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MACRO—SCALE WAKE EFFECTS

About five years ago a perplexing new phenomenon was noticed by several wind energy meteorologists. Each year the winds in certain parts of the Altamont Pass, in northern California, decreased. Initially the cause was thought to be climatological; for instance, in 1984 the low winds were blamed on the "El Nino" (abnormally warm waters in the equatorial Pacific Ocean). As more time passed, the winds at many locations still have not returned to earlier levels, while other areas have remained at historical levels. Although variations in climatological conditions can result in improved or reduced winds from year to year, another explanation for the diminished wind resource has emerged.

Our hypothesis is that the large arrays of wind turbines installed in the Altamont produce significant wake energy deficits that persist much further than 10 or 20 rotor diameters (RD) downwind. This article will present evidence that supports this hypothesis. The supporting data was collected and analyzed by Howden Wind Parks Inc. Results from a Department of Energy (DOE) funded wake deficit study performed by the Altamont Energy Corporation are also presented.

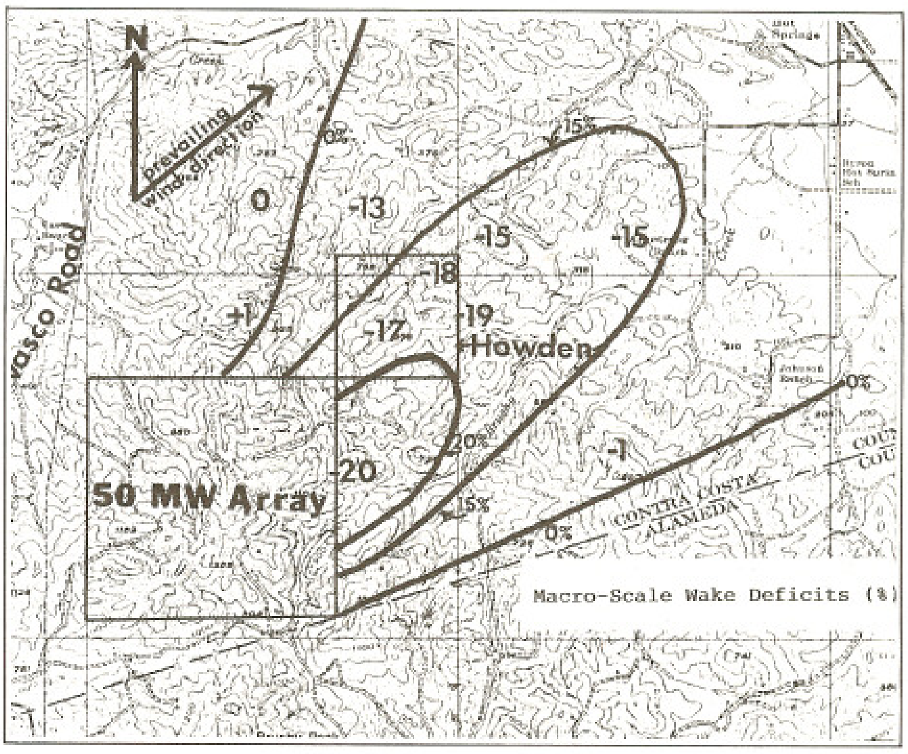
We shall focus first on the impact downwind of the U.S. Windpower (USW) 50 MW windfarm, which was installed upwind of Howden's windfarm in late 1985. The mean wind trajectory passes from USW to Howden about 90 percent of the time on an annual basis. The attached figure shows their locations on the northern Altamont Pass. Construction of these two facilities occurred simultaneously.

The data used in the analysis are hourly mean wind speeds for summers (May-Septmeber) of 1985 and 1986. A comparison will be made between summer 1985, before the windfarms were installed, and when Howden's windfarm was operational, so no wakes from Howden turbines are present. Theoretical energy for these two periods was calculated using data from several anemometers and the Howden 330 kW power curve. The changes in theoretical energy, in percent, from summer 1985 to 1986 have been plotted at various anemometer locations and contoured in the figure. The locations of the contours are based on the available data and are estimated where we have none. The use of different power curves has negligible effects on the results.

The map figure shows a number of interesting things:

1) The one square mile (2.6 sq. km) Howden Wind Park is directly downwind of the USW (late 1985) installation. Note the prevailing wind direction.
2) Immediately downwind of the 50 MW array, the energy decrease or deficit is 20 percent.
3) A large area, extending several miles (250+ RD) downwind of the 50 MW array has a deficit of about 15 percent.
4) The areas to the northwest and southwest of the 50 MW array (crosswind) have negligible (0 to 1 percent) changes.

These deficits are for the summer only



Macro-Scale Wake Deficits (%)

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when the wind direction is predominantly southwest. Annual deficits are slightly lower.

The reader may ask about repeatability in subsequent years. Howden has one anemometer which has operated continuously since 1984 in the middle of their windfarm. The 1988 data is not useful because the Howden windfarm was operational and the wakes affected the anemometer. We have compared theoretical energy for summers of 1984 and 1985 (before installation of the 50 MW windfarm) with those in 1986 and 1987 (after). This anemometer site had a nine percent energy deficit in 1986-87 compared to the first two-year period. However, sites that are crosswind to and upwind of the 50 MW array showed an energy increase of nine percent to 10 percent for this same period. Thus, the site within the wake affected region has dropped almost 20 percent in theoretical energy, relative to the freestream sites.

