Potential assessment of the use of green energy to meet the electricity demand in a land aquafarm

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Abstract

Due to the widespread aquaculture at coastal areas in Taiwan and high wind power potential at the sites, it is worth carrying out the potential assessments of green energy used for aquaculture in Taiwan. This study aimed at the practical installation of a small-scale wind power system. First, the weather data acquired from the newly installed weather station, the Weibull Probability Distribution and power curve provided by the generator manufacturer were used to analyze the wind power potential. After the design and planning had been completed, the small-scale wind power system was installed, being sponsored by the supporting industry. A detailed account of the installation procedure and solutions to the encountered problems were presented in the text.

Keywords: renewable energy, wind power, aquaculture.

1 Introduction

The geographical location of Taiwan is such that it has the opportunity to generate much wind power, mainly on the west coast and on nearby islands such as the Pescadores (Peng-hu). There, the annual average wind speed exceeds 5–6m/sec, yielding a wind power density of over 250W/m² at 10 m height, which value favors the development of wind power. Based on an assessment of domestic wind energy and the government plan entitled, “Challenge of 2008: Project for National Development”, the Energy Resource Committee of Taiwan decided in June 2000 to promote wind power over the long term. A total capacity of 1500MW is expected to be reached by the year 2020, including an
onshore capacity of 1000MW and an offshore capacity of 500MW. Fig.1 shows
the primary target of wind power developed in Taiwan. Due to the widespread
aquaculture at coastal area in Taiwan and high wind power potential in their
sites, it is worthy to carry out the technical potential assessments of small-scale
wind power system used for aquaculture in Taiwan. This study aimed at the
assessment of the practical installation and operation performance.

![Figure 1: Primary target of wind power development in Taiwan.](image)

2 A brief introduction to the wind power system

The application logic of large-scale wind power systems differs completely from
that of small scale power systems. Large-scale wind power systems are
established to increase domestic power capacity, by connection to the electricity
network. Small-scale wind power emphasizes “self-reliance”. The generated
power is provided to regional industries, which thus reduce their dependency on
power from utilities. In Taiwan, the main benefit is to reduce the peak power
load. Small-scale wind power can be subcategorized into three types - micro,
mid-range and mini one, as depicted in Table 1 [1]. The components of a small-
scale wind power system and their special features are described in Reference
[2]. The uncertainties in the quality of wind (related to a lack of wind or a wind
speed that is too low to start up the turbines) and the periods of demand for
energy are such that a small-scale power system must use sub-devices to reduce
the risk of power leakage. These sub-devices include battery systems, diesel
generators, solar power systems or power generated from utilities, among others.

A simple small-scale wind power system includes a main body (turbines and
generator), a charging controller, a battery system, current inverters or a utility
connection system, among others, as shown in Fig. 2. The application modes of
such components can be varied. For instance, the input to the connection
box/charging controller not only receives power generated from wind, but also can be connected to a photovoltaic system, an emergency system or a diesel generator.

Table 1: Classification of small-scale wind power system [1].

<table>
<thead>
<tr>
<th>category</th>
<th>Power output (KW)</th>
<th>Radius of the turbine (m)</th>
<th>Max. rotation speed (rpm)</th>
<th>Generator</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>micro</td>
<td>1</td>
<td>1.5</td>
<td>700</td>
<td>PM</td>
<td>Electric fences, yachts</td>
</tr>
<tr>
<td>mid-range</td>
<td>5</td>
<td>2.5</td>
<td>400</td>
<td>PM or induction</td>
<td>Remote houses</td>
</tr>
<tr>
<td>mini</td>
<td>20-50</td>
<td>5</td>
<td>200</td>
<td>PM or induction</td>
<td>Remote community</td>
</tr>
</tbody>
</table>

Figure 2: Illustrative diagram of the small-scale wind power system.

