Summary Report on Forgen 500 Wind Turbine Performance

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Introduction

The Forgen 500 wind turbine has been tested by UNAVCO in a variety of conditions, including two Antarctic deployments. Results of four tests are summarized here. See notes at the end of this report for details on the turbine.

Description of Test Series

1. Vehicle-mounted test, summer 2006

The turbine was mounted to a truck and driven at various speeds on a calm day, while the turbine was used to charge a depleted 100 amp-hour 12V battery. The turbine was wired directly to the battery, and charging current was measured using a digital multimeter.

2. Niwot Ridge Colorado, autumn 2006

A turbine was installed at the UNAVCO alpine test facility at Niwot Ridge, Colorado. During the four month test (July-October), the NetRS receiver was powered solely from the turbine and one 100 amp-hour battery. Wind speed data was obtained from a nearby observatory and compared with power supplied from the turbine.

3. Observation Hill Antarctica, (austral) winter 2007

The UNAVCO GPS test facility at McMurdo Station was equipped with a NetRS receiver, wireless ethernet comms, a weather station, and two wind turbines (Forgen 500 and Ampair Dolphin). The system was underpowered to allow observation of system shutdown during the winter and startup during the spring. Eleven channels of engineering data were recorded from January 2007-January 2008 including current output from both wind turbines, which were correlated with wind speed at the station. See notes at the end of this report for notes on the Ampair Dolphin turbine.

4. Minna Bluff Antarctica, (austral) autumn 2007

A prototype GPS station equipped with solar panels, sealed lead-acid batteries, and one Forgen 500 was installed at Minna Bluff in February 2007. Minna Bluff is an extremely windy location which is also subject to rime ice formation. One major goal of this installation was to test Forgen 500 survivability and power output performance under severe Antarctic conditions.

Test Results

Three main results are presented here. First, instantaneous wind speed is shown with instantaneous current output and compared with the manufacturer's specifications. Second, longer-term wind data is integrated and used with integrated wind turbine output to create a rough predictor for estimating the expected turbine power output at a site where wind speed data is known. Third, overall results from the Minna Bluff prototype are discussed. Here, the wind turbine output predictor is used to estimate the power produced at Minna Bluff, and comparison is made with the actual power consumed by this system during winter 2007.

1. Instantaneous turbine output

Figure 1 compares the manufacturer's rated output with that measured by UNAVCO. The Vehicle Test data are true instantaneous measurements, while the Observation Hill data are an average of numerous 5-minute averages. In both tests the true output of the turbine is below that of the manufacturer. It is thought that slipstream effects from the truck body and/or high elevation (5280 ft.) account for the lower output at high wind speeds during the truck test as compared to Observation Hill (sea level).

