Wind and Biomass Integration Scenarios in Vermont

Summary of First Phase Research: Wind Energy Resource Analysis

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Introduction

There is much interest in the potential for wind power in Vermont. This project was undertaken to examine technical and cost issues associated with installing wind and biomass plants on the Green Mountain Power system and other electric power systems in Vermont. Results from the study are expected in mid-2002.

Specific objectives of the overall study are to evaluate the effects of high penetration levels of renewable energy on the grid of Vermont (and adjoining areas) by 2010, to determine: (1) transmission and distribution grid systems changes that would be needed, (2) grid operation and control issues, (3) the incremental cost of renewable energy capacity additions, (4) ways to minimize increases in the cost of energy to the consumer, and (5) potential reductions in regional CO_2 emissions. By achieving these objectives, this project will support the goals and strategies under U.S. Department of Energy's (DOE's) Wind Powering America Initiative and other efforts to increase the use of wind and biomass energy in the U.S. through targeted regional efforts.

To assist interested parties in the state before the overall project report is completed, results from the first phase of the study, an analysis of the wind resource in the state, are being released in this documentation report. The results include 4 maps and documentation on the process used to develop them. The analysis identifies both the amount and the corresponding location of wind resources throughout the state, after excluding locations based on several criteria such as environmental sensitivity. Resources are divided into amounts close to the transmission system (grid facilities above 34 kV-class levels), and amounts close to the distribution system (grid facilities below 34 kV-class levels). None of the study participants make any claim or conclusion from this analysis as to the feasibility or likelihood of projects at any of the identified locations, from the economic, technical integration, or siting perspectives. The purpose of the analysis is to supply data for the second phase of the study.

The second phase of the study will employ power system integration analysis to address technical, operational, and economic issues and realistic limits for installing up to 750 megawatts (MW) of wind plants, operating in conjunction with existing hydropower plants in Vermont, and up to an additional 40 MW of new biomass plants. Distributed generation applications will also be analyzed for using wind power in low power (hundreds of kilowatts (kW)) grid connected applications and isolated, off-grid applications, e.g., ski areas, with diesel engine generators. Technical requirements of this renewable energy portfolio on the power transmission and distribution system will be analyzed, including reinforcement options and associated costs necessary to permit the high renewable energy penetration. The study will also provide interested parties with a description of integration issues likely to be faced by a large number of potential wind and biomass projects, and identification of approaches and associated costs to address those issues.

This work is being performed under a grant from the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, with cost sharing from Green Mountain Power Corporation (GMP) (including technical support from Hydro-Québec), and the State of Vermont Department of

Public Service (VT DPS). DOE and GMP are contributing close to 50 percent cost sharing each, with the remaining contribution coming from the VT DPS. Princeton Energy Resources International, LLC of Rockville, Maryland (PERI) is the prime contractor for analysis and project management, with assistance from subcontractors EPRO Engineering and Environmental Consulting, LLC (Vermont Office, Montpelier), and Vermont Environmental Research Associates (Waterbury). Project results are expected in the Summer of 2002.

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Wind Resource Assessment Approach

A geographic information system (GIS)-based screening approach was used to identify the universe of sites that could be developed under high penetration scenarios. Inputs to the GIS (MapInfo Professional Software) included spatial data on wind resources developed previously by the National Renewable Energy Laboratory (NREL) (Elliot 1999), the electric T&D system (34.5 kV and up) for Vermont's electric utilities (Vermont Electric Power Company 1991), along with environmentally sensitive areas and other land use (Vermont GIS Data Warehouse). The identification process considered the strength of the wind resource, proximity to the existing electric transmission and distribution (T&D) system, as well as several criteria to exclude environmentally sensitive and other noncompatible land use areas. <u>Beyond the land exclusion criteria listed below, the analysis does not address siting issues that could prevent installation at specific locations</u>.

The resource assessment process was conducted with consideration for two distinct development perspectives:

- *Class A turbine strings* - Large wind power installations (greater than 6 MW) installed along the windiest ridge lines and interconnected directly to the existing electric transmission system (connected to grid facilities above 34 kV-class levels); and

- *Class B turbine strings* - Small installations (50 kW to 6 MW), generally at lower elevation sites where they could be either connected to the existing electric distribution or sub-transmission system (connected to grid facilities below 34 kV-class levels).

