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Characterizing the Effects of High Wind Penetration on a Small Isolated Grid in Arctic Alaska

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CHARACTERIZING THE EFFECTS OF HIGH WIND PENETRATION ON A SMALL ISOLATED GRID IN ARCTIC ALASKA

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Abstract

Utilities have historically assumed that wind penetration levels of more than 25-30% would result in system instability. Higher levels of wind penetration were expected to cause serious stability and reliability problems in both the generation and distribution systems. Because wind penetration levels in the United States have generally been much lower, little data have been available to determine if such problems actually occur.

This paper examines the operating characteristics of the wind-diesel system in Kotzebue, Alaska, operated by Kotzebue Electric Association (KEA). KEA began incorporating wind power into its 100% diesel generating system in 1997 with three 66 kW wind turbines. In 1999, KEA added another seven 66 kW turbines, resulting in the current wind capacity of 660 kW. KEA is in the process of expanding its wind project again and ultimately expects to operate 2-3 MW of wind capacity. With a peak load of approximately 4 MW and a minimum load of approximately 1.6 MW, the wind penetration is significant. KEA is currently experiencing greater than 35% wind penetration, sometimes for several consecutive hours. This paper discusses the observed wind penetration at KEA and evaluates the effects of wind penetration on power quality on the KEA grid.

Introduction

The KEA wind power plant is a 0.66 MW facility of small commercial-scale wind turbines. The project consists of 10 AOC 15/50 66 kW fixed-speed, stall-controlled wind turbines manufactured by Atlantic Orient Corporation (AOC) of Norwich, Vermont. The AOC 15/50 is a three-bladed, downwind turbine with a 15-m (49-ft) rotor diameter installed on 24.4-m (80-ft) lattice towers on piling foundations, resulting in a hub height of approximately 26.5 m (87 ft). The KEA wind power project joined the U.S. Department of Energy/Electric Power Research Institute (DOE-EPRI) Wind Turbine Verification Program (TVP) as an associate project in 1997. Additional information about the KEA wind project performance and operating experience is reported by EPRI[1].

KEA's project site is located on the tip of the Baldwin Peninsula approximately 42 km (26 mi) north of the Arctic Circle on the northwest coast of Alaska near the town of Kotzebue. With a population of approximately 3,000 residents, Kotzebue is the largest community in northwestern Alaska and serves as the economic, governmental, medical, communication, and transportation hub for the 11 communities in the Northwest Arctic Borough, an area roughly the size of Indiana. Figure 1 shows the location of Kotzebue on the Alaska state map.

