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Review of Operation and Maintenance Experience in the DOE-EPRI Wind Turbine Verification Program

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REVIEW OF OPERATION AND MAINTENANCE EXPERIENCE IN THE DOE-EPRI WIND TURBINE VERIFICATION PROGRAM

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Abstract

All the projects within the U.S. Department of Energy (DOE) Electrical Power Research Institute (EPRI) Wind Turbine Verification Program (TVP) are now in operation. As a result, the emphasis of the owners and operators has shifted from installation and commissioning to a focus on optimizing the operation and maintenance (O&M) activities of the projects. Each project utilizes a unique strategy for performing O&M. O&M personnel for projects in Searsburg, Vermont; Glenmore, Wisconsin; Algona, Iowa; Springview, Nebraska; Kotzebue, Alaska; and Big Spring, Texas include on-site vendor representatives, dedicated utility personnel, and utility personnel who split their time between the wind turbines and other utility responsibilities. Each project has its own set of priorities for balancing turbine availability against safety, minimizing overtime pay, and other utility responsibilities. Various strategies have also been employed to ensure access to tools and spare parts. This paper compares and contrasts the various O&M strategies at TVP projects and reviews the causes of turbine downtime and the frequency and duration of faults.

Introduction

The operation and maintenance of a wind power plant involves the interaction of several different organizations, including the turbine manufacturer, the project owner, the utility dispatcher, and the O&M crews. A successful O&M program includes maintaining appropriate levels of personnel and equipment, implementing effective maintenance strategies, and practicing good safety procedures. Operating of a wind energy plant includes administering daily activities such as monitoring performance, controlling operations, and dispatching maintenance crews when necessary, for preventive or scheduled maintenance as well as forced outages or unscheduled maintenance.

Utilities have historically taken a limited role in the O&M of wind power plants in the United States, although the recent growth of the industry has led to increased utility involvement in some projects. O&M personnel for the seven current TVP projects include on-site vendor representatives, dedicated utility personnel, and utility personnel who split their time between the wind turbines and other utility responsibilities. Each project has its own set of priorities for balancing turbine availability against safety, minimizing overtime pay, and other utility responsibilities.

To some extent, maintenance activities and strategies are driven, by the desire to maintain high turbine availability. Project operators recognize that it may be more cost-effective to exchange an entire component and minimize the downtime of a turbine rather than spend extensive time troubleshooting while the turbine is not producing power.

O&M Approaches

For the TVP project in Searsburg, Vermont, Green Mountain Power (GMP) has an arrangement with Zond Maintenance Corporation to provide all O&M services for the first three years. Zond has assumed full responsibility for preventative maintenance, unscheduled repairs, routine inspections, and operations tasks such as record keeping and inventory tracking.

Three of the TVP projects, in Fort Davis and Big Spring, Texas, and Kotzebue, Alaska, have full-time on-site dedicated employees and vendor support to address warranty issues. The projects in Algona, Iowa, and Springview, Nebraska, are both managed by a primary employee of the host utility who has a part-time responsibility for overseeing the wind facility. At Glenmore, Wisconsin, staff at the nearby coal power plant have revolving responsibility for limited O&M support, and major maintenance and warranty repairs are handled by Polymarin Huron Composites, a third-party vendor.[1]

The number of people employed by a wind power plant depends on the number of turbines and the administrative structure of the project. The size of the maintenance crew depends more on the number of turbines than on the rated capacity of the project. Although some of the maintenance activities on the larger wind turbines may require more time or different equipment to complete repairs, most maintenance activities require the same level of effort regardless of turbine size.

Training approaches have included multiple weeks at a vendor's facility, extensive on-site training (both in the classroom and in the field), brief on-site training, and on-the-job training. Operator skills include mechanical and electrical technical expertise, computer literacy, inventory management, job and equipment scheduling, performance record keeping, statistical trend analysis, and data processing.

