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Establishment of a Removable Experiment Platform for VAWT

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Abstract. This investigation intends to establish an experimental test platform for a small vertical-axis wind turbine (VAWT), which is installed on the rooftop of a building. The experiment platform designed here is flexible and suitable for executing the systematic performance evaluation on different types of VAWT. By utilizing the data acquisition system (DAQ), all environmental information and power data from sensors and generator on the platform are recorded and transferred to the computer automatically. Later, these analogy signals are transformed to digital format for transmitting into computer. Also, with the aids of a visual software programming within the framework of Labview, the real-time monitoring on the input/output parameters of generator and wind condition on the rooftop can be accomplished simultaneously. Afterwards, the data processing and in-depth analysis on the experimental outcomes are carried out via the established computer program. Consequently, the on-site performance of the wind turbine generator system is attained in an automatic and systematic manner. Moreover, to ensure for providing sufficient data and its accuracy, statistic concept is enforced to judge whether the test data are qualified or not in the data-processing procedure. In summary, together with the data-acquisition software programmed under the framework of Labview, this experimental system can provide the capability for monitoring, recording, and filtering these test data in an rigor manner, and is appropriate for executing the R&D and performance evaluation on different VAWTs.

Introduction

Recently, due to environment issues, the renewable energy industries are attracting more R&D attentions from research institutes all over the world, especially in the wind energy development. It becomes one of the promising energy sources candidates in gaining zero carbon content for future applications. From the gigantic-size horizontal axis wind turbine (HAW T) to small-size VAWT for home energy utility are offered by manufacturers to fulfill the alternative energy demand. Within this decade, due to the increasing wind energy demand, Taiwan's wind turbine industry is growing exponentially [1 ,2], and several VAWT companies also is founded to intend filling the niche market of small size wind turbine.

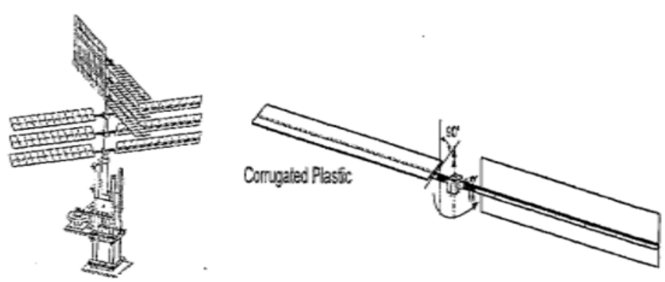
VAWT owns a great potential as an energy harvester since it is suitable in urban population city due to several considerations, such as an omni-directional wind turbine, rotating on low wind speed, unsteady wind conditions, low acoustic noise, and can be mounted on the building [3,4]. These reasons motivate the wind turbine companies to introduce their cutting edge of VA WT technologies such as innovative design, light-weight material, and intelligent control system to consumers. However, it needs verification and quality certified process to be conducted in a systematic wind turbine platform [5], before the new technology implements to the consumer. Therefore, a flexible experimental setup of test platform for a small size VAWT generator system is built to support for Taiwan VA WT development in this research. Note that the experimental platform designed here is flexible and suitable for executing the systematic performance evaluation on different types of VA WT in an automatic and 24-hour-operation manner.

In order to take advantage, the maximum wind energy from the height of building, this experimental platform is installed on the roof top of an approximate 60-m-height building. The wind turbine platform is designed with a swivel-motion experimental shaft system and an adjustable gear-chain system to accommodate the performance measurement for various wind turbine designs. The detailed specification of platform is listed in Table.1. Platform is equipped with data acquisition system for recording the meteorological properties (wind speed, wind direction, air temperature, atmospheric pressure) [3,6], and wind turbine operational properties (electric power output, torque, rotor speed). With the aids of the visual programming language Labview [7,8], all metrology data and turbine operational properties are recorded and analyzed automatically via using the statistic method.

The major objectives of this work are to build up a systematic procedure of data collecting and performance analysis in investigating different wind turbines' characteristics. Consequently, this study intends to support the VAWT's research and development via an integrated measurement platform to assess its actual aerodynamic performance, such as the generator power output and the power curve determination, in a systematic manner.

