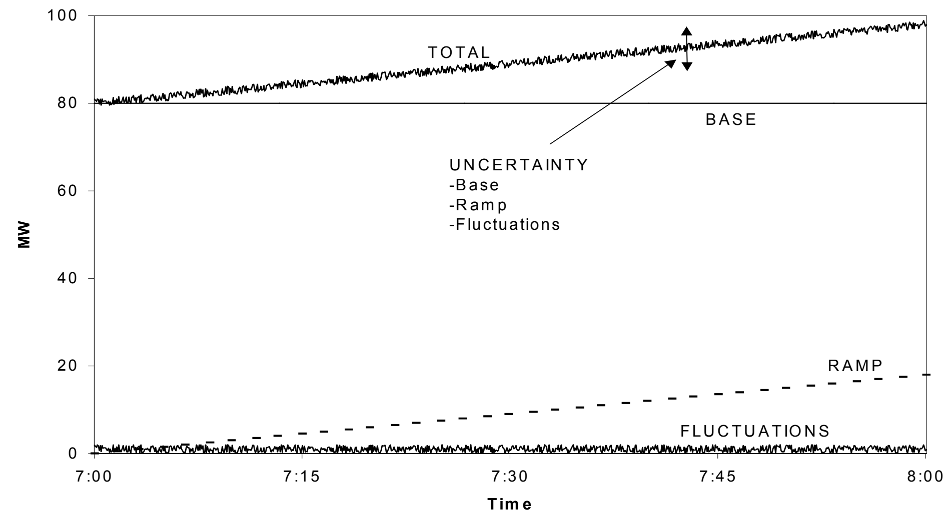


**Figure 2** REGULATION COMPENSATES FOR FLUCTUATIONS IN LOAD OR GENERATION

Fluctuations in electric power generation magnitude and speed are relatively easy to measure. The inertia of the turbine is generally not sufficient to significantly smooth the power output in the 1-2 minute time frame of interest for regulation on a large interconnected system. Figure 3 shows the power output and wind speed for a single turbine at Esperance, Western Australia. *The Esperance wind plant is not representative of plants in the U.S. but it is one we were able to obtain high frequency power output data from*. The Esperance system is an isolated wind/diesel grid with nine V-27 turbines aligned in a row along the shore. This would tend to make the power highly correlated in the 1 to 10 minute interval. Still, Esperance is useful for this illustration. The coefficient of variation (COV is the ratio of the standard deviation to the mean and provides a normalized measure of variability) of this turbine's output is 0.88.

Two factors help reduce the adverse effects of this relatively high COV for an individual turbine. First, wind turbines themselves aggregate nicely into wind plants. Though individual turbines may have fairly high fluctuations in output, each turbine tends to be relatively small (when compared to a fossil fired steam plant, for example) and numerous turbines are frequently combined to create a generating plant. But it is important to be sure that the turbines are uncorrelated over the time frame of interest. Rosser (1995) collected output data from each Esperance turbine at 1/4 second intervals and found that they aggregated as expected. The nine-turbine plant exhibits only 1/3 the fluctuations per KW of output as do the nine individual machines. When we examined the individual machine and aggregated plant output on a 10-minute basis, however, we found that the output from individual turbines was highly correlated and the plant output was only slightly improved when compared to individual turbine outputs, emphasizing the importance of ensuring that the fluctuations are uncorrelated in the time frame of interest. The shorter time frame is important to the application Rosser was investigating but when delivering power to the interconnected U.S. grid the time frame of interest for regulation is 1-2 minutes.

