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A Proposal for

Characterizing the Impacts of Significant Wind Generation Facilities on Bulk Power System Operations Planning

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Prepared for

The Utility Wind Interest Group

By

Introduction

A recent survey of the UWIG membership identified "an improved understanding of the impact of wind plants on utility system operating requirements" as the highest priority activity to be pursued with available resources within the organization. For almost two decades, research and development efforts have addressed the range of technical and economic questions that together make up this general issue. Now, however, the "answers" to those questions, and perhaps more appropriately the approaches and methodologies for resolving them in specific contexts, are taking on increased importance. Commercial wind plant development has expanded beyond the traditional wind resource areas in California, bringing a larger number of power system operators and interconnection issues into play.

Electric generating resources that are part of the interconnected power system must be controlled so that their aggregate output matches the electric load at any given time. Frequency deviations and unscheduled tie-line transfers between control areas are indicators of a mismatch between load and generation. Reliable and economic operation of interconnected power systems relies on multiple layers of automatic control systems to insure that generator output follows the changes in load. At the same time, these systems must keep the operation of individual system components within safe limits and maintain adequate security margins for likely contingencies.

On the smallest time scale, individual governors on the prime movers of individual generators act to keep the mechanical system at a speed corresponding to the nominal 60 Hz power system frequency. Automatic generation control (AGC) coordinates the individual actions of multiple generators in an area to quickly respond to load changes and frequency deviations in the most economic (least cost) manner given the profile of generating units in operation at the time. These actions occur on time scales from a fraction of a second (for speed governor adjustments) to several minutes.

At the bulk power system (transmission) level, changes in aggregate system electrical demand on a second-by-second or minute-by-minute basis reflect the diversity inherent in a very large number of relatively independent and small electric loads; i.e. diversity has a filtering effect on the magnitude of load changes on these time scales. Furthermore, many years of operating experience have contributed to a very good understanding of these changes and to the development of generation control and dispatch strategies for dealing with them.

The intermittent and mostly uncontrollable nature of wind generation introduces new variables into the power system control problem. Since wind generation on a significant scale (relative to the bulk electric power system) is relatively new, there is a general lack of historical operating experience. The effects of fluctuating wind generation resources on generation control have been previously addressed in general or hypothetical terms, with the objective of many of these evaluations being to determine the wind generation penetration level below which no impacts would be expected. NREL has recently begun an effort to monitor the long-term output of several wind plants at very high time resolution, which should result in a valuable database for assessing system operating impacts. This work is to be conducted by Electrotek, so its results will be readily available for this proposed project.

Wind generation development in the U.S. has progressed to a point where some individual wind plants and projects have reached the size of a single medium-to-large conventional generating plant. At this size, there is some anecdotal evidence that system operating and control strategies are being impacted. The fluctuating output of the wind plant, along with the potential loss of that resource due to a

transmission system event, must be taken into consideration in the overall equation for deploying and controlling other generating plants in the control area.

The objective of the activity proposed here is to conduct a quantitative investigation into the impacts of large wind generation resources on power system operations and scheduling functions. It is proposed that the work be based on actual case study data, rather than a hypothetical situation or synthesized data. The case study will utilize conventional utility analyses and software tools. It is likely, however, that these conventional tools and approaches might not be suited for representation of wind plants or wind generation characteristics. Hence alternative approaches and methodologies will be developed to facilitate appropriate characterization and representation of wind plants in the various technical and economic analyses.

A utility member of the UWIG has agreed to participate in and cosponsor the case study. The focus of this project will be to answer questions regarding the specific impacts of wind generation on operations, scheduling and planning for the case study system. Extrapolating and generalizing the results of this project for application to a wider range of utility systems and wind generation technologies will be a substantial undertaking in itself, and is recommended as a future, follow-on activity. However, a preliminary attempt to generalize findings will be conducted within the scope of this project.

The UWIG considers this to be the most critical problem for the future integration of large amounts of wind capacity into utility systems. Consequently, UWIG will cosponsor the work with a contribution from its modest discretionary funds. Selected experts from within UWIG-member utilities will also provide ongoing detailed technical review of the work to enhance its validity and credibility within the electric sector. A successful outcome will require addressing a very wide range of technical and economic issues. Tools and methodologies utilized in utility-system operations planning must be modified to accommodate the technical characteristics of wind plants and wind generation. As representatives of major utility organizations, the UWIG utility experts are well-versed in the relevant technical disciplines, and can provide essential guidance for the work.

