Applied Energy 39 (1991) 235–240

Scheme for Evaluating Usage of Wind Energy by Electric Utilities

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ABSTRACT

The benefits of integration of electric power, produced by wind energy, into utility networks, are studied by correlating the electric power load and the wind energy daily *curves. A conceptual procedure for applying this approach and schematic illustrations are provided.*

1 INTRODUCTION

Cost-production evaluations of wind energy (WE) converted into electric power, which is supplied to a closed electric utility network, should consider the following: (i) energy displacement (i.e. the amount of electrical energy not required to be generated by conventional generation because of WE usage), and (ii) capacity displacement (i.e. the amount of conventional generating capacity that may be omitted from the utility planned requirement because of WE usage).[1] Evaluations of (i) and (ii) should emphasize the WE characteristics during the daily electric-load peak hours. A large WE

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Applied Energy 0306-2619/91/$03·50

availability, during these hours, tends to have relatively high economical and operational merits because it reduces the requirement for electric production from conventional sources which become relatively expensive in high load levels.[1] Obviously, high WE availability has an additional merit in extreme situations, when electric consumption becomes larger than the utility production capability. On the other hand, when a WE farm is planned to produce electric energy in amounts large enough to substitute for regular electricity production units, then examination of the WE availability during the peak load hours is imperative for the implementation of appropriate strategies involved with such capacity displacement.

The level of electric-power consumption during the daily peak hours, at mid-latitude and sub-tropical geographical locations, varies with seasonal weather conditions. In the warm season, this variation is, in many countries, dominated by a demand for air conditioning and agricultural irrigation needs. Increased electric-power demand for building heating, as well as residential and industrial water heating needs during the cold season, is typical in some countries. Winter daytime electric illumination needs, a result of the shorter sunlight hours and increased cloudiness, may be very significant. In a given month, the level of weather-related electric energy consumption (WRE) for these purposes typically fluctuates from day to day as a result of the changes in the daily weather conditions. These frequently result in significant increases/decreases of WRE compared with average monthly levels. In industrialized countries, where WE power may be fed into utility networks in relatively large amounts, the following are likely to be applicable: (i) electric energy consumption for WRE purposes will be larger than the WE contribution to the related electric network; (ii) the relation between the daily pattern of WRE as affected by parameters such as air temperature and humidity, cloudiness, and solar radiation, at the areas of high electricity consumption, can be established quantitatively. Therefore, it is suggested that economical/operational evaluations of WE availability significance can be done by relating it to the characteristics of WRE.

Increased concerns about the adverse environmental impacts caused by fossil-fuel consumption for energy production, may revive the interest in the integration of WE into electric utility networks. Previous studies of the significance of WE availability statistically correlated its daily features with the corresponding electric-load variations (mostly affected by the WRE) from the average load curve data. However, usually the in-situ wind measurement period, in locations examined for WE, is shorter than the period needed for establishing a reliable wind climatology (at least 2–3 years of wind data are needed). Also, the statistical data-analysis studies do not lead to the capability of daily forecasting of the WE–WRE relation needed for daily load management of a utility with an integrated WE.

In the present investigation a conceptual scheme is suggested for an improved evaluation of the relations between WE availability and WRE demand, while introducing a *synoptic climatological classification* parameter (see Section 2). The advantages of this methodology as compared with a purely statistical analysis, are summarized in Section 3.

2 WE–WRE GENERAL EVALUATIONS

To help evaluate the economical/operational significance of the WE in relation to WRE, the general grading scale in Table 1 is suggested. Classification of the annual prevailing meteorological synoptic conditions (termed S) is made.[2,3] The WE–WRE relations for each synoptic condition, S, are established, based on a representative data set for each synoptic condition, thus, enabling quantification of the WE–WRE–S relation. In the schematic illustrative classification of WE–WRE, a grade of A is economically the most beneficial situation, whereas a grade of D is the least favorable. The relationship between WE and WRE should be analyzed while emphasizing the daily high electric-load hours, which are usually the evening hours during the winter and the afternoon hours in the summer. Several years of daily cycles of wind data, in likely WE farm locations and daily WRE related data, would be required to establish adequate WE–WRE relations based on a purely statistical approach. However, as will be discussed in the next section, establishing these relations can be refined, while on the other hand, the time period needed for data collection can be reduced when the daily synoptic condition is considered.