Figure 1 shows that staffing levels at TVP projects increase fairly consistently with the number of wind turbines. The TVP projects average approximately one full-time equivalent (FTE) site employee for every ten turbines, compared to the industry average of one FTE per twenty or more turbines. The high TVP site staffing levels indicate the research nature of the projects and the use of newly-commercial wind turbine technology. The number of O&M staff at Fort Davis has been higher than the TVP average primarily due to aileron retrofit and repairs. Turbine availability does not necessarily increase with increased staffing levels due to other turbine or site-specific factors that affect availability. For instance, while the Fort Davis project has had the highest staffing level in the TVP, it has also ranked among the lowest in terms of availability due to extensive aileron and lightning-related downtime.

The availability that the projects achieve is also associated with the attitudes of the O&M staff and the level of vendor support. It is important for the site personnel to develop a sense of personal ownership and responsibility for the turbines in order to achieve the best results. The Searsburg project has achieved high availability levels in large part due to diligent efforts of the site operator. Zond's on-site service representative receives financial incentives that are based on the availability that the turbines achieve. Two different operators who have worked at the site over the past three years have both gone to extraordinary efforts to keep availability high, including resetting faults in the middle of the night. The

[1] PHC, whose primary business is blade manufacturing, was formerly the North American branch of Tacke Windtechnik and sold the Glenmore turbines to WPS. The PHC employees purchased the business from the parent company prior to Enron's acquisition of Tacke.

Algona and Kotzebue projects have also achieved high availability due to personal efforts of the site managers. By contrast, the Glenmore project has had relatively low availability, attributed in large part to the lack of personal ownership that some of the maintenance staff have felt for the project. The Glenmore project is operated by personnel from another power plant and their priority is clearly more focused on the power plant than the wind turbines. Faults have been left without reset for 5 days or more.

The majority of maintenance activities, require climbing the turbine's tower and working either within the confines of the nacelle or outside on a platform directly below the nacelle. Prior to hiring a local technician to provide part-time support at Searsburg, personnel from GMP's local office in Wilmington were occasionally asked to provide assistance for safety reasons when the site supervisor needed to climb a tower. Because of reductions in GMP staff and Zond's increased demands at other new projects around the country, scheduling of repairs and maintenance was delayed on several occasions when insufficient manpower was available to allow climbing or completion of other tasks. Nonetheless, the project has experienced high availability and fault response time has been exemplary.

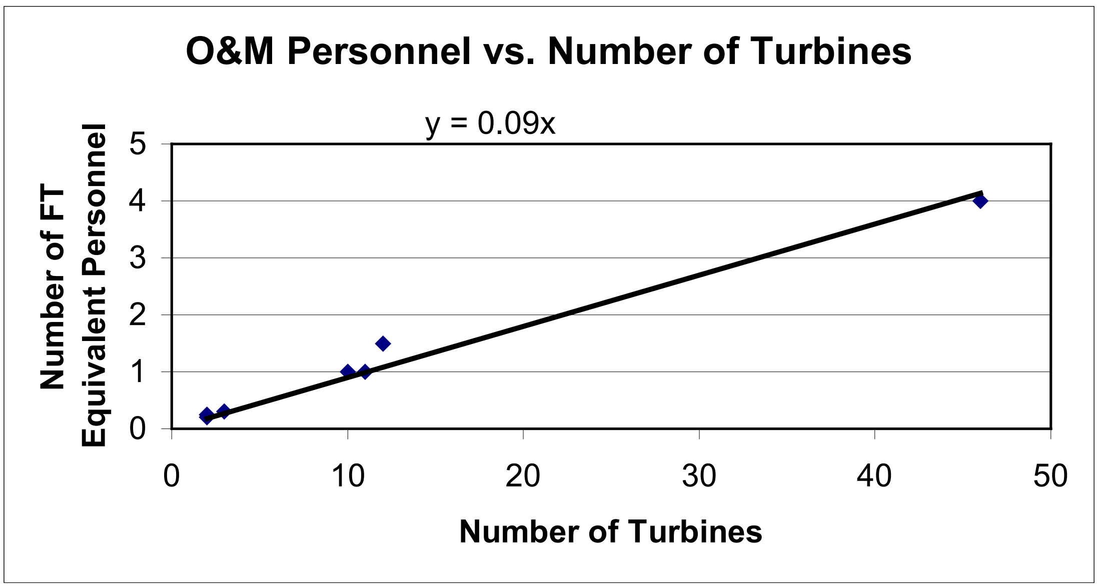


Figure 1. Staffing levels at TVP project sites

Vendor presence varies widely at the TVP projects. A Zond site supervisor works full-time at Searsburg, and additional Zond technicians are brought to the site to assist with special service activities as necessary. Turbine manufacturer representatives were on-site full-time during the initial shakedown period at Big Spring and Fort Davis, and are dispatched from nearby service centers associated with larger facilities for the Algona and Springview projects. Vendors provide remote and occasional on-site assistance for the Glenmore and Kotzebue turbines.