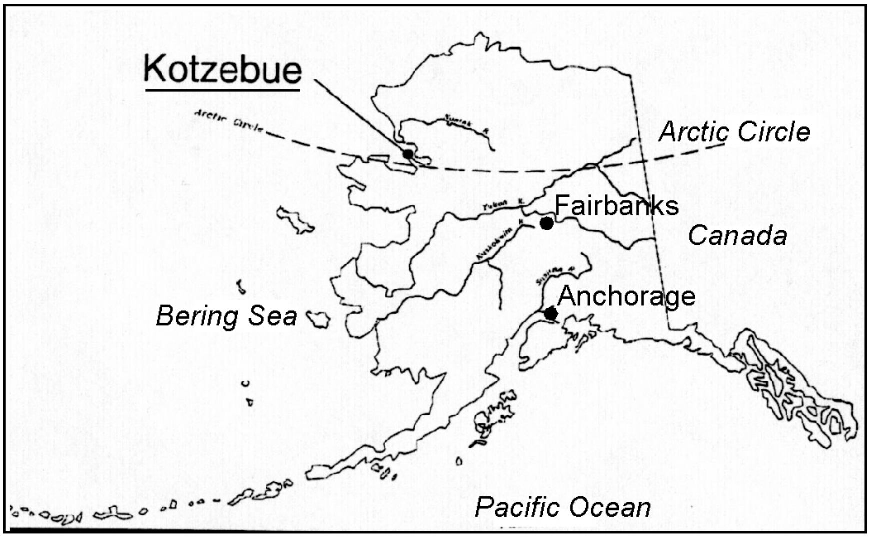

FIGURE 1: KOTZEBUE LOCATION MAP

The only source of generation for the KEA power grid is an 11 MW diesel generating plant consisting of six diesel generators. Normally the diesel plant has only one or two generators operating, with the remaining generators providing redundancy. Typical loads on the grid range between 2 and 3 MW, with a peak load of approximately 4 MW and a minimum load of approximately 1.6 MW. The load varies with the time of day and with climatic conditions.

Methodology and Data Used

For the purpose of this paper, data from August 21 through September 20, 2000 were evaluated. This period was selected because total system load can be somewhat lower during the warmer summer months. The TVP reporting period for the KEA project ends on the 20th of the month, so the period evaluated corresponds to one monthly period.

Data for the wind project were generated using the Second Wind Advanced Distributed Monitoring System (ADMS), a commercial supervisory control and data acquisition system (SCADA) that KEA uses to manage and operate the wind project. Parameters measured by the SCADA include turbine production and performance, meteorological data, and a variety of power quality measurements collected by the Second Wind Phaser® power transducers located in each turbine. The Phaser has also been used by TVP to make power quality measurements at other distributed wind projects, as reported by Green [2].

KEA meter readings indicating total system load and production by the diesel generating facility were also available. Wind penetration estimates were calculated by dividing the measured power output from the wind facility by the total KEA system load.

KEA Grid Load and Observed Penetration Levels

Figure 2 presents the diurnal pattern of grid loads during the period evaluated. The solid line indicates the average load for each hour over the month. Minimum and maximum values within the month are indicated with bars off of this line. The approximate capacity of the wind farm (i.e., approximately 660 kW) is also indicated.