Background - Power System Operations and Scheduling

The primary objective in power system operations and scheduling is to continuously provide sufficient generation to match load at the lowest possible cost to the utility. This objective must be accomplished while maintaining system voltage and frequency within specified tolerances, and providing for system security. Time frames of interest range from seconds to weeks, months, and even years. As installed wind plant capacity approaches and possibly surpasses that of other single units within a given power system, integrating the performance characteristics of wind plants into the various algorithms and programs used for planning and monitoring system operation will become more important.

AGC and Economic Dispatch

Stable operation of the interconnected power system is dependent on an instantaneous match between load and generation. System frequency is a primary indicator of this balance. When electric load on a synchronous generator exceeds mechanical input, the generator will begin to slow down as kinetic energy is extracted from the machine's rotational inertia and is converted to electric power. The decrease in shaft speed corresponds to a decrease in frequency in a synchronous generator. Conversely, when power supplied by a generator prime mover exceeds electric demand, the generator mechanical system will accelerate as the excess input is stored as rotational energy, with a corresponding frequency increase.

Speed governors on individual generating units maintain constant generator speed by adjusting the mechanical input from the prime mover (steam turbine, penstock, diesel engine, etc.) in response to a speed error signal. These systems provide the fastest response to speed deviations caused by mismatch between generator input and output.

Automatic generation control, or AGC, is the principle mechanism for coordinating the output of all system generators to match aggregate electrical demand. In a given control area, governor setpoints of generating units assigned responsibility for system regulation are coordinated by AGC to maintain system frequency at 60 Hz. AGC involves two interrelated functions: 1) Load/frequency control; and 2) Economic dispatch. Response of load/frequency control is on the order of seconds; variations which occur more quickly are handled by the individual units' speed governors.

The economic dispatch function in AGC attempts to minimize the cost of meeting the load demand by adjusting individual generating units' participation in load/frequency control. While load/frequency control acts to adjust generation every few seconds, the economic dispatch adjusts participation every few minutes to minimize generating cost. Inputs to economic dispatch algorithms include incremental generating costs for participating units, transmission penalty factors, and scheduled interchanges with other control areas.

Unit Commitment

Unit commitment is part of a set of programs for scheduling thermal generation on an hourly to weekly basis. Using forecasts of system load and power purchases or sales to other utilities, unit commitment programs determine which units are to be put on-line and when, and when units are to be taken off-line. The objective is to minimize total operating costs over a time period of one to 10 days, taking into

account unit start-up and shut-down costs, maintenance schedules, unit operating costs, and other constraints.

Unit commitment programs use dynamic programming techniques to schedule units of a fixed size to meet the predicted demand for each hour. It is sometimes necessary to coordinate the use of these programs with other specialized routines, like those used for predicting hydroelectric production.

Load Forecasting

Forecasts of load for the next hour, day, season, or year drive the utility scheduling process. Load forecasting is often subdivided into "long-term", where seasonal load peaks and energy requirements are predicted on a long-range basis, and "short-term", where hour-by-hour predictions are made for a particular day. Accurate forecasting of system load is critical for minimizing operating costs. Load forecasts are the primary inputs to the power system scheduling and operations process. When load forecasts are inaccurate, adjustments to the generation schedule result in additional fuel expenses and wear and tear on generating equipment. New and improved methods for load forecasting are continually being developed because of the critical importance of accurate forecasts for minimizing operating costs.

Short-term load forecasts rely on historical data and various other inputs such as weather conditions, daily and seasonal patterns, and industrial demand, to predict the hourly load for the next day. Short-term forecasting is a complex problem, and even if it were possible to accurately predict the load based on known factors, random occurrences such as storms, strikes, etc. can upset the prediction.

Proposed Work Scope

To assess the impact of wind generation on electric utility operation, we will decompose the problem by time scales (time scale decomposition). The first time scale is close to real-time. Here we examine the impact of wind generation on electric utility operation over time periods of a few seconds to several minutes. This can be considered the Automatic Generation Control/Economic Dispatch (AGC/ED) time scale. The second time scale of interest is that of several hours to several days. This can be considered the Unit Commitment (UC) or more generally the Short-term Hydro-Thermal Scheduling (STHTS) problem. The reason for this separation is that the models, tools, and phenomenon of interest are different. However, as in all such time scale decomposition approaches, there is a link between the longer term decision and the shorter term operation.

