A Residential Example of Hybrid Wind-Solar Energy System: WISE

O. A. Soysal, Senior Member, IEEE, H. S. Soysal

Abstract—A residential size hybrid system powered by wind and solar energy has been developed on Frostburg State University campus to supply a small building through net metering. The main purpose of the demonstration system is to develop a knowledge base on residential electric generation from wind and solar energy in Western Maryland and the surrounding area.

The paper discusses the pre-design study for site selection, an assessment of the solar and wind potential at the selected location, the system outline, experience gained during the design and construction phase, and an assessment of the system performance based on collected output data.


I. INTRODUCTION

A grid-tied residential size hybrid system combining solar and wind power generation was constructed at Frostburg State University (FSU) to supply a small building through net-metering. The idea behind the project was to create a small scale demonstration system to study the feasibility and effectiveness of solar and wind power in Western Maryland and the surrounding region.

The main purpose of the wind and solar energy demonstration system named “WISE” is to promote electric generation for residential, agricultural, and small business applications in the region. Expected outcomes of the project include increasing public awareness of the benefits of renewable energy, developing a knowledge base to assist the local community to develop their own generation systems. This paper describes the public opinion surveyed at pre-design phase, the system outline, and the experience obtained during the construction of the system. The output data collected up to the date of the manuscript submission are presented in the paper. The presented data will be updated at the conference.

II. PRE-DESIGN STUDY

Since the ultimate goal of the demonstration system is to promote the idea of distributed electric generation by residential hybrid systems, public cooperation is crucial for the success of the project. Before starting the design and development of the hybrid system, the Frostburg State University community has been informed about the purpose and expected outcomes through information meetings, e-mails, and the Internet. The public opinion about the residential use of wind and solar energy as well as concerns of possible impacts of the project on FSU and Western Maryland were sought by a survey distributed to faculty, staff, and students. The results of the survey were discussed in detail in the paper presented by the authors at the IEEE PES General Meeting in 2007 [2].

Several locations on the FSU campus were considered for the installation of the WISE system. The major criteria listed below were used for site comparison and selection.

a) Supplied from the low voltage distribution network for grid connection through net metering
b) Available space for wind turbine tower and PV arrays
c) Suitable roof orientation for adequate solar exposure
d) Adequate exposure to dominant wind
e) Visibility and accessibility for public outreach
f) Safety
g) Security

Four buildings meeting the criteria a – c were compared based on criteria d – g. The selected building located on the southern edge of the campus meets all criteria, whereas the surrounding buildings present a disadvantage for the wind portion of the system. The advantages of the selected site include southern exposure of the roof, better visibility, and easier access to public.

III. OUTLINE OF THE SYSTEM

The configuration and size of the hybrid system to be developed on the FSU campus were defined in the grant contract with Maryland Energy Administration. According to the Scope of Work, FSU was required to build a grid-connected hybrid demonstration system consisting of 2-kW PV array and 1.8-kW wind turbine to supply a residential type building through net metering. The finished WISE system is shown in Figure 1.
Figure 1 The FSU Hybrid demonstration system “WISE”

Due to the system requirements described in the contract, budget constraints, and space limitations selection of the wind turbine has been a major challenge. While several wind turbines developed for residential electric generation are available on the USA market, the Skystream® manufactured by Southwest Wind Power (Flagstar, AZ) met the project requirements. The selected wind turbine has 1.8-kW rated power and includes a controller and inverter in the nacelle, such that the unit provides 240-V, 60-Hz output for direct connection to the split-phase low voltage system.

Due to the space limitation at the selected location and for aesthetic reason, a monopole tower was the preferred over guy-wired and lattice tower types. At the beginning of the project, only 33-foot monopole tower was available for Skystream®. Because of the turbulence and wind shear produced by surrounding buildings, at least 70-foot tower height would be adequate for the system to receive reasonable wind speed. By the time the system components were selected, the turbine manufacturer was developing taller monopole towers and a 60-foot tower was expected to become available in early 2007. The construction was delayed more than three months waiting for a taller tower, but due to the project timeline, a 45-foot tower was purchased as soon as it became available.

A variety of PV modules available on the market were considered for the solar part of the system. SANYO HIT® (Heterojunction with Intrinsic Thin layer) panels were selected for their higher panel efficiency. The PV array mounted on the southern side of the roof as shown in Figure 1 consists of ten modules. Each module has 200-W rated power for 1-kW/m² insolation. An external 2.5-kW Xantrex-GT® inverter/controller provides 240-V, 60-Hz output for grid connection.

For grid connection of the system and net metering contract, Allegany Power, the supplier of electricity for the building, requires that all components of the system comply with the National Electric Code and UL 1741. An external disconnecting means is also required for safety. The solar and wind components of the system are connected to the main service panel of the building and the low voltage distribution network via individual outdoor disconnecting switches and one common single-phase bi-directional net active energy meter. The outline of the system is shown in Figure 2.