3 Local wind resource assessment

3.1 Analytical method for predicting long-term wind energy availability

The Weibull Probability Distribution \( h(v) \) is a mathematical expression which has been found to provide a good approximation to the measured wind speed distribution [2].

\[
h(v) = \left( \frac{k}{c} \right) \left( \frac{v}{c} \right)^{(k-1)} e^{\left( \frac{v}{c} \right)^{k}}
\]  

(1)

where,

- \( h(v) \) = probability associated with wind speed \( v \) in a certain period. Unit: \%
- \( v \) = wind speed Unit: m/s
- \( k \) = shape parameter Unit: dimensionless
- \( c \) = scale parameter Unit: m/s
K and c are important parameters, and can be determined from the average wind speed \( V \) and the standard deviation \( \sigma \).

\[
C = \frac{V}{0.89} \quad (2)
\]
\[
V = c \gamma (1+k) \quad (3)
\]
\[
\sigma^2 = c^2 \left( \gamma (1+2/k) - \gamma (1+1/k) \right) \quad (\gamma : \text{Gamma Function}) \quad (4)
\]

when the height of the wind-power devices (\( H_2 \)) differs from the height at which the wind-speed is measured (\( H_1 \)), a formula proposed by G. Hellman, can be used to predict the wind speeds at height \( H_2 \)

\[
V_2 = V_1 \left( \frac{h_2}{h_1} \right)^{\alpha} \quad (5)
\]

where \( \alpha \) is the friction coefficient of the surface. The site of this research was on a plane, and therefore, \( \alpha \) is fixed at 0.15 in this study [2].

3.2 Wind speed measurement

The guidelines for properly planning and designing wind-power systems depend on accurately estimating wind energy potential. The power system in this investigation was located in a suburb close to the ocean. Its background environment differs greatly from those of the central weather bureau ground stations, since both Tainan station and Yung-Kang station that in cities. Weather information from the Tainan Salt Factory from 1983 to 1995, and detailed weather information recorded to help in the planning of the Cheng-Si Li Coastal Recreation Area by the Tainan City Government, was obtained. However, the data from such reports cover only up to 1995. Given the changes in the landscape, the actual wind-speed recently at the site must be understood. A weather measurement station at a height of 4m was activated next to the aquafarm (DAVIS Instruments) to measure factors such as the wind-speed, the direction of the wind, the temperature and the humidity and rainfall. The sampling interval was fixed at 10 minutes.

4 Planning, designing and establishing a small-scale wind power system

4.1 Planning and designing

The wind power system adopted herein had a small capacity. All components of the system are easily available on the open market for small-scale power systems. The designed and established electrical supply system therefore met the requirements for generating low-voltage electricity.
Figure 3: Electricity demand and estimated energy output of wind power.

(1) Demand for power
The type of aquatic product, the amount of oxygen required, the scale of the aquafarm, the water circulation devices and the equipment in the farmhouse all affect the demand for power and the mode of operation. A milkfish aquafarming generally uses one of two cultivating styles, as illustrated in Fig. 3.

(a) Style A: Cultivation period of six months.
Every March, young fish are released into the aquafarm; October is the harvesting month. Gas irrigators, as shown in Fig.4, are operated for promoting oxygen exposure from dusk to dawn of the following day. In the initial stage of the cultivation, only one gas irrigator is required for an aquafarm with an area of about 1000 m² and the operating time is short. However, as the young fish grow, the second gas irrigator is used and the operation time is gradually increased. This is the most often used approach to cultivating milkfish in aquafarms in Taiwan.

Figure 4: Gas irrigators can be easily found at an aquafarm in Taiwan.
(b) Style B: Year cultivation (also called “through the winter cultivation”)

The young fish are allowed to grow until after the harvesting month of October; they are harvested only in the following year to meet the demand of the market.

(2) The adoption of the small-scale wind-power system

The monthly and annual energy generation data with a 1.05 safety margin can be estimated from the monthly distributive data derived from the weather statistics and the power curve of the GaleForce Passat 1.4kW wind power generator, as shown in Fig. 3. The ratio of theoretical energy generation to actual energy generation can be estimated for each generator. Hence, the number of generators and the type of generators that should be used to replace to satisfy the demand for energy can be determined. Table 2 presents the load coverage for the two cultivation styles.

Table 2: Estimation of the electricity generation.

