

HYBRID LENZ2 VAWT AND SOLAR PV PANEL FOR RURAL LIGHTING

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Abstract

The hybrid Lenz2 vertical axis wind turbine (VAWT) and solar photo voltaic (PV) panel for rural lighting is a renewable energy technology application which is suitable for sustainable development in Thailand. The objective is aimed at designing the system, investigating the system's performance, and simulating the system's potential at different locations. The experimental setup shows that most of the electric power generated by the system came from solar PV panel but the Lenz2 VAWT provided more reliability in terms of the operating times even though it generated lower power due to low wind speeds which is normal for most locations in Thailand. From the experiment, a wind turbine of the Lenz2 VAWT type has 25% power coefficient but the power curve cannot be achieved due to the limitation in the equipment. The system can provide enough electric power for 10 h street lighting at night, as expected. The simulation results show the potential of the system for using data at Pakchong, Thailand. For future improvement, increasing the power coefficient of the wind turbine can be achieved by a new design of wind turbine with a more swept area and lightweight materials.

Keywords: Hybrid system, Lenz2 VAWT, solar PV panel, wind turbine, lighting, power generation

Introduction

Due to the steady increase in energy demand and decrease in fossil fuels used in energy consumption, renewable energy has been promoted for decades with the expectation of the availability of fossil fuels declining (Energy Policy and Planning Office, 2018). Solar and wind energies are the most commonly used renewable energy sources, but

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both energy sources are intermittent resulting in fluctuating outputs (International Renewable Energy Agency, 2017). To overcome an unsteady power generation, a hybrid Lenz2 vertical axis wind turbine (VAWT) and solar photovoltaic (PV) panel is introduced.

The advantage of the hybrid system is the increase in reliability of the power generation system. The solar PV panel can generate power in the daytime and the wind turbine can generate power at night or in cloudy conditions. Besides that, the system's operation is pollution-free with no gas emissions (Ricci *et al.*, 2014). Moreover, the hybrid system is suitable for use in remote and rural areas where the utility grid cannot be accessed.

In this study, the hybrid Lenz2 VAWT and solar PV panel for rural lighting is presented. The study's objective is the design and construction of a workable hybrid Lenz2 VAWT and solar PV panel for rural lighting and a demonstration of the performance of the Lenz2 VAWT.

Materials and Methods

System Design

The hybrid Lenz2 VAWT and solar PV panel for rural lighting consists of 6 main components which are the Lenz2 VAWT, the solar PV panel, a charging controller, a battery, a digital timer, and LED lights. The Lenz2 VAWT and solar PV panel are utilized as the main energy resources and the battery is used as a storage device.

Dimensioning and Selection of Lighting and Battery

For the 12W 12V LED lights to last for 10 h per day, the daily electric energy requirement is calculated by multiplication of the power of the lighting and period of daily use shown in Equation (1), where $P_{one\ day}$ is the daily electric energy requirement, P_{LOAD} is the power of the lighting, and t is the period of daily use:

$$P_{one\ day} = P_{LOAD} \times t \quad (1)$$

The assumption is that the average DC-DC charging controller output is 95%. The selected battery and digital timer specifications are shown in Tables 1 and 2, respectively.

Table 1. Specification of DC 12V 20AH lead acid battery

Specifications	Details
Model	NP20-12 12V lead acid battery
Nominal voltage	12V
Rated capacity	20Ah (20 H)
Dimensions	181×77×167×167 mm
Weight	5.4 kg

Table 2. Specification of DC 12V digital timer switch

Specifications	Details
Timer model	Cn101A DC
Voltage	12V
Battery	Lithium-Ion 1.2V/40mA
Output	16A
Weight	80 g
Dimensions	6.5×6.5×4 cm

Dimensions and Design of the Lenz2 VAWT

According to the wind energy potential analysis in Thailand, the wind velocity is extremely low (Chingulpitak and Wongwises, 2014; Smuthkalin *et al.*, 2018). VAWTs are fit for this condition. In addition, they have a relatively low environmental impact and can produce electricity from any direction (Saad and Asmuin, 2014). In this study, the Lenz2 type of VAWT is used.

The Lenz2 VAWT converts the kinetic energy from wind into electrical energy using a rotor mounted on a shaft connected to the generator (Sivamani *et al.*, 2017). Generally, the maximum theoretical wind power can be calculated assuming that the wind speed behind the turbine is equal to 0. In practice, it is impossible to achieve 100% efficiency, therefore C_p or the power coefficient is introduced into the theoretical model. The theoretical C_p maximum is labelled to Betz's limit which is 0.593 (Ragheb and Ragheb, 2011). For the Lenz2 VAWT, assume that the C_p is around 0.35.