The process involved the following steps:

1) A base map was created to show county and town boundaries, roads, surface waters, population centers and similar broad-scale geographic information.

2) A digital version of the best existing wind power map (developed by NREL) (Elliot 1999) was prepared to represent wind resource areas broken into seven standard wind power classes. Wind data on this map has a resolution of 1 square kilometer (km^2). That is, each km^2 of land is assigned a designation of one of the seven standard wind power classes throughout its entire area. The resulting digital map may be thought of as a grid, broken into 1 km^2 squares. In a GIS system, the original map and each subsequent set of data overlain on the map is called a "layer." After creating the base wind resource map, the next layer to be developed was one for potential wind turbines sites. Because the windy areas in Vermont are primarily along the north-south oriented mountain ranges, "turbine strings" were first drawn roughly through each grid square with a wind power designation of class 3 or higher, and oriented perpendicular to the prevailing wind flow. The term "turbine s
the simplifying assumption was made that only one row of turbines, i.e., a "string", can be installed at any site. This turbine placement pattern will be typical in most of the ridge sights in Vermont. Then, to more accurately place the turbine strings closer to the actual ridge lines or hill tops, a more refined turbine string layer was created using a shaded relief topographic map overlay to distinguish prominent physical land features. After this process was performed for both Class A and B turbine strings, the following criteria were applied to further refine potential turbine locations.

- *Class A turbine strings* - Using a map of electric transmission lines as an overlay, Class A turbines strings were sited where a part of the string was within 3 miles of existing suitable transmission lines or a neighboring turbine string was 3 miles or less away. Suitable transmission lines were defined as those with a rating in the range of 34.5 to 120 kilovolts (kV). Emphasis was placed on identifying relatively long strings several miles in length, in the windiest areas that can support relatively large wind facilities.

- *Class B turbine strings* - Class B turbine strings were mapped based on their proximity to electric distribution lines. Since an electronic version of distribution lines is not available for all of Vermont, a map of all township-level roads and better (i.e., state and federal highways) was used as a proxy for distribution lines.[1] Electrical line

[1]Roads in the state are officially designated using the following classification system: Class 1 = federal highways, Class 2 = state highways, and Class 3 = town roads. Thus, all roads Class 3 and above were used for this effort. For wind, the term "Class" signifies a standard rating for wind power, which ranges from lowest (Class 1) to highest (Class 7).

maps were spot-checked to confirm the reasonableness of this simplifying assumption, although a quantitative correlation between the presence of roads and distribution lines was not established. Turbine strings that lie within approximately 0.25 miles of these roads were mapped. Emphasis was placed on identifying relatively short strings that could support up to several megawatts of installed capacity, that were generally on windy hilltops at lower elevations.

3) All turbine strings were then screened for general land use and environmental compatibility by applying the following criteria:

Proximity to the Appalachian and Long Trails. Turbine strings within approximately 0.5 miles to these trails or major side trails were eliminated.

Public lands with the highest protection level. Turbine strings that intersect public lands where wind development is prohibited were eliminated using the Vermont Conserved Land Database.

Green Mountain National Forest restrictive Management Areas. Turbine strings that intersect with federal land managed to be prohibitive or highly restrictive to wind power development were eliminated, including Green Mountain National Forest Management Areas 5.1, 6.2, 8.1, and 9.2 (GMNF Plan 1986).

Green Mountain National Forest restrictions for siting visually prominent facilities. Areas mapped by the GMNF as having the "highest" level of sensitivity to siting visually prominent facilities were eliminated (USFS Plan 1986).

Potential for conflicts with known rare, threatened, or endangered species. Turbine strings that fell within 0.5 miles of a rare, threatened or endangered species were subjected to individual scrutiny. If the turbine string could be shortened or moved to avoid the immediate vicinity of the species of concern, it was, otherwise it was eliminated.

4) Turbine strings that passed the exclusion screens were each assigned an average wind power class based on wind power density values for each km^2 cell in the wind power map (Elliot 1999) that they traversed. An average wind turbine net capacity factor for each turbine string was then assigned using a Vestas V47 (660 kW) wind turbine power curve considering air density, together with estimates for losses associated with availability (2 %), transmission (3 %), turbulence (3 %), icing (6 %), and in-line wakes (2 %).