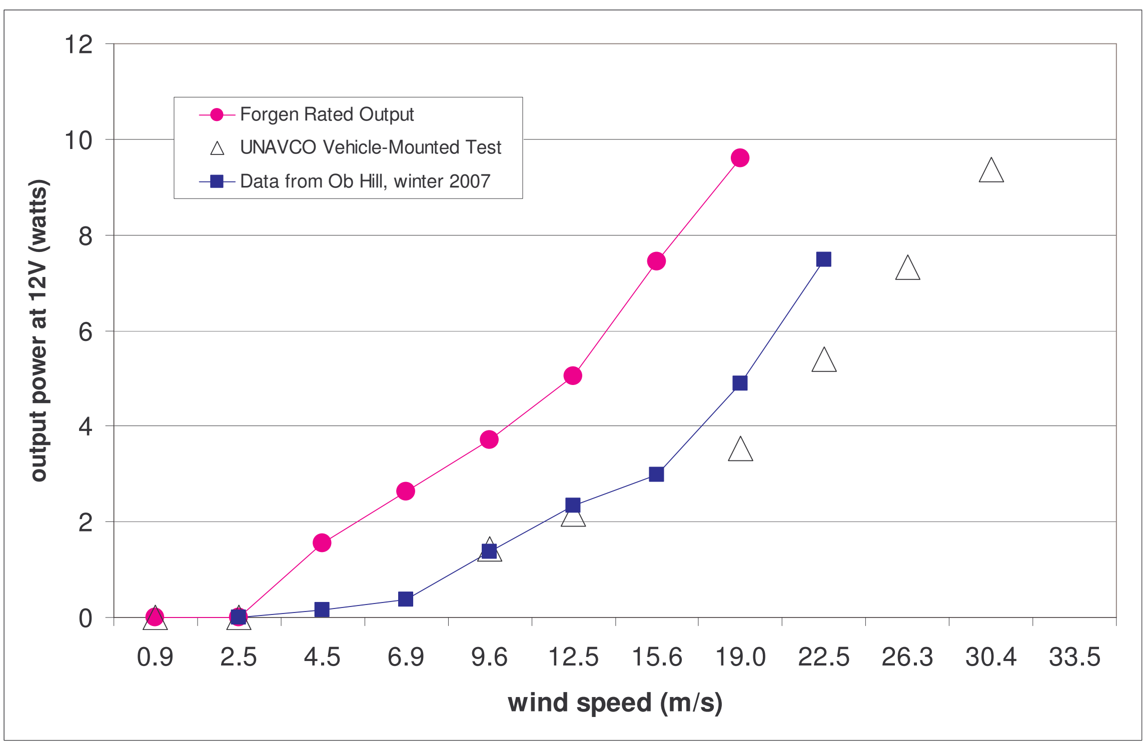

Figure 1. Forgen 500 output power at 12V.

2. Predicting Forgen 500 Output from Wind Speed Data

To obtain an approximate predictor of wind turbine performance for locations where wind speed data is available, integrated turbine current output was correlated with integrated wind speed using intervals of the Observation Hill data. However because the Forgen 500 has a cut-in wind speed of approximately 5 m/s, all wind data below 5 m/s was removed before integration. The Figure 2 shows integrated wind speed, in units of (m/s*hours), compared with turbine output, in amp-hours. Data shown in this plot was taken from ten week-long sections between sunset and the date at which the system shut down for the winter.

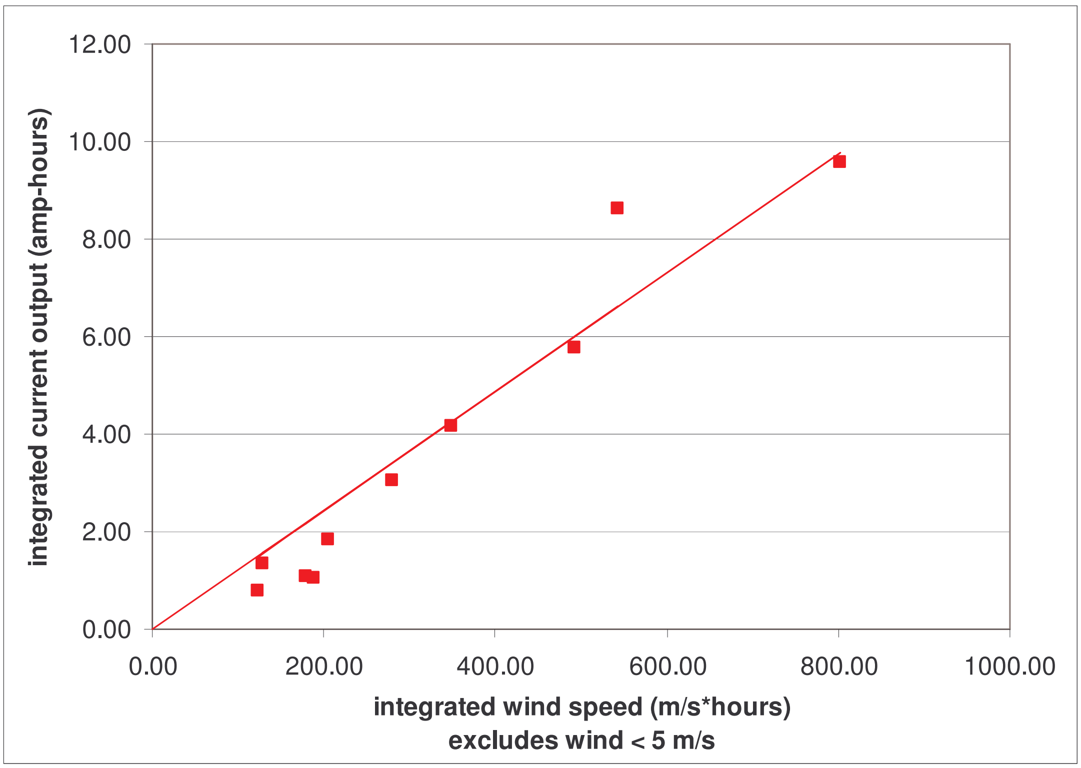

Figure 2. Using Wind Speed Data to Predict Forgen 500 Output

A linear fit to this data was used as the predictor for wind turbine performance. This relationship was:

(Integrated current output, amp*hours) = 0.0122 * (Integrated wind speed, m/s*hours)

where the integrated wind speed does not include wind below 5 m/s.