Although the wind power plants function automatically and many faults are self-resetting, operators are still needed to monitor turbine performance and respond to "hard" system alarms. Sophisticated Supervisory Control and Data Acquisition (SCADA) systems are designed to alert the appropriate service personnel through computer warnings and automated telephone calls. The TVP projects utilize the SCADA systems at varied levels. Most of the host utilities use the SCADA for turbine control but do not conduct their own analysis or research. However, the vendors do draw on SCADA data for analysis and troubleshooting.

As shown in Figure 2, Algona Municipal Utility plant operators monitor the wind-facility SCADA along with utility operations. The reliability of the SCADA system is important to high availability; typically, remote access and SCADA call-out features improve availability considerably. Glenmore's ongoing SCADA communication problems were a major cause of the long fault response time at that project, and the average availability at Springview was more than 10% higher during the months after the SCADA system was operational than it was prior to its installation.

Site supervisors at Fort Davis, Searsburg, and Glenmore use an O&M database developed by the TVP in November 1997 to facilitate record keeping and reporting tasks. The O&M database has been valuable in tracking, storing, and disseminating information on the project beyond what is included in the SCADA systems. The Second Wind SCADA provided by the National Renewable Energy Laboratory (NREL) to all TVP III and Associate TVP projects established consistent data formats with the various wind turbine vendors and enabled standardized data collection and analysis methods for TVP reporting.

Other logistical issues related to O&M include site access and tower climbing, proximity to equipment and services, spare parts inventories, availability of supplies, and information on discontinued turbine models. The distributed, remote nature of many of the TVP projects increases the importance of these issues to prevent repair delays.

Site access during the winter was less of a problem than expected at Searsburg. Although the site receives heavy snow, there were only a few instances when winter conditions affected the response time to reach the turbines and conduct necessary maintenance. At Algona, gravel on the site access road was replaced with a grade that could be cleared with the utility's snow blower to expedite maintenance. The degree of ice shedding from the turbine blades and tower at Springview was not anticipated, so special shelters were designed to protect both equipment and maintenance workers.

Figure 2. Supervisor computer in AMU's plant operations room

Warranties have varied signficiantly by project, and roles and responsibilities for warranty repairs were unclear for some of the TVP projects. Warranty types for TVP projects include defects in materials and workmanship, availability, power performance, noise, and power quality. The warranties typically include exclusions for lightning damage and other force majuere events.

Maintenance Activities and Other Downtime Events

During 1999, the major causes of downtime were O&M work and faults, and the variability between projects is clearly illustrated in Figure 3. Searsburg had the smallest amount of downtime per turbine in 1999; on average, each turbine was down for less than 43 hours per month at Searsburg, compared to nearly 127 hours per month at Fort Davis. Glenmore experienced less O&M downtime but considerably more fault-related downtime than the other projects; Kotzebue experienced very little fault downtime. A breakdown of downtime for the Big Spring turbines is not available, although they did have very high availability in 1999 compared to other TVP projects.

Although downtime and availability are commonly used as performance measures in the wind energy industry, it is important to understand the time of occurrence and the cause of the downtime as well as the actual number of downtime hours. Obviously, 10 hours of downtime during a low wind period is less significant than 10 hours of downtime during a high wind period because of the lost opportunity to produce energy during the higher wind period. The year's two highest wind-speed months at Fort Davis, April and May, had the lowest project availability, resulting in relatively greater lost energy. The year's highest wind-speed month at Springview, May, was one of the lowest months of project availability, but the month with the lowest availability, July, had the lowest mean wind.