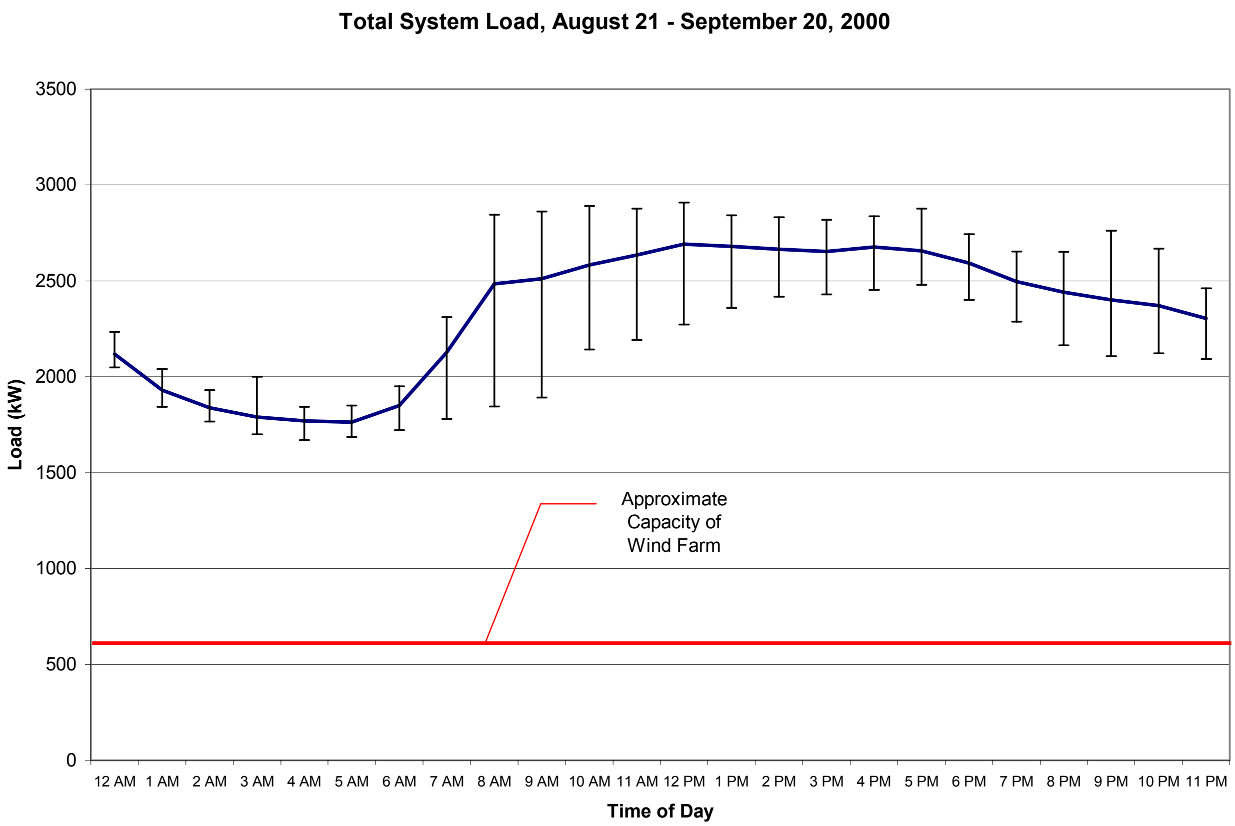

FIGURE 2: DIURNAL DISTRIBUTION OF KEA LOAD

As shown on this figure, grid loads are lowest during early morning hours, usually falling below 2 MW from approximately 1:00 a.m. to 6:00 a.m. The minimum load observed during the month was approximately 1.67 MW. Loads are higher throughout the day, although loads did not exceed 3 MW during the month.

The minimum system load occurred at approximately 4:00 a.m. on August 29, 2000. The highest overall wind penetration of approximately 35% was also measured at this time. Figure 3 presents the wind speed and temperature measured over the time around this event, as well as the calculated wind penetration values. August 29 was an unusually warm morning in Kotzebue, with temperatures exceeding 13 degrees Celsius during the overnight hours. These temperatures were over 3 degrees warmer than measured values for the same time period on other days during the month. In addition, the winds were moderate to strong throughout the early morning hours, exceeding 15 m/s at 4:00 a.m. This combination of high winds and low demand on the KEA grid resulted in the unusually high penetration values.