To evaluate the benefits of the WE analysis, based on the relationships given in Table 1, illustrative general evaluations for the northern hemisphere mid-latitude geographical locations are outlined for several typical summer and winter meteorological synoptic conditions. In a specific case study, an analysis including additional refinements related to the detailed meteorological synoptic conditions in the geographical location under consideration

TABLE 1
Schematic Economical Classification of WE Availability–WRE Consumption Relations

Grade	*WE availability*	*WRE consumption*
A	high	high
B	high	low
C	medium/low	medium/low
D	medium/low	high

would be required. Also, it is assumed that the WE farms are most likely to be located in mountainous or coastal areas, as is typically suggested by WE climatological documentation.

2.1 Summer evaluations

High WRE consumption in the summer is usually associated with a persistent high-pressure synoptic system (excluding the initial time of the establishment of the high pressure by relatively cool post-frontal air). The air temperature (and occasionally the humidity), under these conditions, increases above normal while the wind speed is typically weak. Intensification of the near daytime surface wind due to a thickening of the daytime atmospheric boundary-layer, which results in a downward momentum flux from the upper intense wind layers, is pronounced in most mountainous regions. The relatively intense atmospheric thermal-stability involved with high-pressure synoptic situations leads, in most cases, to a reduction in the effect of this process. In general, based on Table 1, this situation is suggested to be graded as D.

Another common synoptic situation in the summer is associated with low-pressure systems, which often lead to a reduction in the temperature below normal, intensified winds, increased cloudiness, and therefore, a decrease in the WRE consumption. This situation is suggested to be graded as B.

2.2 Winter evaluations

Intense low-pressure synoptic systems occur frequently during the winter, and typically, they are involved with relatively strong winds in mountainous areas. These meteorological conditions lead to a decrease in temperature and, for most occasions, increased cloudiness and an increased demand for indoor and outdoor illumination. Obviously, this situation is associated with optimum WE–WRE and is graded as A. However, if winds are too strong in this situation, the cut-out threshold may be exceeded, thereby reducing the grade to a D.

High-pressure synoptic systems, associated with light winds, are also frequent in the winter. Although this situation includes relatively-high daytime temperatures, the evening temperature may drop sharply, so suggesting a grade of C for the daytime period, and a grade of D for the evening hours.

Finally, extremely cold winter weather in mid-latitudes results from the penetration of arctic air, due to a synoptic situation which is usually involved with relatively strong winds, and is likely to be graded as an A.

3 DISCUSSION

Statistical analyses of WE, in relation to WRE level on a day-by-day basis, while related to typical synoptic meteorological classes, should provide the capability for various refined economical/operational evaluations of WE usage as a supplementary power source to a closed electric-utility network. Quantification of WRE can be established by statistical analysis of the air temperature (and also be improved by considering the air humidity and solar radiation/cloudiness) and the electric load level of the involved utility. The following advantages are gained with the suggested WE–WRE–*S* relation:

(i) It provides capability for an explicit understanding of the WE and electric load relations. Thus, it can be established with reasonable accuracy, and when a limited set of wind data is available for the predominant meteorological synoptic conditions in the area under consideration. The climatology of synoptic situations is well established in all populated regions of the world.[3]

(ii) In many cases, WE site evaluations are based on wind surveys in various locations. However, because of the limited periods of in-situ wind measurements, applying the suggested methodology (even qualitatively), is likely to provide complementary information which would be useful in various decision-making during the measurement stage. This is most applicable when a portable wind-measurement system is established for surveying several potential sites for limited periods of time. Wind measurements from each site should cover the various typical synoptic conditions in that geographical location. Knowing the synoptic climatology of the region enables a generalization of WE–WRE–*S* and an optimized shorter period of measurements to be obtained.

(iii) When WE farms are integrated into electric-utility networks, such analysis results and the daily synoptic forecasting will provide the capability for forecasting the daily availability of WE as compared with the daily load projection, thus, supporting the daily load-management decisions.

The evaluations suggested assume a closed utility network. When power from one utility can be shifted to a second utility, based on a mutual optimized electric-load management, the basic concept suggested for WE–WRE–*S* relations in a closed utility network is applicable. However, further refinements, as well as an appropriate modification in the suggested analysis, should be considered.

ACKNOWLEDGEMENTS

The study was partially supported by EPRI under contract No. RP-1630-53.

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