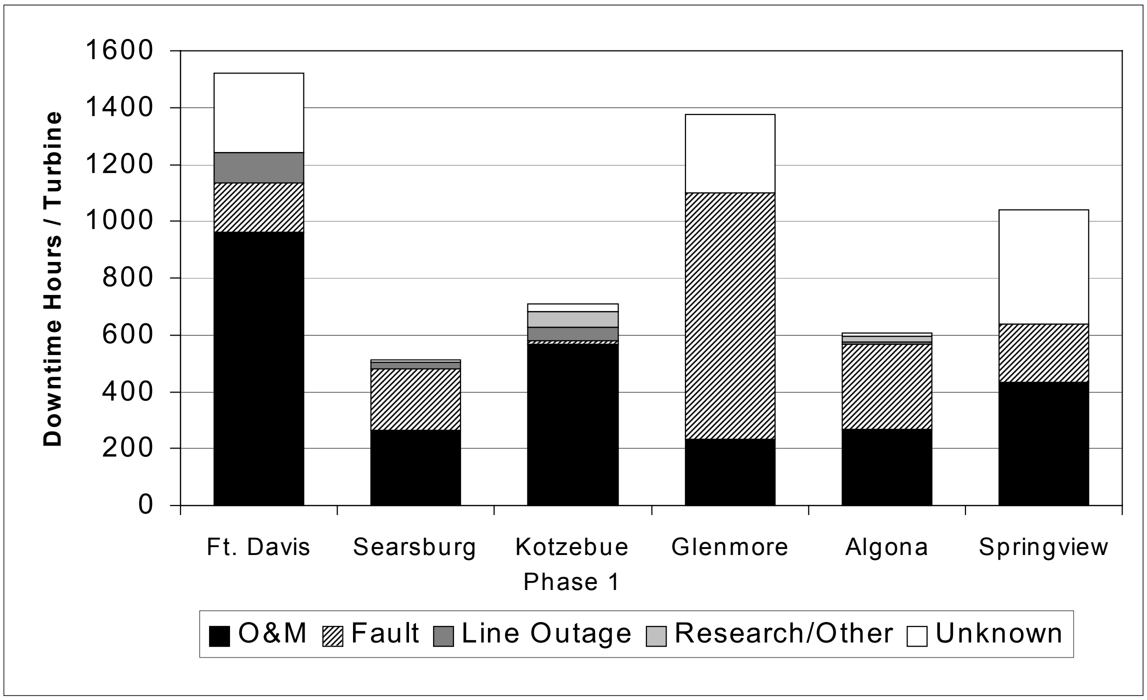


Figure 3. Causes of downtime at TVP projects - 1999

The cause of downtime and the cost to return a turbine to service are also important considerations. For example, 10 hours of downtime due to a fault that is reset without additional action has less impact on the project than 10 hours of downtime due to a repair that requires significant labor, equipment, and parts replacement, assuming the winds are comparable during both periods.

The downtime categories shown in Figure 3 include:

- *O&M* – All troubleshooting, inspections, adjustments, retrofits, and repairs performed on the turbines, and the downtime that accumulates while waiting for parts, instructions, or outside services that are not available on site but are required to bring a turbine back on line. Downtime associated with the SCADA system is not included in this category if the turbines continued to operate. O&M downtime accounted for nearly 51% of the total 1999 downtime at the six projects, ranging from 17% at Glenmore to 63% at Fort Davis.

- *Faults* – Turbine faults that required a reset with no further action. If a maintenance activity immediately followed a fault, the downtime associated with the fault was combined with the repair hours, and the event was included in the O&M category. In some cases, faults are not cleared until personnel or parts are available or after a repair is made. In these instances, the fault time was also re-classified as an O&M event if sufficient information was available to make that determination. Faults occurring in the evening or on weekends are often reset in the morning of the next business day. The response time before the fault was reset is included in the fault category as long as the fault was not followed by repair work requiring tower climbing or other maintenance. High wind and certain cable twist “soft” faults are not counted as downtime as they are considered a normal part of turbine operation and are reset automatically. Faults accounted for 19% of the total downtime at the six projects during 1999, ranging from less than 2% at Kotzebue to 63% at Glenmore.