Equation (2) shows the power generation by the Lenz2 VAWT (P_T) where ρ = the

density of air, A = the designed frontal area, and C_p = the power coefficient of the turbine:

$$P_T = \frac{1}{2} \rho A V_0^3 c_p \quad (2)$$

According to the Lenz2 design parameters, the following dimensions needed to be calculated:

i) Wing width; Edward Lenz, the designer of the Lenz2 VAWT, has suggested the empirical relation for wing width calculation and it is given as Equation (3):

$$\text{Wing Width} = R \times 0.14, \quad (3)$$

where R is the radius of the turbine (m);

ii) Chord length; the empirical relations for calculation of the chord length of the Lenz2 VAWT is given by Lenz as Equation (4):

$$\text{Wing Chord} = R \times 0.0937, \quad (4)$$

where R is the radius of the turbine (m);

iii) Number of blades; a three-blade turbine is the most preferred and most often used for a VAWT. Two blades produce a noise, rattle, and imbalance. Too many blades cause, among other problems, increases in the weight and the production costs. Table 4 shows the parameters of the Lenz2 VAWT.

Dimensions and Selection of Solar PV panel

From the Lenz2 VAWT design, the electrical power generated is predicted to be only 2W. The electrical power generated by the solar PV panel should be 120 Wh/day and the average time to harness the solar energy is 5 h per day (Department of Alternative Energy Development and Efficiency, 2019). The specifications of the solar panel chosen in this project are shown in Table 3.

Experimental Setup

After finishing construction of the prototype, the performance of each part of the system needed to be demonstrated in an open-environment experiment. To examine the performance of the Lenz2 VAWT, electric fans are used to generate various wind speeds of 3.5, 4.3, and 5 m/s. Connection with the

lighting recording of the voltages and currents produced by the generator, and the performance curve of the wind turbine can be obtained. The solar PV panel's performance can be demonstrated by setting up the panel and measuring the solar radiation with the voltage and current coming out of the panel every 15 min.

Table 3. Technical Data for Solar PV Panel

Parameters	Value
Type	Monocrystalline
Maximum Power	30W
Voltage at Maximum Power	18V
Current at Maximum Power	1.67A
Open Circuit Voltage	21V
Short Circuit Current	1.73A

Table 4. Design Parameters of Lenz2 VAWT

Parameters	Value
Shape of Blade	LENZ2 Type
Aspect Ratio	1.0917
No. of Stages	1
No. of Blades	3
Diameter	683 mm
Height	745 mm
Frontal Area	510000 mm ²
Wing Width	170 mm
Chord Length	375 mm
Pitch Angle	9°

Results and Discussion

Workable Prototype

The workable prototype consists of the Lenz2 VAWT, solar PV panel, streetlight, electrical control box, and aluminum pole. The system is shown in Figure 1 and was set on the rooftop of the Laboratory Building at Sirindhorn International Institute of Technology, Thammasat University, Pathumthani, Thailand.

Lenz2 VAWT Performance

From the experiment, the power coefficient of the Lenz2 VAWT can be obtained at 25%. The equation representing the relationship between the wind speed (V_{wind}) and electric power generation (P_{Lenz2}) is

determined by the performance curve of the Lenz2 VAWT in Figure 2 and is shown in Equation (5):

$$P_{Lenz2} = 0.4156(V_{wind}) - 0.3181 \quad (5)$$

Solar PV Panel Performance

From the experiment, the power generated by the solar PV panel is dependent on the solar radiation. Equation (6) represents the relationship between the solar radiation (I_g) and the electric power generated by the solar PV panel (P_{Solar}) as determined by the data in Figure 3:

$$P_{Solar} = 0.0237I_g + 0.3135 \quad (6)$$

Hybrid System Performance

The completed prototype was set on the rooftop of the 6-floor Laboratory Building at Sirindhorn International Institute of Technology at Thammasat University to harness the energy in an open environment. The results in Figure 4 show that power is mainly generated from the solar PV panel while less wind power was present on that day.