Descriptions of Vertical-Axis Wind Turbine and Test Platform

The measurement platform is located on the rooftop of a 15—story building. The platform consists of a wind turbine rotor, tower, and metrology tower. In this study, a 400-W, multi-blade, drag-type VAWT [9] is chosen as the wind turbine tester. This selection primarily results from this VAWT's economic advantages, such as low manufacturing cost and the ability to rotate at low wind speed condition. It possesses great economic potential to be manufactured easily and cheaply as a wind energy product for under-developed countries. As illustrated in Fig. 1, this VAWT consists of 6 sets of blades with crossed configuration. Each set of blades contains two identical blades installed oppositely with 90° difference from blade's axis. This 90° difference configuration causes the down-wind-direction blade faces the wind direction while the up-wind-direction blade lays along the wind direction for each level. When the wind turbine rotates around the vertical rotor-axis, blades will be pushed by drag force dominantly. Until a certain rotation angle where the blade set is aligned with the wind direction, an auto-flap mechanism will be occurredby a counter-balance force between these two blades. This mechanism may decrease the negative torque from the down-wind-direction blade.



(a) Wind turbine and test platform designs. (b)Blade system

Fig. 1 Multi-blade VAWT, experimental platform and blade set designs.

This VA WT is estimated to produce a 400 Watt rated power at 12 m/s, which is listed in Table 1. This 200-cm-radius blade is made of a corrugated plastic (35 cm x 190 cm with 5 mm thickness) and is strengthened with the square stainless-steel frame (2.5 cm x 2.5 cm) as the blade's axis. The total dimension of VAWT is 195 cm x 400 cm (height x diameter). Since the rated speed of this wind turbine is rather low, a sprocket-chain transmission system with a speed ratio is linked with an axial permanent magnet synchronous generator (PMSG) to produce electric power. A variable resistor bank is implemented as the loading system, in which the PMSG's electric output will go through, and thus to furnish this off-grid VAWT generator test system.

Table 1. Specifications of the experimental platform for the VAWT generator system.

Wind Turbine	Vertical axis wind turbine
Blade type	Multi-blade drag type
Blade number	12 blades
Blade profile	flat plate, 5-mm-thick corrugated plastic, strengthen with 2.5cm x 2.5cm square profile stainless steel.
Blade Dimension	length: 200 cm, chord length: 35 cm.
Height	215 cm
Rotor diameter	400 cm
Swept area	8.60 m2 (height x rotor diameter)
Rotational Speed	90 rpm (max)
Base	Concrete with 4 x M15 bolts
Tower	L-shape steel structure with a swivel shaft
Dimension	height = 2.15 m , shaft length = 1.3 m
Transmission sys.	Adjustable sprocket-chain system with
Generator	3φ 1.5 kW Axial PMSG
Sensor	Wind speed, wind direction, temperature, air pressure, rotation speed, electric power measurement device
Control System	Off-grid LabVIEW based DAQ system

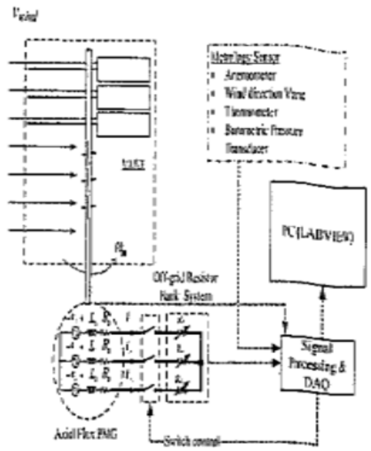


Fig. 2 The schematics of VAWT test platform.

In order to collect the meteorological properties properly, the anemometer, wind direction vane, barometric sensor, and temperature sensor were installed on the meteorological station at the same height as the wind turbine's hub (see Fig. 2). It was mounted at 7 meters away from the center of wind turbine. This distance is more than 2.5 times of the wind turbine's diameter in order to prevent the uncertain test result caused by wind turbine blade's turbulence. Also, it meets the terms stated in IEC 1400-21 wind turbine power quality measurement standard [10].