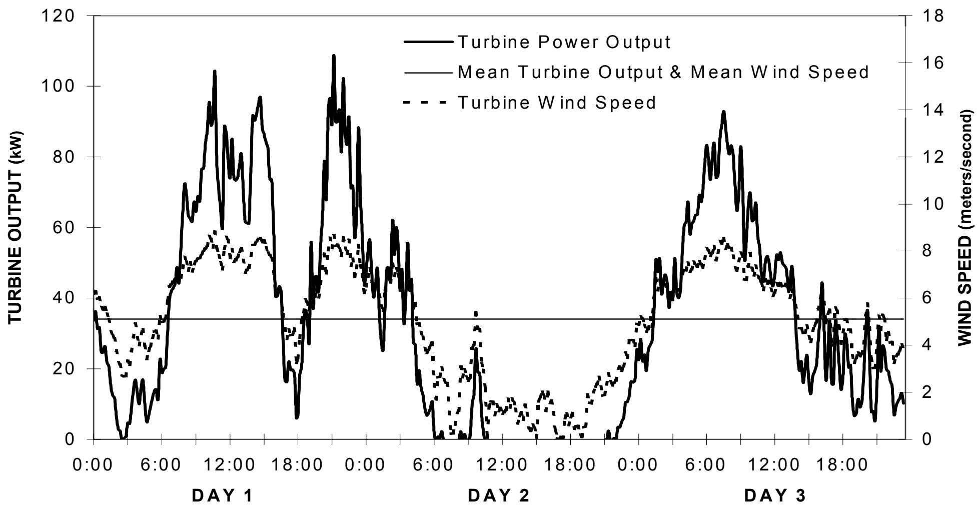


**Figure 3** THREE DAYS OF WIND SPEED AND POWER OUTPUT DATA FOR A SINGLE TURBINE MEASURED AT 10-MINUTE INTERVALS

Second, suppliers of regulation will have different costs and presumably different prices. It may be worthwhile to utilize dynamic scheduling and shop for a regulation provider. It may also be possible to negotiate compensation for only the incremental impact on system regulation requirements, greatly reducing the cost.[2]

To get a feel for the regulation requirements of a larger wind plant (and implicitly the relative cost) we attempted to compare the regulation requirement of two wind plants in the western U.S. with the regulation requirement of a collection of non-regulating fossil fired steam plants. Unfortunately, data for the wind plants was not available at the more appropriate 1-minute interval and we were forced to use 3- and 5-minute data. Table 3 shows the standard deviation of the intra-hour fluctuations for three time intervals for each of the wind plants. The amount of regulating generation capacity required to compensate for intra-hour fluctuation is typically proportional to the standard deviation of the intra-hour fluctuations. Table 3 also shows the standard deviation if the wind plant is to make the same contribution to the regulation burden as a conventional thermal plant.[3] While these results are based on a very small set of data and require extensive additional investigation, they imply that, if restructuring requires that all generators pay for (or supply) regulating reserves to compensate for the burden they impose on the system, wind resources will be assessed between one and four times the requirements of conventional thermal generation.

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[2]Unlike real losses, incremental regulation requirements get progressively lower as the system load increases. An individual would like to argue that it is only responsible for its incremental contribution to the aggregated regulating requirement (Hirst and Kirby 1996b).

[3]Stated another way, this is the intra-hour standard deviation that N independent plants, each producing the stated average power, could each have if their aggregated output was to equal 10,500 MW with a standard deviation of 33 MW.

Table 3 COMPARISON OF WIND PLANT AND NON-REGULATING FOSSIL STEAM PLANT INTRA-HOUR VARIABILITY

| **Case Description** | **Data Set Interval/ Duration** | **Average Power MW** | **Inra-Hour StDev MW** | **StDev to match Fossil Performance MW** | **Ratio of Wind to Fossil** |
|---|---|---|---|---|---|
| 10,500 MW Fossil generation | 4hr/1min | 10,500 | 33 | 33 | 1.0 |
| 200-MW Wind Plant | 2.7hr/3min | 179 | 4.5 | 4.3 | 1.0 |
| | 4.2hr/3min | 80 | 3.5 | 2.9 | 1.2 |
| | 2.4hr/3min | 68 | 4.4 | 2.7 | 1.6 |
| 1000-MW Wind Plant | 19hr/5min | 348 | 13 | 6.0 | 2.2 |
| | 12hr/5min | 393 | 13 | 6.4 | 2.0 |
| | 10hr/5min | 219 | 21 | 4.8 | 4.4 |

## MITIGATION TECHNOLOGIES & STRATEGIES

Wind turbines and projects are generally optimized to maximize annual energy production in an effort to optimize profitability. In a restructured electric market it will be necessary to optimize across all revenues and all costs. There are a number of technologies and strategies that may help. The importance of each will depend upon factors specific to each wind project:

- Re-Optimization of Wind Projects - The design of individual machines and of the integrated wind plant should be re-examined. One simple concept is to have a larger rotor and a smaller generator to maximize capacity factor. This would reduce power fluctuations because each turbine would be above rated capacity more of the time. An alternative would be to design a project with two sizes of turbines, the smaller of which could tolerate being stopped and started frequently, again minimizing fluctuations in electric power output. Pitch controlled rotors or variable speed generators might be preferred because of the added degree of control.