<table>
<thead>
<tr>
<th>Measured weather data</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly average wind speed (m/s)</td>
<td>4</td>
<td>3.7</td>
<td>3.2</td>
<td>3.7</td>
<td>2.2</td>
<td>1.8</td>
<td>2.78</td>
<td>1.68</td>
<td>2.44</td>
<td>3.59</td>
<td>3.67</td>
</tr>
<tr>
<td>Standard deviation of wind speed</td>
<td>1.81</td>
<td>1.59</td>
<td>1.69</td>
<td>1.3</td>
<td>1.2</td>
<td>0.98</td>
<td>1.35</td>
<td>0.96</td>
<td>1.35</td>
<td>1.31</td>
<td>1.27</td>
</tr>
<tr>
<td>k (shape parameter)</td>
<td>2.37</td>
<td>2.46</td>
<td>2.03</td>
<td>3.11</td>
<td>1.65</td>
<td>1.94</td>
<td>2.19</td>
<td>1.84</td>
<td>1.9</td>
<td>4.02</td>
<td>3.17</td>
</tr>
<tr>
<td>c (scale parameter)</td>
<td>4.51</td>
<td>4.14</td>
<td>3.66</td>
<td>4.14</td>
<td>2.42</td>
<td>2.03</td>
<td>3.14</td>
<td>1.89</td>
<td>2.75</td>
<td>2.99</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Electricity information (GaleForce Passat@1.4kW)

| Daily average power output (W) | 430 | 399 | 329 | 408 | 175 | 110 | 272 | 83 | 211 | 342 | 465 | 526 |
| Daily average energy output (kWh) | 9.8 | 9.1 | 7.5 | 9.3 | 4.0 | 2.5 | 6.2 | 1.9 | 4.8 | 7.8 | 10.6 | 12 |
| Monthly energy output (kWh) | 304 | 255 | 140 | 279 | 124 | 75 | 192 | 59 | 144 | 242 | 318 | 372 |

Relationship between energy output and demand (one wind power generator @1.4kW) unit : %

| Load coverage ratio of Style A | 100% | 100% | 100% | 100% | 53% | 17% | 41% | 13% | 32% | 52% | 100% | 100% |
| Load coverage ratio of Style B | 65% | 61% | 50% | 100% | 53% | 17% | 41% | 13% | 32% | 52% | 71% | 80% |

Relationship between energy output and demand (two wind power generators @1.4kW) unit : %

| Load coverage ratio of Style A | 100% | 100% | 100% | 100% | 33% | 33% | 83% | 25% | 64% | 100% | 100% | 100% |
| Load coverage ratio of Style B | 100% | 100% | 100% | 100% | 33% | 33% | 83% | 25% | 64% | 100% | 100% | 100% |

Note: Safety Margin was set to be 5%.

: energy output that can not meet the demand (estimated).

The results reveal that under the common cultivation style (Cultivation Style A), one small-scale power generator can supply sufficient energy only in the
early stage of the growth of the young fish, for around 1.5 months. The generated electricity is insufficient after mid-April. Two wind power generators also cannot provide enough power in May. At the peak hours, even two sets of generators cannot meet the demand for energy for Style A Cultivation. The low wind speed in the summer and autumn at the research site is responsible for the lack of energy generated even when the number of devices is increased. One set of wind power generators could not provide sufficient energy to meet the demand in the one-year cultivation mode (Style B Cultivation). However, the strong northeastern wind in winter at the research site enables the generated energy to meet the need for electricity from October to the following March. The same problem arises in summer and autumn when the power output is too low. Therefore, the other climatic feature, high exposure to sun, is considered. The high potential for wind-power and the solar energy at the research site, given that they appear to generate power in a complimentary manner makes worthwhile the study of the potential for using a small-scale wind and supplementary photovoltaic power system.

Figure 5: The wind power tower was installed on an RC foundation.

Figure 6: The turbines were built on the ground and integrated into the frame.
4.2 Establishment

The correctness of the installation strongly influences the safety and efficiency of a small-scale wind power system. The steps in the installation must be followed to prevent accidents.

5 Conclusion

This work analyzed the wind power potential, using a Weibull Probability Distribution based on weather data acquired from the Central Weather Bureau and a newly installed weather observation station. The wind power system used in this work had a small capacity and the components of the system are commonly available on the market. The design and construction of the power system were suitable for lower-voltage use. After the design and planning had been completed, small-scale wind power systems were installed, being sponsored by the supporting industry. Accurate and detailed account of the installation procedure and the solutions to the encountered problems were presented.

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References