IV. ASSESSMENT OF THE SOLAR POTENTIAL

One side of the roof of the building selected for the hybrid system is oriented to the south and has a fairly good exposure to solar radiation. However, the tall evergreen trees at the other side of the street obstruct the sunlight during winter, creating a less favorable exposure especially when less sunlight is available.

The solar potential available at the selected building has been analyzed using the solar site assessment tool and accompanying software “ASSET 1.29” [3].

Figure 3 shows the panoramic picture taken in front of the building the PV array is located. The camera is oriented to the geographic south considering the magnetic declination of -11° and an array of 2x9 pictures are taken by rotating the camera 22.5 degrees between each picture. The software utilizes the “PVWatts” calculator developed by NREL [4] in conjunction with an image processing of the panoramic site view. For a rated power of 2-kW installed PV array, a total yearly AC generation of approximately 2,000-kWh is expected.

Figure 2 The WISE system configuration

Figure 3 Solar path seen from the location selected for the WISE system
The average wind speed over the observation period is 5.05-mph with a standard deviation of 5.29 and the median of the distribution is 3.3-mph. The maximum wind speed recorded was 33-mph.

It should be noted that the output power of a wind turbine is proportional to the cube of the wind speed \( P = K \cdot V^3 \). Therefore an evaluation merely based on hourly average wind speed clearly underestimates the energy that a wind turbine would actually generate.

### Table: Solar Potential

<table>
<thead>
<tr>
<th>Month</th>
<th>light shaded (%)</th>
<th>sunlight per day (hours)</th>
<th>available sunlight (hours)</th>
<th>AC energy (kW-hr per kW of PV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>31.1</td>
<td>3.59</td>
<td>2.47</td>
<td>62</td>
</tr>
<tr>
<td>February</td>
<td>25.4</td>
<td>4.49</td>
<td>3.35</td>
<td>74</td>
</tr>
<tr>
<td>March</td>
<td>8.6</td>
<td>4.78</td>
<td>4.37</td>
<td>103</td>
</tr>
<tr>
<td>April</td>
<td>2.1</td>
<td>4.99</td>
<td>4.89</td>
<td>109</td>
</tr>
<tr>
<td>May</td>
<td>6.5</td>
<td>5.08</td>
<td>4.75</td>
<td>105</td>
</tr>
<tr>
<td>June</td>
<td>3.8</td>
<td>5.43</td>
<td>5.22</td>
<td>107</td>
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<tr>
<td>July</td>
<td>5.3</td>
<td>5.37</td>
<td>5.08</td>
<td>107</td>
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<tr>
<td>August</td>
<td>4.5</td>
<td>5.13</td>
<td>4.90</td>
<td>103</td>
</tr>
<tr>
<td>September</td>
<td>3.8</td>
<td>4.90</td>
<td>4.71</td>
<td>98</td>
</tr>
<tr>
<td>October</td>
<td>21.4</td>
<td>4.97</td>
<td>3.91</td>
<td>88</td>
</tr>
<tr>
<td>November</td>
<td>31.3</td>
<td>3.68</td>
<td>2.53</td>
<td>58</td>
</tr>
<tr>
<td>December</td>
<td>31.5</td>
<td>2.94</td>
<td>2.01</td>
<td>49</td>
</tr>
</tbody>
</table>

**average**: 14.6 | 4.61 | 4.02 | Total: 1063

**Figure 4** Estimated solar potential available for the hybrid system

V. ASSESSMENT OF THE WIND POTENTIAL

Frostburg State University is located in Western Maryland, approximately 120 miles west of Baltimore as marked on the wind map shown in Figure 5 [6]. The elevation of the Frostburg State University Campus is about 2000 feet. The 50-m wind map indicates that the wind potential in this region is between “poor” and “marginal” with an average wind speed below 12.5-miles/hr. In addition, the surrounding hills and buildings produce significant turbulence and wind shear on campus.

**Figure 5** Maryland wind resource map

For more realistic assessment of the wind potential, hourly wind speed data recorded on the roof of the Compton Science Center were analyzed. Figure 6 shows the distribution of wind speed values recorded over nine months between February and November 2007.

**Figure 6** Wind speed profile near the turbine location

The output characteristic of the Skystream 3.7© wind turbine derived from the product specifications is shown in Figure 7 [5]. The downwind rotor with stall regulation has a diameter of 12 feet (3.72 m). The turbine is designed for 21 mph (9.4 m/s) rated wind speed. The cut in wind speed is 8 mph (3.5 m/s), and the survival wind speed is 140 mph (63 m/s).