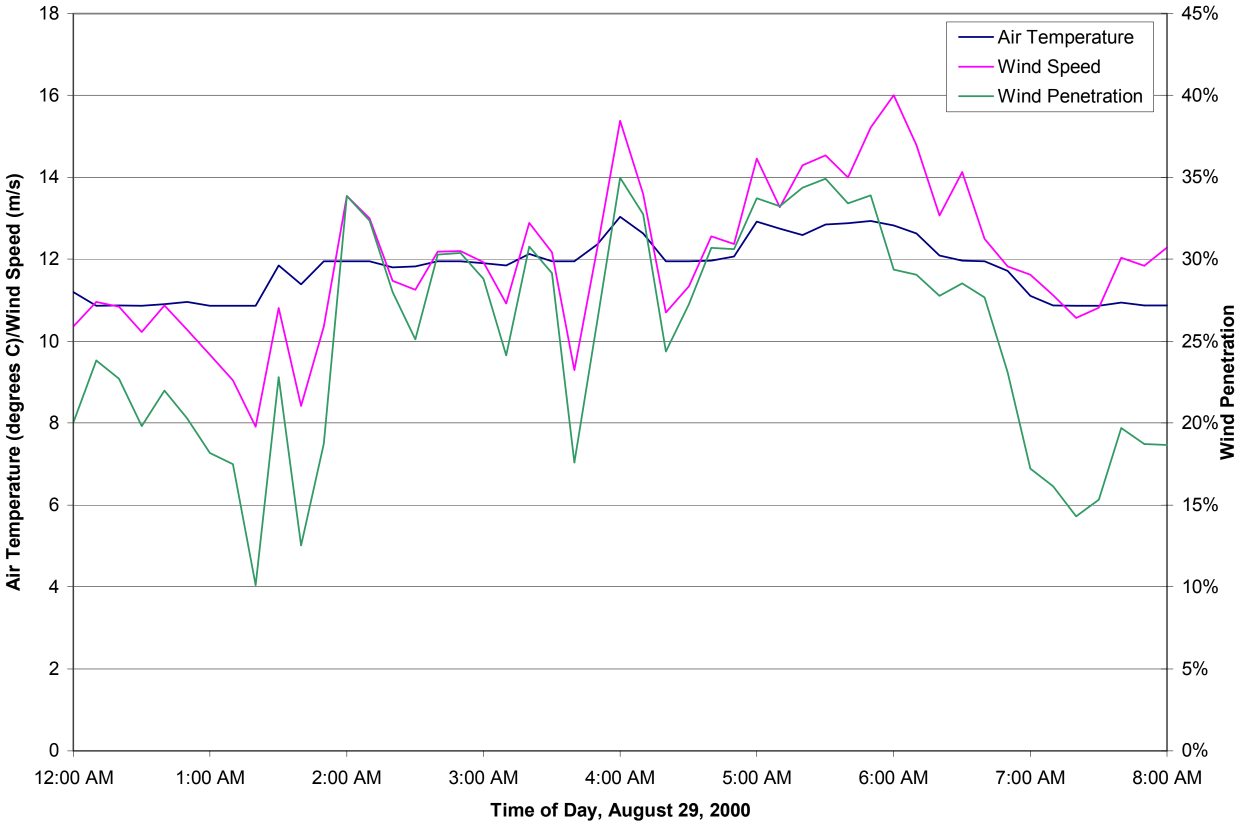

FIGURE 3: AIR TEMPERAURE, WIND SPEED, AND WIND PENETRATION, AUGUST 29, 2000

In addition to the morning of August 29, penetration values in excess of 25% were observed during the early morning hours for several days following the 29th. A summary of the observed penetration values is presented in Table 1. Despite a few periods of high penetration, the overall average penetration for the month was approximately 5.6%. This average is highly influenced by the few significantly higher values. The median penetration for the month was 2.0%. Penetration values of less than 1% were calculated for approximately 46% of the month; penetration values of less than 10% were calculated for approximately 77% of the month.

Overall, penetration varied only slightly with the time of day. During the early morning hours (from midnight to 8:00 a.m.), the median penetration was 0.71%, which is somewhat below the overall median value. This reflects the generally lower wind speeds during this period, with the exception of August 29 and the days immediately thereafter. However, the early morning average penetration was 6.0%, reflecting the lower energy demand during this period. The opposite trend was seen during evening hours, with a higher 3.1 % median penetration due to higher winds but a lower 5.3 % average penetration because of higher energy demand.

Overall wind penetration values are presented graphically in Figure 4.

TABLE 1: SUMMARY OF WIND PENETRATION VALUES

Parameter	Overall	Early Morning (12 a.m. - 8 a.m.)	Day (8 a.m. - 5 p.m.)	Evening (5 p.m. - 12 a.m.)
Maximum penetration	35.3%	35.3%	24.5%	24.2%
Average penetration	5.6%	6.0%	5.4%	5.3%
Median penetration	2.0%	0.7%	2.0%	3.0%
Time with less than 1% penetration	46.2%	50.5%	46.8%	40.5%
Time with less than 10% penetration	77.1%	74.6%	76.9%	80.4%
Time with less than 20% penetration	92.9%	91.0%	93.4%	95.0%