The overall activity is therefore divided into two tasks

- Task 1: Analysis of Impact on Generation Control and Reserve Requirement
- Task 2: Analysis of Impact on Unit Commitment Decisions

A scope of work for each task is described next.

Task 1: Analysis of Wind Generation Impact on Generation Control and Reserve Requirements

Define Operating Criteria

In order to evaluate the effect of wind generation on spinning and operating reserve, we need to define how we will "measure" this impact. One approach is to simply simulate the with and the without case (i.e., with wind generation and without wind generation) and identify differences in key system variables (frequency, net interchange, unit control). While this will provide an indication of whether wind generation causes performance degradation, it is subject to the argument that any impact is not significant due to lack of comparison with an absolute criterion. Therefore, instead, we propose to use the NERC Control Performance Criterion as the measure. This is an accepted criterion in North America and will be used in this task to determine whether meeting this criterion imposes additional requirements on the conventional generation in systems with wind generation.

Develop Model of Wind Generation

We will need to use a "short" term model for simulating the wind generation. By short term we mean over a period of a few seconds to 30 minutes. Since this will depend on the forecast of wind behavior, we will need to have a probabilistic forecast of wind speed over this period. In addition, local wind generation dynamics and controls active during the time frame of interest will have to be simulated.

Since we are interested in substantial wind generation capacity (hundreds of MW), the area over which the individual wind turbines are installed will be extensive (several square miles). Therefore, it will be necessary to look at the spatial and temporal variation of wind in order to achieve a realistic prediction of wind generation. Simply extrapolating from a singe location with a single unit will result in an unreasonable estimate.

Define Properties Needed to Meet Criteria

For real time control of generation, the two major attributes of the generating unit are the reserve capacity available and the permissible rate of change of that capacity. These are commonly called spinning reserve and ramp rate values. These parameters need to be determined for the specified generation mix. From a system perspective, we also need to establish how many of the on line units are controllable.

Upgrade Simulation Tools

For this study, we intend to use a software package that consists of the following major modules:

- An AGC program that essentially is a batch version of a standard AGC program of the type found in an Energy Management System (EMS). It includes for example
    1. Data Acquisition
    2. Area Control Error (ACE) Calculation
    3. Control allocation to units
    4. Generating Unit Response Monitoring
    5. System Performance Modeling

- A simulation program to model the dynamics of the generating units. Basically, it models the generating units to correctly calculate the behavior in the seconds to minutes time frame. Faster transient phenomena are neglected. In essence, the turbine, governor, and a limited boiler model are used. Only the real power models are of interest. Thus, for example, excitation systems are not included.
- An equivalent, low order model of the "external" network. This will predict the frequency of the interconnected system. To illustrate, the external network may represent the Eastern Interconnection frequency dynamics while the detailed simulation program represents the single control area being studied.

We will augment this software by adding a model for the wind generation. The nature of this model will be defined as part of this project. In general, it will be necessary to model the inertia of the blades, the behavior of the induction generator and the controls as well as the wind characteristics.

Define Scenarios to be Studied

The definition of the scenarios to be studied is a critical task. System variables to be considered include:

- Wind profiles
- Load/Demand Profiles
- Time of day
- System events (such as loss of a generating unit)
- Number and types of generating units on control

In addition, we need to define the base case. For example, the base case could be the current generation system without any wind generation. Then the wind generation impacts would be evaluated by adding the wind generation to the existing generator mix. This case is one in which the wind generator is simply added to the existing mix. Alternately, the base case could be the existing generating mix PLUS a conventional generator (i.e., not a wind generator) with a certain capacity and characteristic which would meet the forecast needs. Then the wind generator would REPLACE this new capacity. The system performance would then be evaluated for these two expansion scenarios – one with a conventional unit and one with a wind unit.

Obtain Utility System Data to be Modeled

In order to obtain results that are generally applicable and valid, we will use data from an actual utility. This data will include generating unit parameters, wind generation penetration, load shapes, interchange levels, and interconnection data.

Run Simulation Studies

For the specified scenarios and the utility model, simulation studies will be run. The time horizon will be up to a maximum of 30 minutes with a one second discretization interval.

The results of the simulation will be based on whether the system performance meets the selected operating criteria such as the NERC criteria. Thus for example we do not base conclusions on relative behavior but whether the system with or without wind generation meets the industry accepted performance levels and at what cost.