- *Line Outages* – Time when the entire project was off line due to a utility line outage at the site. While no line outages occurred at Glenmore and Springview, line outages accounted for 7% of the downtime at Fort Davis and 5% of the total 1999 downtime for all six projects.

- *Other* – Routine maintenance, inspections, miscellaneous troubleshooting, site tours, and time associated with repairing and removing additional instrumentation and data acquisition systems to support testing activities. Although more than 7% of the downtime for Kotzebue’s Phase 1 turbines was attributed to these activities, most of the TVP projects had little or no downtime in this category, (less than 1%). At Kotzebue, the downtime in this category was due in part to the construction activities on the Phase 2 turbines, which caused some project-wide shutdowns.

- *Unknown* – Periods when no documentation related to downtime is available due to missing data or prior to SCADA installation. The cause is unknown for 12% of the total 1999 downtime at the six projects is in this category, ranging from 1% at Searsburg to 20% at Springview.

Downtime Due to O&M Activities

Unscheduled maintenance involves responding to any unexpected event, ranging from minor activities such as resetting sensors or circuit breakers, to major repairs, such as removing a nacelle from a tower to replace the yaw gear. These activities can involve anything from two operators working for an hour to a large crew using a crane for a full day or more. Figure 4 shows a breakdown of 1999 downtime included in the O&M category.

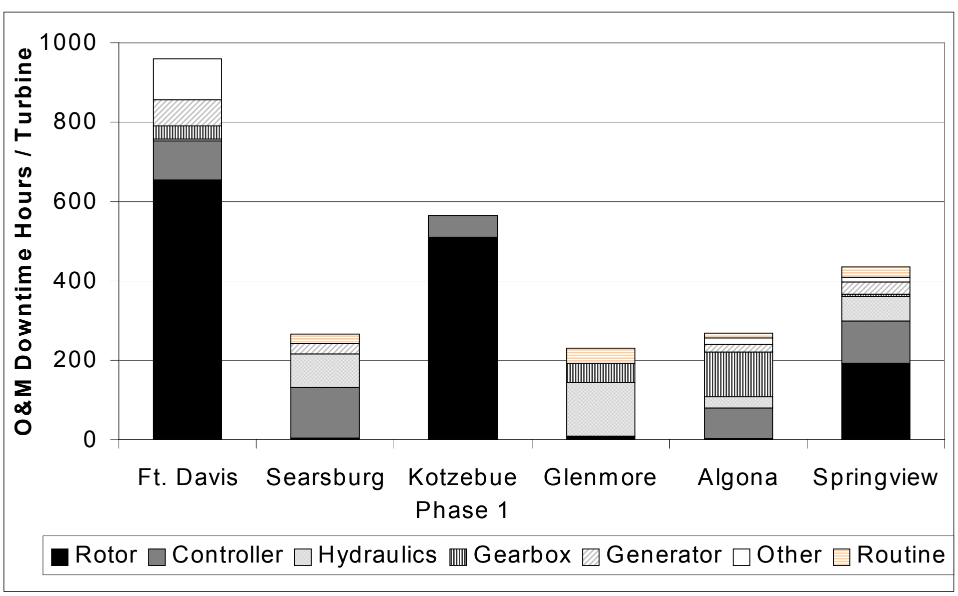


Figure 4. Breakdown of 1999 O&M downtime by major turbine systems

The majority of O&M downtime occurred in April and May. In general, the frequency of O&M events was high relative to the duration at most TVP sites. In other words, the downtime tended to be associated with events that did not require significant time to repair or troubleshoot. Some general observations on each of the component systems are provided below:

- *Rotor-related* – Aileron components on the Z-40A turbines at Fort Davis continued to fail during 1999 despite of a major retrofit in 1998 to replace aileron hinges, bolts, and bell cranks. Bolt replacements and push-tube repairs continued throughout the year, and all turbines at Fort Davis were taken off-line in late April after ailerons were thrown from two turbines. Tip brakes on the AOC 15/50 turbines also required considerable troubleshooting (shown in Figure 5), and accounted for 32% of the 1999 O&M downtime for Kotzebue's Phase 1 turbines. Blade damage from lightning strikes accounts for 24% of O&M downtime at Springview. This category also includes yaw-system maintenance, troubleshooting, and repair of radial adjustment bolts. While very little rotor-related downtime occurred at Searsburg, Glenmore and Algona during 1999, rotor-related retrofit and repair work accounts for 68% of the O&M downtime at Fort Davis and nearly 54% of all 1999 O&M downtime at the six projects.