Simulation of the System Using Data at Pakchong, Thailand

The simulation of the system using data collected by the Thai Meteorological Department (Thai Meteorological Department, 2019) is shown in Figure 5. With a relatively

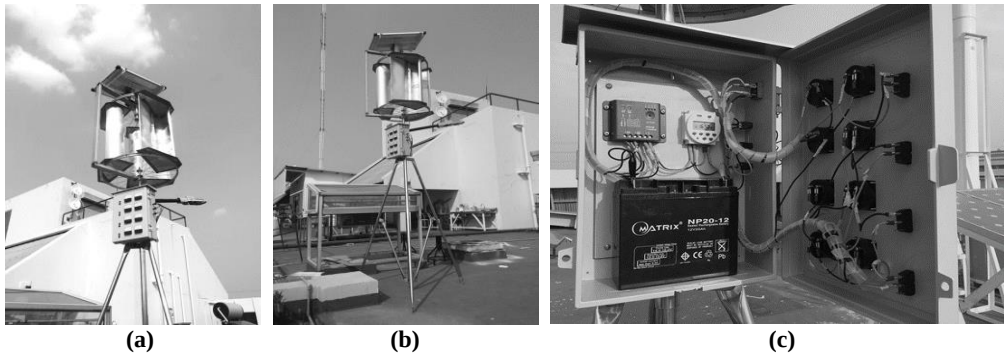


Figure 1. Workable prototype of Hybrid Lenz2 VAWT and Solar PV panel for rural lighting set on the rooftop of the 6-floor Laboratory Building at Sirindhorn International Institute of Technology, Thammasat University, Pathumthani, Thailand: a) overall view and b) electrical control box

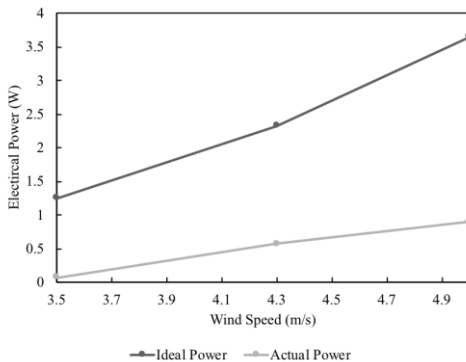


Figure 2. Power curve of Lenz2 VAWT

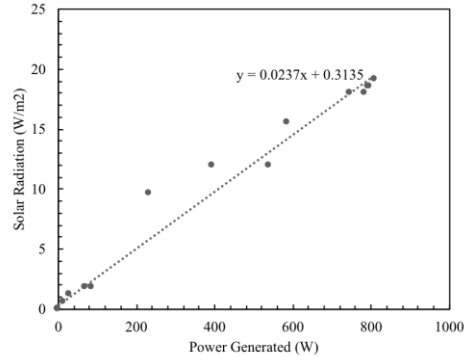


Figure 3. Relationship between solar radiation and power generation from Solar PV panel

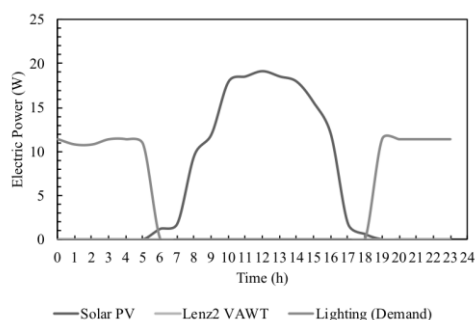


Figure 4. Power generation and power demand during a day in January at Sirindhorn International Institute of Technology, Thammasat University, Pathumthani, Thailand

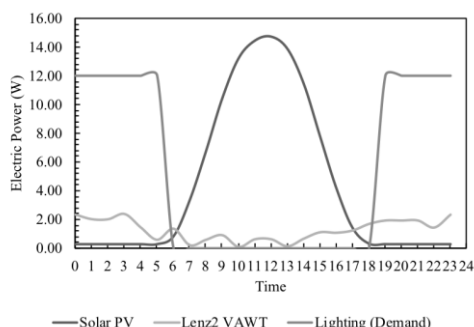


Figure 5. Power generation and power demand during a day at Pakchong, Nakhon Ratchasima, Thailand

low wind speed, most of the power generation is from the solar PV panel but the Lenz2 VAWT provided more reliability in terms of the operating time period.

Conclusions

Most electric power generated by the system came from the solar PV panel but the Lenz2 VAWT provided more reliability in terms of the operating time period even though it generated low power due to the low wind speed which is normal for Thailand. The system can provide enough electric power for the street lighting for 10 h per day, as expected. Therefore, the hybrid wind-PV system for rural application can help Thailand in terms of sustainable development.

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