Expected Results

This effort is expected to yield three important results, which will be summarized in a task report:

- A detailed analysis of cases being studied, with recommendations for alternate wind plant operating strategies for minimizing cost and maximizing benefit.
- A detailed analysis of wind turbine and wind plant design and control characteristics, with recommendations for changes in turbine design and control system strategies to improve operating performance.
- Identification of the wind plant characterization necessary for system operating studies.

Task 2: Analysis of Impact on Unit Commitment

Background

As the amount of wind generation becomes a larger percentage of the total on-line capacity, the traditional spinning reserve criteria (percent of demand, largest unit on-line) may not be valid. Additional reserve may be needed to ensure the same degree of reliability in the presence of a variable generation source. Since this may require bringing additional conventional generation on-line, a unit commitment study will be necessary. The time horizon of this study is typically 24 to 168 hours and requires wind generation forecasts.

The objective of the analysis will be to determine any additional costs that may be incurred in the presence of wind generation and to study tradeoffs between the cost of additional reserve and the benefit (higher reliability). Wind generation will be treated as a stochastic variable with a specified distribution in these studies. Also, since wind forecasts become increasingly inaccurate as a function of lead time, some conflicts may occur between generating unit startup times and forecast lead times, i.e. differences between predicted and actual wind speed may render it difficult to accurately schedule units with long lead times for start-up.

Key Issues

The traditional Unit Commitment programs minimize the total cost subject to demand and reserve constraints. Both the demand and reserve constraints are deterministic, i.e., the value of demand and reserve is a fixed quantity for each hour of the scheduling horizon. Although other variants exist, such as reserve constraint by area, area interchange constraints and, in the most comprehensive approach, an Optimal Power Flow integrated with the Unit Commitment program, none of these variants changes the fundamental nature of the reserve and demand constraints represented in the traditional unit commitment program.

The reserve constraint is the more interesting one since it is based on some predefined criteria such as loss of largest unit, percentage of load, or an interconnection reserve requirement. While these are heuristic values based on experience and some analysis, their applicability to systems containing wind generation needs to be carefully examined and is discussed below (see Define Reliability Criteria).

Major components of this task are described in the following paragraphs.

Define Wind Generation Models

The wind generation models needed for the unit commitment studies will have to be valid over a period of several hours to days. Generally, the UC runs on an hourly (occasionally half hourly) time interval and the wind generator models will need to be compatible.

Electrotek has some of the raw data from a large wind plant in the Midwest at 15 minute intervals, and is expecting to receive additional data at one second intervals. It is anticipated that we can synthesize the necessary models for the simulation study using this data.

Define Reliability Criteria

Currently the reserve requirement may be viewed as a single-worst-contingency (loss of the largest unit or other generation source) criterion. The percentage-of-load criterion is based on similar considerations. Introduction of wind generation, which is both intermittent and non-dispatchable, raises some interesting issues. First, if one treats the wind generation as a conventional unit, then the same criteria could be used. However, this is not realistic because it does not take into account the intermittent nature of wind generation, which in principle could fluctuate between zero and maximum output as a stochastic variable. Therefore, the worst case scenario is to have reserve equal to the sum of the capacity of the largest unit plus the wind generation capacity. This of course is also the most expensive. What we would like to achieve as a part of the study is to come up with a reserve requirement that is optimum in the sense that it meets the reliability criteria at least cost.

It will be necessary to define the reliability criteria since one can no longer use “largest unit”. Perhaps something similar to the loss of load probability will be appropriate. Then we can use the simulation to come up with some rules relating wind variability, peak wind generation, and the expected additional reserve requirements. We would like to stress that this is not, in our view, a “double contingency” criteria but one that simply combines the worst single contingency with the intermittent resource.

Obtain Utility Model Data and Parameters

The Unit Commitment data needed includes minimum up and down time, start-up costs as a function of down time, ramp rates, and operating costs. This data will be gathered in cooperation with the host utility selected for the case study.

Select and Upgrade Simulation Tools

The simulation will be carried out using a Unit Commitment Program that uses Lagrangian Relaxation. The program will have to be upgraded to include the model for wind generation and for the reliability criteria. Currently in the Unit Commitment program, the reserve requirement is specified as a fixed amount for each hour.

Conduct Simulation Studies

The unit commitment tool will be used to conduct simulation studies with the objective of determining reserve criteria that must be met to satisfy a certain level of reliability.

Expected Results

This effort is expected to result in reserve criteria for unit commitment programs used in modeling electric power networks with significant amounts of wind generation. A Final Report which summarizes the results of this task and incorporates the results of the previous task will be prepared.