Note that this relationship was derived from a Forgen 500 used at sea level, with temperatures between -10 and -30 C; at higher elevations or warmer/colder temperatures, the slope of the above relationship would change proportionally with any change in air density. Also, because the integration and least-squares fit were strictly linear, this analysis is very conservative since the actual power available from wind varies roughly as the cube of wind speed.

A similar analysis was also performed using data from the alpine test site at Niwot Ridge, Colorado. Although this test was not as straightforward and involved several key assumptions, a similar result was obtained. Here, the slope of integrated wind turbine output versus integrated wind speed was 43% less than Observation Hill. This difference is largely accounted for by elevation (11,600' vs. sea level), however altitude only accounts for 35% of the reduction in power. It is thought that differences in the test setup and physical separation between the wind turbine and wind sensor account for the remaining 8%.

3. Overall Wind Turbine Performance at Minna Bluff

From an analysis of solar panel output and battery capacity alone, it was estimated that system would lose power around June 19. In actuality, aside from approximately 6 weeks of downtime due to failure of an LVD circuit the system remained powered during the entire winter. Furthermore, according to voltage data retrieved from the system, enough power remained to supply more than 6 additional weeks of operation. This additional lifetime was solely the result of the single Forgen 500 wind turbine.

Upon revisiting the site in October 2007, the wind turbine was seen to have sustained moderate but not catastrophic damage, as shown in Figure 3. The blade surfaces had been sandblasted by airborne particles and were deformed in several locations due to small rock strikes. Two blade struts on the top end had detached, and the rotor had two "sticky" spots as it rotated, caused by deformation of the rotor/stator interface area from rock strikes.

Figure 3. Forgen 500 Turbine Damage After Winter at Minna Bluff Antarctica.

The GPS station at Minna Bluff was positioned near a south-facing cliff edge on the southern tip of the bluff, where it likely experienced the strongest localized winds at one of the more severe locations in the Ross Sea area. In addition to providing meaningful power during an entire winter of operation here, the turbine was still in place and would still deliver power in spite of its physical damage. However, higher startup wind speeds would be required to overcome friction at the rotor/stator interface.

Although the University of Wisconsin Automatic Weather Station (AWS) at Minna Bluff is several miles distant from the GPS station, the AWS data was used to estimate the net power output of the wind turbine using the power predictor from Section 2. Between April 18 (sunset) and July 31 it is estimated that the turbine produced approximately 220 amp-hours of charge. However to operate these additional 42 days beyond the nominal shutdown date of June 19, the system consumed approximately 390 amp-hours of charge. Therefore this predictor, derived from data at moderately windy Observation Hill, is seen to be quite conservative when applied to a more extreme location at Minna Bluff.

4. Notes on the Forgen 500 and Ampair Dolphin

1. UNAVCO has used stock Forgen 500 turbines with two modifications provided by the manufacturer: cold-rated cable (-50 C) and low-temperature bearings. For future sites, UNAVCO is purchasing turbines with a high-gloss black polyester coating on the rotors, in an attempt to mitigate rime ice buildup.

2. Each turbine is wired directly to the batteries via a 10-amp breaker. Since the Forgen 500 requires ~20 m/s wind to generate enough power to run the system, all current output from the turbine is delivered directly to the GPS system during normal winds. During extreme winds, any excess power will charge the battery banks.

3. At the Observation Hill site, the Ampair Dolphin was seen to provide roughly 40% more power output than the Forgen. This unit was modified by polar systems engineer Ronald Ross to strengthen the mechanical design, however the stock unit also appeared to possess several improved mechanical design features as compared to the Forgen 500. The rotor assembly looked stronger, and the rotor/stator interface appeared to be stronger and better sealed against particle intrusions. However, there was no opportunity for a side-by-side test of the two turbines at an extreme location such as Minna Bluff, and the Dolphin has been discontinued by the manufacturer.