**Figure 7** Output characteristic of the wind turbine

Using the wind profile (Figure 6) and the turbine characteristic (Figure 7), the distribution of the output power over one year period is estimated as shown in Figure 8.
The estimated output power of the wind turbine is arranged in magnitude versus hours in Figure 9. According to the chart, the wind turbine is expected to generate electricity during 2,074 hours out of 8,766 hours of the year.

VI. SYSTEM PERFORMANCE

The system output has been monitored regularly since August 2007.

The grid-tie inverter of the PV system Xantrex© has an internal data logger to record the voltage, current and power at the DC and AC sides in addition to the efficiency, energy, and frequency values. A sampling interval of 10 s is selected and data is downloaded to an MS Excel® spreadsheet by means of the shareware software GT-View® [6].

Skystream™© wind turbine has an internal data transmitter, which can communicate with a remote monitor available separately. In addition to the remote monitor, a Fluke1735 power logger was connected to record the wind turbine output data. The average, maximum, and minimum values of voltage, current, active power, reactive power, active energy, reactive energy and the power factor has been recorded at a 10-minute sampling interval.

The average daily energy generation of the 2-kW PV array has been 6.630-kWh between June 8 and November 16. The total energy generated during the same period is 1,127,459-kWh. The wind turbine has generated 1.42-kWh/day over a period of 45 days between October 1st and November 15th. As of the date of submission of this manuscript, the PV system has generated 1,159 kWh at the AC side. This corresponds to approximately 695 kg of CO₂ should the same energy be produced by coal burning power plants.

Figure 10 shows the daily energy generation of the hybrid solar and wind components of the hybrid system over a period of 45 days between October 1st and November 15th, 2007. Although the presented data covers a small portion of the year, it clearly shows that the solar and wind parts of the system contribute to the energy output in a varying proportion depending on the weather conditions. Clearly the contribution of the PV generation is more significant during summer. The wind turbine started to contribute significantly in November. As the output data is populated through the year, a better view of the solar and wind energy harnessed by the WISE system will be available.

VII. CONCLUSIONS

The WISE system constructed on Frostburg State University campus provides a real life example and a valuable resource for individuals who wish to develop their own generation systems.

Study of the wind potential at the site indicated that the location of the WISE system is not excellent for electric generation by wind. However, assessment merely based on hourly average wind speed underestimates the wind energy potential of a site and may be misleading. One of the purposes of the project is to collect actual power and energy data over a long period of term to assess the wind potential available to residential generators.
Moderate solar energy is available at the location. In summer, the output energy of the system is mainly produced by the PV system. In winter, the wind turbine output becomes greater while the PV output decreases because of less sunlight available and shading by surrounding obstacles. The wind turbine contributes to the energy output of the system significantly in cloudy and windy days, when the PV output is not great. When a one-year cycle has been completed, a better evaluation of the overall system output will be available.

Since the residential developers are limited to their backyards, they should assess their energy need and the available wind and solar potential to make a rational decision.

VIII. REFERENCES


IX. ACKNOWLEDGMENT

This WISE system was constructed with funding provided by the Maryland Energy Administration. The authors thank Dr. Jonathan Gibralter, President of Frostburg State University, Mr. Stephen Spahr, Vice President for Economic Development and Government Relations at FSU, for their support and guidance. The valuable input and continuous support of Frostburg State University community is also acknowledged and appreciated.

X. BIOGRAPHIES

Oguz A. Soysal received the B.Sc., M.Sc., and Ph.D. degrees from Istanbul Technical University, Turkey. In 1983 he joined ABB-ESAS Power Transformer Company (Istanbul, Turkey) as an R&D engineer. From 1986 to 1993 he worked for Black-Sea Technical University, Turkey. In 1987 he visited The Ohio State University (OSU) as a Post Doctoral Scholar, and in 1991-1992 he spent a sabbatical leave at the University of Toronto. Between 1993 and 1997 he has been with Istanbul University, Turkey, and Bucknell University, Lewisburg, PA, USA. He joined Frostburg State University in fall 1998. Currently, Dr. Soysal is Chair of the Physics and Engineering Department and he is teaching electrical engineering courses. His areas of research include power engineering, renewable energy, and electrical engineering education.

Hilkat S. Soysal received a Law degree from University of Istanbul, Turkey. She practiced law in private companies and two state universities as a counselor. In 1993, she joined Istanbul University College of Engineering as a Lecturer. While teaching law courses for undergraduate engineering students, she completed her graduate study in the Marine Engineering program and received a M. Sc. degree in 1996. Between 1997 and 2000, she took various MBA, Computer Science, and engineering courses at various institutions. Since fall 2000, she has been working as an part time faculty at the Department of Physics and Engineering at Frostburg State University.