- Geographical Diversity and Aggregation - As discussed above, aggregation is a powerful tool for reducing the regulation (and other) requirements. The larger the aggregation, both in numbers of generators and in geographic diversity, the greater the benefit. Dynamic scheduling may be useful to aggregate non-electrically-contiguous wind plants.

- Variable-Speed and Solid-State Utility Interface - Variable-speed wind generation offers improved energy capture because the turbine can operate at peak performance longer. This should also reduce regulation requirements. Interfacing the wind turbine to the power system through a solid-state inverter gives additional control over the turbine real power output, helping to reduce power fluctuations. It also offers the ability to control reactive power independent of real power. The extent to which active control of real power delivery can be effectively utilized will depend on both the turbine design and the characteristics of the power system.

- Array Control - Energy can be "traded" for reduced regulation burden by controlling turbine output (Javid, Younkins, and Hauth 1985). Control could be exercised over individual turbines or over the total wind plant to “spill” peak power, reducing undesired fluctuations. Curtailment or dumping of energy might be restricted to periods of rapid output rise and gusty conditions. It may be useful to tie this strategy to the new NERC control area performance standard which does not penalize control areas for over-generating when system frequency is low or under-generating when frequency is high. A control system designed to reduce fluctuations might be suppressed when the fluctuation is in a direction that will help restore system frequency, increasing the energy output of the wind plant.

- Wind Forecasting - The DOE program ceased forecasting efforts in 1982 because of limited funding and a belief that techniques had gone as far as possible. Much has changed in the intervening time, including more rapid updating of mesoscale forecasts by the National Weather Service. Danish utilities ELSAM and ELKRAFT are forecasting their wind plant energy routinely. NREL has initiated a modest effort in forecasting wind for the 3 to 24 hour period. NREL will be seeking utility partners for validation in the near future. Wind power forecasting would also assist transmission planning and scheduling (Milligan, Miller, Chapman 1995).

- Wind/Gas Hybrid projects - A wind project and a gas project could be operated jointly to take account of the best features of each with the gas-fired generation providing the rapid response required for control and wind extending the energy and possibly the capacity (Cadogan et al. 1992). Generation technologies other than gas, such as hydro, might be used if the economic and physical match is attractive. The hybrid might utilize dynamic scheduling to synchronize output if the projects were not co-located.

- Short-term storage - A small amount of storage (perhaps 5 minutes of storage at 10 percent of rated wind plant power) could significantly reduce the regulating burden.

- Dynamic scheduling - Dynamic scheduling can be used to electronically move the wind output to a control area where regulation is not as costly. Alternatively, dynamic scheduling can be used to facilitate multi-wind-plant aggregation or a hybrid system. It can also be used to aggregate the wind plant with a specific load, such as a municipal utility that prefers renewables and wishes to use the benefits of aggregating its load with the wind generation to reduce the overall cost of regulating the wind generation.

## CONCLUSIONS

The U.S. electricity industry and its state and federal regulators are in the midst of a massive job of restructuring the industry. The future will be market-based rather than cost-of-service-based. We believe this trend will extend to the ancillary services. These changes will dramatically affect the opportunities for renewable resources such as wind that will compete either in the overall market or within a protected portion of the market.

In this paper we have begun to look at the implications of unbundling a single service: regulation. Each of the ancillary services has its unique concerns. A common feature is that actual minute-to-minute performance of both the renewable resource and the power system will determine the price of each of the services. Additional research, especially involving collection of higher speed data from operating plants, is required to help the industry understand how wind can best participate in competitive markets. This will also help value advances in wind technology, further implementation of recent technical improvements, and help to direct future work.

Ancillary Service prices will depend upon the characteristics of the wind resource itself, the equipment employed at each turbine, the configuration and operation of the wind plant, the electrical characteristics of the interconnected power system, and the behavior of the power markets. Consequently, prices will vary substantially from project to project and from one time interval to the next. It will behoove project owners to pay careful attention to the governance of the power markets, individual contracts that are negotiated, real-time performance of the project, and the real-time performance of the markets.

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