There are many other examples of this phenomenon in the Altamont Pass. The Howden windfarm became operational again in the spring of 1988. Using the same analysis techniques, we measured theoretical energy deficits of 20 percent to 25 percent, in summer 1988, one mile (50 Howden RD) downwind of our own installation.

A wake energy deficit study was conducted by the Altamont Energy Corporation for the DOE using an array of Nordtank 65 kW turbines in another part of the Altamont Pass. The array spacing was 2 x 8 RD (2 RD crosswind by 8 RD downwind). Energy deficits were measured at one row of turbines, downwind from two rows (one at 8 RD and one at 16 RD upwind). There were several significant results from that study *(1)* that relate to this topic.

1) Energy deficits were inversely proportional to wind speed, i.e., higher winds yield lower energy deficits.

2) In typical summer winds with an average speed of 23 mph (10.2 m/s), the wind energy deficit from the row at 8 RD upwind was 13 percent.

3) In 23 mph winds, the energy deficit from the row at 16 RD upwind was 12 percent, almost the same as from the 8 RD row.

A possible explanation for the persistent wake deficits measured by Howden and Altamont Energy Corporation, is the temperature inversion (warm air above cold air) found in the Altamont Pass. This inversion is a persistent climatological feature, the dynamics of which contribute significantly to the high winds found in the Altamont Pass. Measurements by Howden and others have shown that the inversion can be found from near the surface to several hundred feet above ground level. The high wind layer in the Altamont Pass lies beneath the inversion, with wind speeds decreasing very rapidly above the inversion. The stabilizing nature of the inversion inhibits the downward mixing of momentum from above. Thus, the amount of wind energy flux in the Altamont is finite and each row of wind turbines removes a portion of this energy, permanently.

There are several important implications of these findings to wind energy developers. First, it helps to explain the decrease in wind speeds in many parts of the Altamont area since turbines were first installed in 1981. Second, due to the inverse relationship between wind speed and wake deficits, turbine array effects can amplify downward trends in wind speed caused by climatological variations. That is, in a low wind year, wake effects will be worse, and downwind sites will experience larger energy deficits. Third, long-term estimates of the wind resource must be adjusted to account for upstream wake deficits.

A historical wind data record at one site spanning many years but subjected to upstream development for some portion of the total duration cannot be treated as one continuum. The data need to be analyzed in discrete time segments, corresponding to periods with and without upstream development. Otherwise the upstream wake effects will not be accounted for and estimates of the wind resource will be too optimistic. And finally, developers should keep in mind the potentially detrimental effects of future projects installed upstream of their existing or planned projects.

The extent of any macro-scale wake effects will depend on the local atmospheric structure, overall wind resource, percent of time the wind trajectory is from the upstream development, and the size of and distance to the upstream development. The energy deficits in the Altamont Pass may be higher than would occur in other parts of the world. Nevertheless, the macro-scale energy deficits could be significant.

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(1). Nierenberg, R. 1989: Wake Deficit Measurements on the Jess and Souza Ranches, Altamont Pass. Solar Energy Research Institute, Golden Colorado.

PROMISING RESULTS FROM BLADE RESEARCH PROGRAM

Blade root failures in Aerostar wind turbine blades was the impetus behind a recently completed study on the subject conducted by the Danish Windmill Owners Association (DV).

The main conclusion resulting from the study was that annual monitoring of blade root rigidity is essential to help ensure a long blade life. Also included in the findings were the identification of the different problem areas most commonly found in a blade and their frequency of occurrence.

However, I would like to point out that the appearance of a crack in a blade should not automatically be interpreted as serious damage. A crack can indicate anything from a harmless flaw in the gelcoat to severe fatigue.

Also of noteworthy interest was the development of a new method of monitoring and documenting blade root condition. It was proven that high measured values indicating low rigidity in a root do not necessarily imply damage due to fatigue. In fact, high values usually only indicate that the root bushings have not allowed the metal sections of the blade's root to compress the fibreglass root materials as required. However, high values measured in root rigidity tests will always indicate that there is some sort of problem which will sooner or later lead to fatigue if preventative action is not taken.

For Aerostar blades this preventative action calls for the countersinking of the metal flanges and the filling of the fibreglass flange before re-assembly takes place. This process has now been adapted by most Danish turbine manufacturers and maintenance companies which earlier installed Aerostar blades.

Another reason for high measured values is believed to be improperly tightened root bolts. Torquing to 350 Nm for greased hot dip galvanized M20 bolts is recommended.

In order to verify the reliability of the blade root monitoring method developed in the DV rotor study, Danish AeroForm received a government grant to conduct fatigue tests on the 7.5 meter Aerostar blade. The questions to be answered by the study were:

1) Does the root rigidity measurement describe the state of root fatigue?

2) Can root repair ensure a reasonable lifetime for an undamaged blade?

For the test a set of blades was ob-