To develop a reliable data recording system, NI USB-6210 DAQ-card is selected as a PC-based data acquisition system. All the analog measuring signals will be converted into ± 5 VDC signal before entering the DAQ-card. Also, with the aids of a visual software programming, the real-time monitoring on the input/output parameters of generator and the climatic condition on the rooftop can be accomplished simultaneously. Consequently, the actual performance of the wind turbine generator system is attained easily in an automatic and systematic manner. Moreover, to ensure for providing sufficient data and its accuracy, statistic concept is enforced to judge whether the test data are qualified or not in the data-processing procedure.

Data processing and performance analysis

Using a visual programming constructed within the framework of software Labview, all collected ±5 VDC analog signals are converted into 16 bit digital signal for further calculation and analysis process. Then, records in each channel will be averaged statistically for every second to monitor the fluctuation of wind turbine's power measurement, and to save into a data bin for every 10 minutes. Several calculations are conducted to obtain the additional parameters.

In order to acquire a reliable and stable data during measurement, all test data will be recorded when the wind speed exceeds 4 m/s for preventing the unstable starting operation of wind turbine. This action is taken to diminish the fluctuating data caused by starting up condition. Note that axial axis wind turbine is operating under the start-up and low-acceleration condition for the wind speed ranging from 2 to 4 m/s. Also, incorporated with the variable load system, the control system utilizes a similar strategy such that the loading will be applied only for the wind speed higher than 4 m/s. By removing the loading system, this small wind turbine should rotate to pass the start-up and low-acceleration stage more quickly and easily. In addition, this approach may help the wind turbine sustaining its rotation speed and keep rotating during the low-wind-speed situation.

After the measurement data are stored in sequential data files, wind distribution graph, wind speed data filtering, statistical study of every wind speed data, and wind turbine performance chart are analyzed and conducted. By using WAsP software from RISØ National Laboratory, wind properties within a certain time interval is analyzed statistically using Weibull distribution, as plotted on Fig. 3. This figure graphed the wind direction and wind speed distribution which are recorded from March 2010 to October 2010.

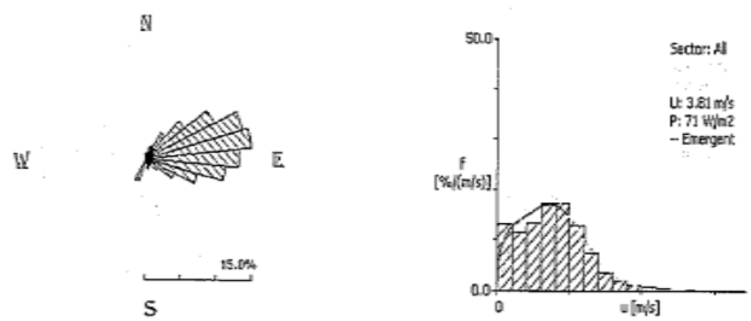


Fig. 3 The wind distribution at VAWT test platform.

Since controlling resistor bank in off-grid system may create the fluctuating results during the power measurement, so the filtering process and statistic analysis are introduced to attain the steady and reliable data. By proceeding in spreadsheet software, all experimental data will be separated and sorted according to the wind speed with I-m/s interval database. Every wind speed database includes wind speed, wind direction, barometric pressure, air temperature, rotational speed, generator outputs, and loading resistor. Thereafter, all data are averaged to find the mean value and standard deviation (σ) of each data distribution. By enforcing the 95% confidence level from approximately 2000 data points, the confidence interval is obtained within ±0.954, which is illustrated in Fig. 4. Figure 4 shows the distribution of rotation speed. It is found that rotational speed is 8.99 ± 0.954 rpm for a 6-m/s wind speed. Overall speaking, most of the data can be analyzed with the similar confidence criterion, except for the cases of 4~6 m/s wind speed. Since wind turbine is entering the cut-in speed at 4~6 m/s, the transition situation for adding loading on generator frequently make the rotational speed falling to near 0 rpm, as indicated in Fig. 5. Even this kind of influence will gradually reduce for wind speed higher than 6 m/s; it might cause unexpected result for the data distribution.