Figure 5. Troubleshooting tip brakes in Kotzebue

- *Controller* – Control-system events included troubleshooting and replacing damaged components, software upgrades, and modifications to control settings (shown in Figure 6). Firing boards, Silicon Controller Rectifiers (SCRs), and SCR cables required the most attention. Lightning damage to controller components has contributed significant downtime to several of the TVP projects, although a retrofit developed with assistance from TVP has improved the lightning resistance of the controllers. Controller downtime accounts for 20% of all 1999 O&M downtime at the six projects, ranging from less than 0.1% at Glenmore to more than 45% at Searsburg.

Figure 6. Zond technician adjusting controller setpoints

- *Hydraulic System* – All projects except Kotzebue experienced some downtime for repairs and troubleshooting on the hydraulic systems. Hydraulic system repairs and parts delays account for more than 58% of the downtime at Glenmore but only 7% of the total for all six projects.

- *Generator* – Four generators failed at TVP projects during 1999, at Searsburg in March and December, at Algona in September, and at Fort Davis in October. While no generator-downtime occurred at Kotzebue or Glenmore during 1999, generator repairs account for 9% of Searsburg's O&M downtime, and nearly 7% of the O&M downtime at Fort Davis, averaging nearly 6% of all 1999 O&M downtime at the six projects.

Figure 7. Zond technician checking oil level in turbine nacelle

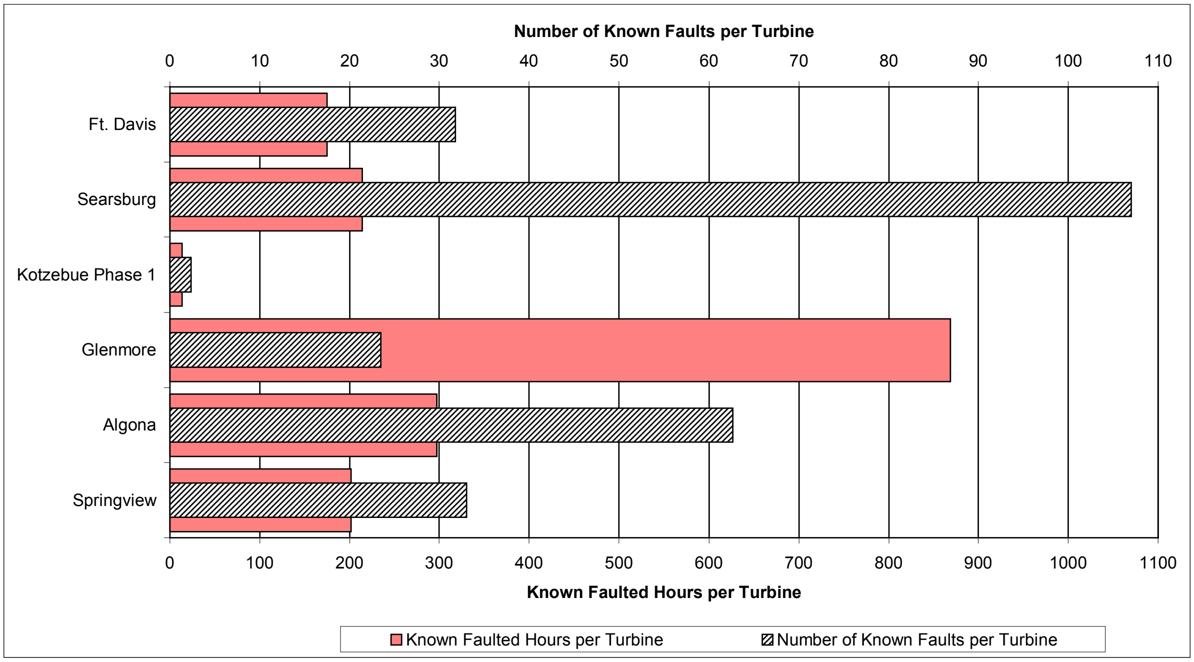
- *Scheduled Maintenance* – Scheduled maintenance consists of several basic tasks including inspecting the condition of components (i.e., checking the wear on brake pads); servicing items that require some type of activity on a regular basis (i.e., retorquing bolts); and replacing consumable items at or before a specified age (i.e., replacing filters or changing the oil in the gearbox [shown in Figure 7]). All of the projects received routine inspections during the year, ranging from less than two hours per turbine at Fort Davis and Kotzebue to more than 38 hours per turbine at Glenmore. Scheduled maintenance activities accounted for more than 16% of Glenmore's 1999 O&M downtime but only 2% of the total 1999 O&M downtime for all six projects.