5) The number of wind turbines and the installed capacity for each turbine string were estimated assuming a five-rotor diameter spacing requirement between wind turbines. The larger Vestas model V66 (1.65 MW) wind turbine is typical of the newest large wind turbines

used in commercial power plants and was used for this step because it results in the maximum potential estimated capacity. Combining the estimated capacity with the calculated net capacity factor for each string, annual energy production estimates were then determined. (The V47 turbine was chosen for estimating energy production because the study authors already had data from this turbine in the correct format. Although there is some difference between the capacity factors of the V47 and the V66, the error in resulting total energy production introduced by this assumption is dwarfed by the total energy production from all potential turbine strings.)

At the end of this report are four maps that were produced from the analysis described above. The maps show separate plots of turbine string Classes A and B plotted over 1 km^2 wind resource class cells and topographic features. Other data represented in the various GIS "layers" is also shown as indicated in the map legends. Table 1 summarizes the wind power generation potential for Class A and B turbine strings, and shows the impact of the land use exclusion screening process on limiting the "technical potential" for wind energy capacity levels. Technical potential is defined for this study as the level obtained after applying the land use exclusions, but NOT CONSIDERING economic, technical, or siting feasibility at any location. Note that the total potential capacity estimates for the Class A and Class B string approaches are NOT additive. That is, although they represent different approaches to siting and connecting wind turbines to the transmission and distribution system, they both utilize the same capacity of the system to handle additional power flow.

The state-wide peak load in Vermont is about 1,000 MW. The totals in Table 1 indicates there is more than enough potential "technical" wind resource to meet this study's target of "high penetration" on Vermont's grid from any combination of Class A and Class B turbine strings. Even using much more severe land use exclusion criteria would leave enough resource available for a high penetration scenario. In other words, the state is not resource-constrained. The table shows that there are similar amounts of resource available for Class A and B strings, i.e., just over 6,000 MW. However, the reader is cautioned again that no conclusions have been drawn to-date by the study authors as to what portion of the resource may be economically attractive, technically feasible, or possible from the perspective of gaining public acceptance for siting wind energy facilities. The final phases of this study will provide information on the first two aspects (economic and technical feasibility), but not on siting issues or constraints.

Table 1. Technical Potential of Wind Power Generation In Vermont (not considering economic, technical, or siting restrictions)

Wind Class	Miles of Turbine String Before Exclusions	Miles of Turbine String After Exclusions	Capacity Before Exclusions (MW)	Capacity After Exclusions (MW)	Net Energy Production Before Exclusions (TWh/yr)	Net Energy Production After Exclusions (TWh/yr)
Class A Turbine Strings						
3	122	97	976	773	2.2	1.7
4	122	102	976	816	2.5	2.1
5	149	114	1,192	914	3.3	2.6
6	307	222	2,456	1,773	7.7	5.6
7	469	225	3,752	1,798	15	7.2
Total	**1,169**	**759**	**9,352**	**6,074**	**30.7**	**19.1**
Class B Turbine Strings						
3	286	224	2,284	1,791	5.1	43
4	174	144	1,390	1,150	3.5	2.9
5	159	131	1,269	1,050	3.5	2.9
6	259	167	2,074	1,337	6.5	4.2
7	141	103	1,130	826	4.5	3.3
Total	**1,019**	**769**	**8,147**	**6,153**	**23.2**	**17.3**

1. Installed capacity based on Vestas V66, 1.65 MW wind turbines spaced 5 rotor diameters apart.
2. Energy production is based on annual estimated mean capacity factor for each wind power class. This was determined using the power curve for a Vestas V47 (hub height = 50 m) and the mean wind speed for each wind power class.

References

1. Elliott, D.; Schwartz, M.; Nierenberg, R. (1999). Wind Resource Mapping of the State of Vermont. 9 pp.; NICH Report No. CP-500-27507
2. Green Mountain National Forest Plan. 1986
3. Vermont Electric Power Company. Map of Electricity Transmission Lines and Utility Service Territories for the State of Vermont. 1991.
4. Vermont GIS Data Warehouse. (http://geo-vt.uvm.edu/cfdev2/warehouse_new/warehouse.cfm).