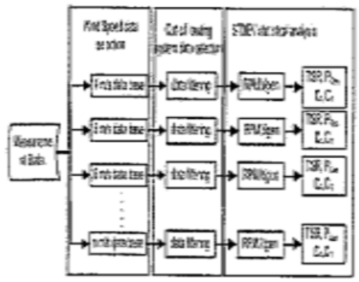


Fig. 4 Data processing and statistic analyses.

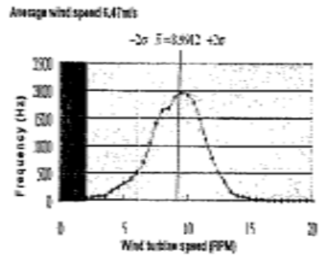
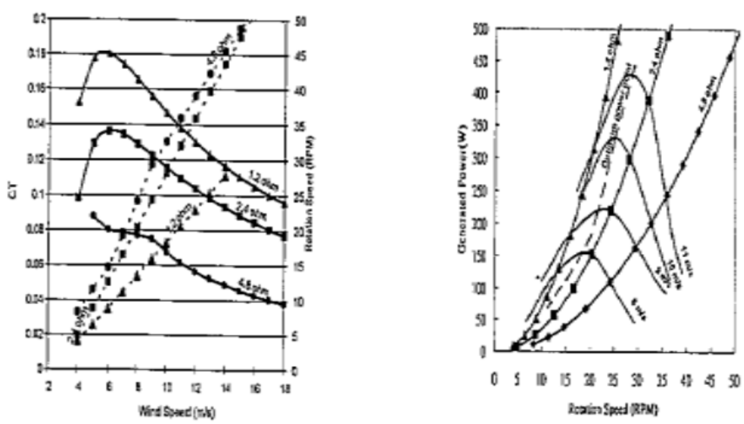


Fig. 5 Rotational speed distribution at wind speed 6 m/s.

After all data are analyzed, the aerodynamic characteristics of wind turbine are illustrated by plotting wind speed to rotational speed at various loading conditions, such as 1.2 ohm, 2.4 ohm and 4.8 ohm. These loading amounts represent low, medium and high loading conditions. Figure 6a shows the relationship between coefficients of torque distribution and rotation speed distribution at different wind speeds. The straight line symbolizes the torque coefficient at different wind speeds, while the dash line represents the relationship between rotational speed and wind speed.

By carefully observing the torque curve, it is found that wind turbine tends to have torque optimum at low wind speed, which is in accordance to the aerodynamic characteristics of drag type VA WT. Besides, the generated power of wind turbine is illustrated in Fig. 6b for different wind speeds and loadings. Clearly, the power characteristic curve of a wind turbine can be determined by connecting various loading condition at the same wind speed. With this systematic and lengthy process, the performance of VA WT can be determined in a rigorous manner. Consequently, these measurement data are considered as a reliable outcome after imposing the statistical analysis on the raw data.



(a) Torque coefficient (b) Generated power

Fig. 6 Experimental performance characteristics of the VAWT under various loadings and wind speeds.

Conclusions

A removable experiment platform for VAWT was conduct in this integrated numerical and experimental research. It is started with developing an adaptable platform which may conduct the performance evaluation for different VAWTs, Then, together with the data-acquisition software programmed under the framework of Labview; it can provide the capability for monitoring, recording, and filtering these test data in a real-time and systematic manner. This flexible and automatic test platform is appropriate for executing the R&D and the on-site performance evaluation on various VAWTs. Moreover, to ensure for providing sufficient data and its accuracy, statistic concept is enforced to judge whether the test data are qualified or not in the data-processing procedure. Consequently, the actual performance of the wind turbine generator system is attained conveniently in an automatic and rigor manner.

Acknowledgments

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