- *Other* – The remaining downtime consists of miscellaneous hub bearing, blade pitch, tower cleaning, and break repair events on various turbines. Occasionally, neighboring turbines are taken offline during O&M work for safety reasons or to use components for troubleshooting activities. This category accounted for 7% of the total 1999 O&M downtime for the six projects.

Additional information on the types and timeframe of O&M downtime experienced at each project is included the in annual operational reports.

Downtime Due to Faults

Faults accounted for more than 19% of the total downtime at the six TVP projects during 1999. Figure 8 shows the frequency, the total faulted hours, and the average duration of the faults by project. As previously noted, the faults in this category are only those "nuisance" faults for which the site operator takes no action other than to reset the turbines. The act of resetting a turbine takes only a small fraction of an hour; therefore, most of the hours in this category represent the time it took the operator to become aware of the fault condition and respond with a reset action.



Project Site	Number of Turbines	1999 Fault Frequency	Total Hours	Ave. Duration (hours)
Fort Davis	12	381	2,099.5	5.5
Searsburg	11	1,177	2,356.6	2.0
Kotzebue Phase 1	3	7	40.4	5.8
Glenmore	2	47	1,737.5	37.0
Algona	3	188	891.5	4.7
Springview	2	66	403.3	6.1
Average per Turbine		43	295.0	4.0

Figure 8. Fault frequency and duration

The most common faults related to the hydraulic, generator, and electrical systems generally increase in frequency during periods of high winds and often occur at the same time. On average, each turbine faulted approximately 3.6 times per month and was down for an average of 4.0 hours for each fault during 1999. Although the Searsburg site experienced nearly three-times the number of faults, the average fault duration was hald of the average at the other sites, indicating exemplary response time.

Additional information on the types and timeframe of the faults experienced at each project is included in the annual TVP operational reports.

O&M Observations

The operating strategies at the TVP projects are evolving over time as the owners and operators are gaining more experience with the O&M activities at their sites and realizing the benefits of focusing attention to these areas. At most locations, the operators are beginning to schedule maintenance and repairs during the low wind periods in order to reduce the impact on energy output. Some project owners are also evaluating other strategies to optimize their project performance such as quantifying the trade off between paying overtime and losing potential energy during downtime periods; conducting research and/or initiating storm damage mitigation actions; and prioritizing the responsibilities of the maintenance staff. As the utility owners are becoming more familiar with the technology, they are working to better define the roles and responsibilities of their staff and the vendor representatives, clarify warranty conditions, and plan for the future when warranty support is not available.

As with the operation and maintenance of any piece of machinery, the TVP has stressed that safety procedures and polices are important considerations. The on-site personnel are typically well-trained in electrical safety practices commonly employed by utilities and they have incorporated vendor-recommended wind turbine safety procedures into their site regulations. Most of the TVP sites have also conducted tower rescue training with local fire departments.

TVP has found that the overall motivation for a project, whether commercial or research, impacts the O&M approach and strategies. Relationships are important, and champions are essential for achieving high performance. The level of effort at some sites was higher than initially anticipated, however, many of the early issues have been resolved and staffing, costs, and downtime is expected to decrease at many of the sites. Although there was not as much emphasis on the O&M strategies for most TVP projects as there should have been in the planning stages of the projects, the owners are now focusing their attention on optimizing their projects' performance.

Figure 9. Troubleshooting controller components at Kotzebue

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