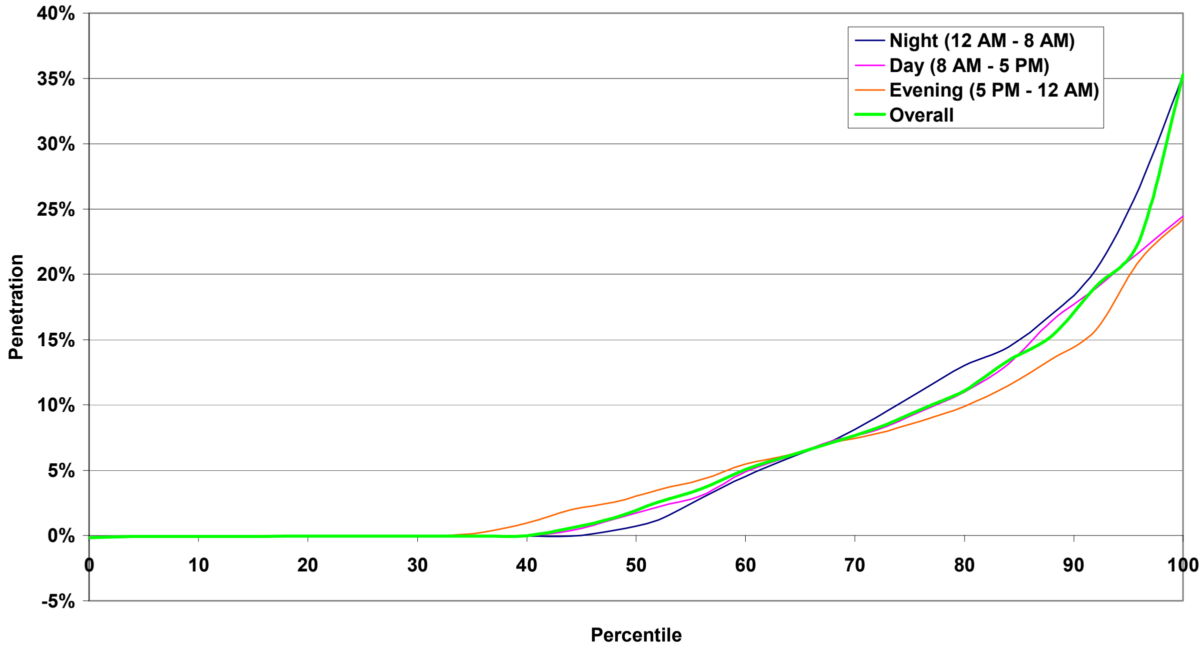

FIGURE 4: WIND PENETRATION PERCENTILES

Power Quality at High Penetration

A variety of power quality parameters are measured by the Phasers and recorded in the SCADA system or can be calculated from the measured values. These parameters include (among others) line voltage, voltage imbalance, total demand distortion, and frequency deviation. The following section presents an overview of how each of these parameters varied as the wind penetration increased. Power quality measurements described in this section were recorded by the Phaser at Turbine 8. This turbine was used in power performance testing conducted at the site, and the Phaser recorded a wider range of parameters than those at the other turbines. The measurements at this turbine are believed to be representative of the rest of the wind farm.

For the purpose of this analysis, data were used only when the wind facility was on-line and producing at least 200 kW of power. Below this output level, it was assumed that any irregularities in power quality measurements would be caused by sources other than the wind farm.

Voltage

Figure 5 presents a scatter plot of 10-minute average voltages compared to the wind penetration values. The nominal voltage for the grid is 480 V. As shown, the measured voltage exceeded the nominal value by up to approximately 20 V during the time period evaluated. However, no relationship can be seen between voltage and wind penetration. At the highest penetration levels, voltage was closer to nominal than at some lower penetration values. Consequently, it appears that any effect on line voltage caused by high penetration is dwarfed by effects external to the wind farm, and possibly by effects caused by the wind farm independent of the penetration level.

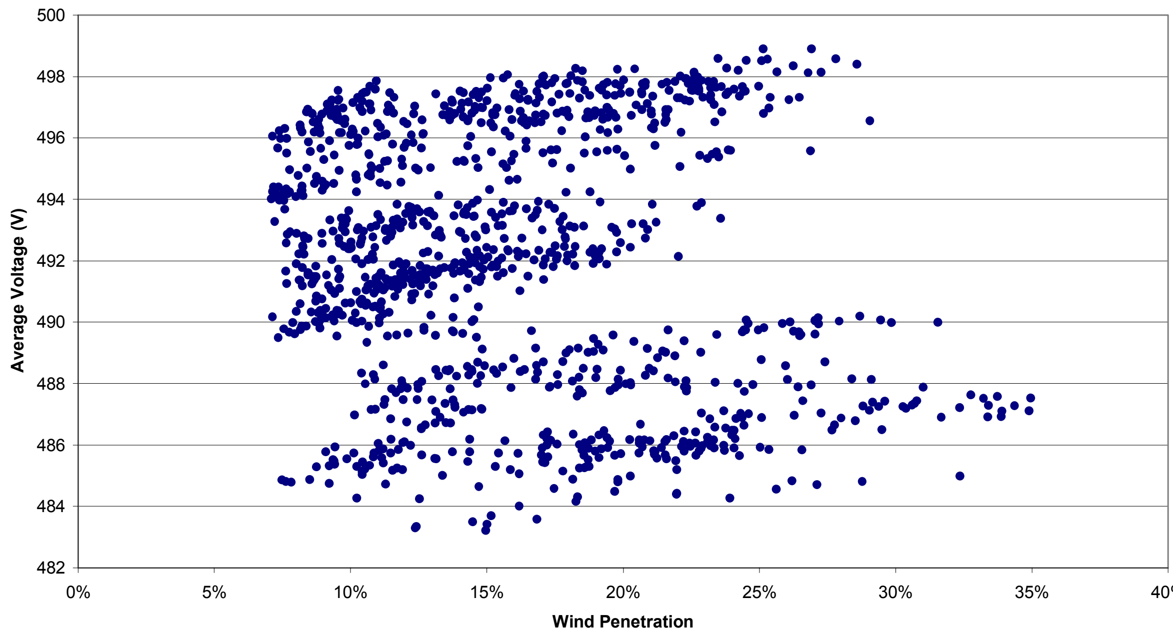

FIGURE 5: AVERAGE VOLTAGE VS. WIND PENETRATION

Voltage Imbalance

Figure 6 presents a scatter plot of 10-minute average voltage imbalance compared to the wind penetration values. There is relatively little scatter in the measured values, with a range between about 18.2 V and 19.6 V. No relationship can be seen between wind penetration and voltage imbalance.

Total Demand Distortion

Figure 7 presents a scatter plot of 10-minute average total demand distortion compared to the wind penetration values. There appears to be a slight inverse relationship between wind penetration and total demand distortion; however, the relationship is not strong and may be more related to other factors. Regardless, no adverse effect on total demand distortion is observed as wind penetration increases.

Frequency Deviation

Figure 8 presents a scatter plot of 10-minute average frequency deviation compared to the wind penetration values. As shown, the frequency deviation appears to remain relatively constant as wind penetration levels increase.

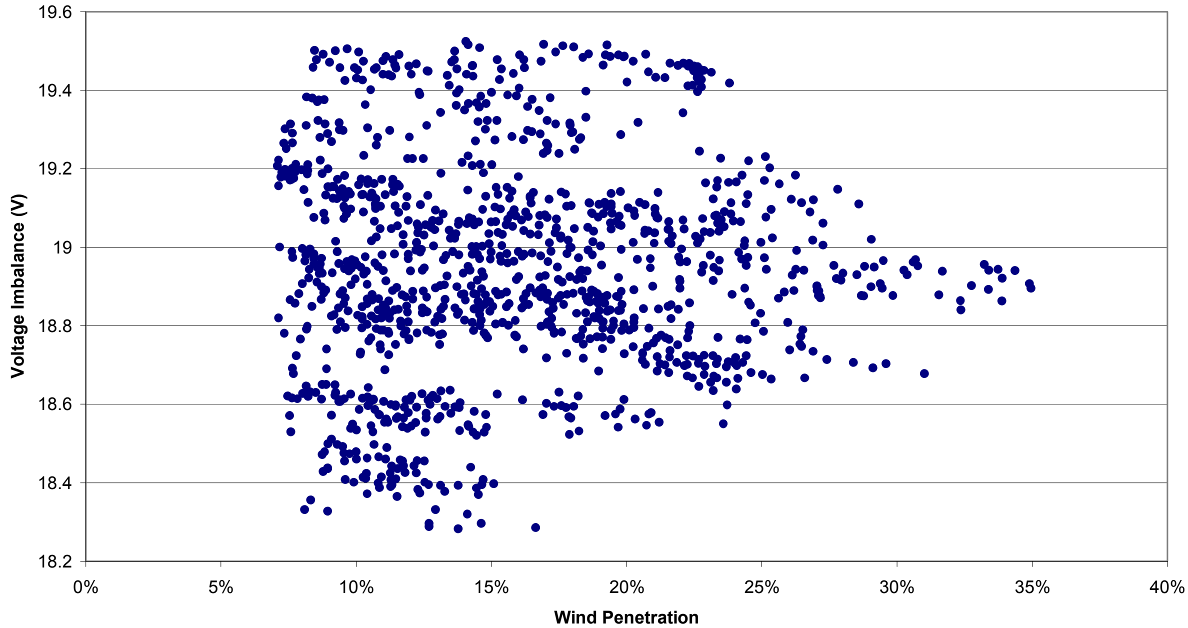

FIGURE 6: VOLTAGE IMBALANCE VS. WIND PENETRATION

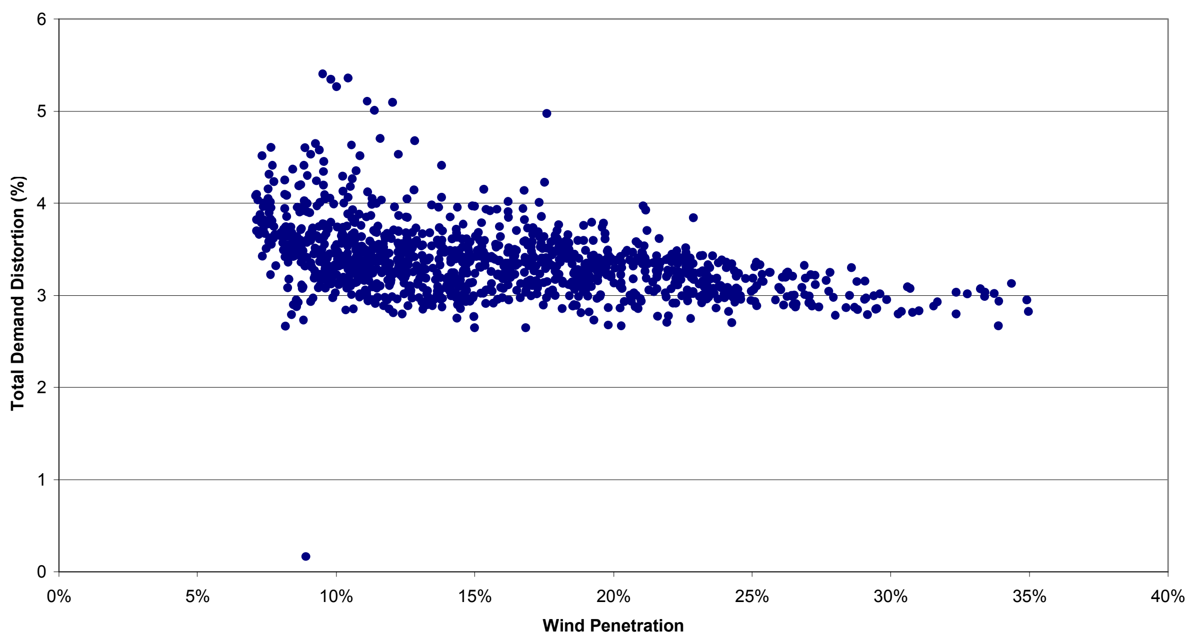

FIGURE 7: TOTAL DEMAND DISTORTION VS. WIND PENETRATION

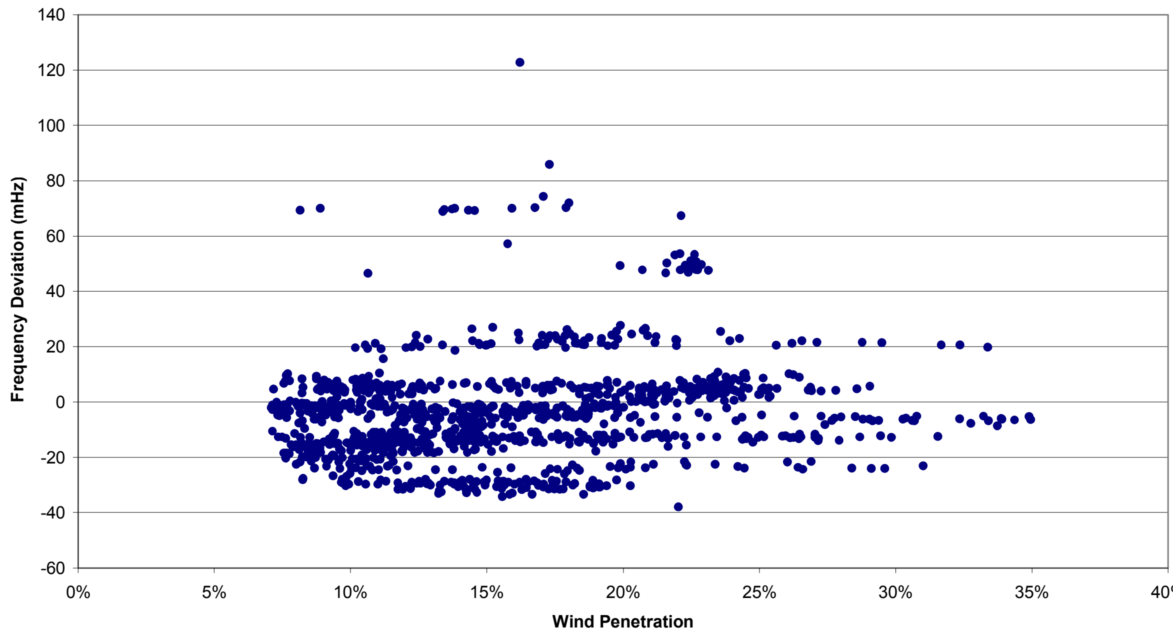

FIGURE 8: FREQUENCY DEVIATION VS. WIND PENETRATION

Conclusions

Based on measurements collected between August 21 and September 20, 2000, there is no apparent adverse effect on power quality on the KEA grid as wind penetration increases. During this period, wind penetration reached a maximum level of approximately 35%. It is unlikely that wind penetration will significantly exceed 35% at KEA with the current wind turbine capacity, as the highest observed penetration levels occurred during time periods with a combination of high winds and low system load.

KEA plans on expanding the wind farm in the near future. Current plans for expansion include addition of two AOC 15/50 turbines during the summer of 2001. With these additional turbines, wind penetration could reach maximum levels of approximately 45%. Eventually, KEA plans to increase wind generation capacity to a total of 2 to 3 MW.

References

1. *Kotzebue Electric Association Wind Power Project First-Year Operating Experience: 1999-2000*, U.S. Department of Energy - EPRI Wind Turbine Verification Program, EPRI 1000957, December 2000.
2. Green, J., VandenBosche, J., Lettenmaier, T., Randall, G., Wind, T. *Power Quality of Distributed Wind Projects in the Turbine Verification Program.* WindPower 2001 Proceedings, AWEA, Washington, DC, June 2001.

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