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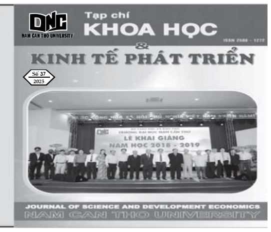


# Feasibility study and performance evaluation of quiet-revolution/GB wind turbines in urban lighting applications

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**ABSTRACT**

*Amidst escalating energy costs, the financial burden on municipal budgets for public lighting systems has become particularly heavy. This has propelled the need for the search and implementation of sustainable energy-saving solutions. In this study, we focused on the potential application of the Quiet-Revolution/GB (Gorlov) wind turbines as a promising solution for providing renewable energy to public lighting poles. Specifically, we designed and developed a lighting pole system with a 50W capacity, incorporating the Gorlov wind turbine, optimized for efficient operation even at low wind speeds. The turbine was designed with three blades, each with a twist angle of 64.1 degrees, a height of 1.5 m, and a radius of 0.5 m, aimed at achieving the highest efficiency. Through testing, we found that the turbine could operate on its own at wind speeds as low as 2.5 m/s, producing a 12V output and 50W power at wind speeds of 6 m/s and above, while maintaining a low noise level, highlighting the broad application potential of this solution in urban lighting. This study opens a new direction in the application of wind energy in public lighting systems, contributing to the reduction of energy costs and enhancing the sustainability of urban infrastructure.*

## 1. INTRODUCTION

Vietnam, a developing nation, is witnessing a robust growth in its transportation network to meet the demands of goods transportation and population mobility. This development not only requires improvements in road infrastructure but also a focus on public lighting systems, especially street lights, to ensure safety for night-time travel. However, the increasing demand for electricity poses a significant challenge, as power generation capacity has not kept pace, leading to shortages and a heavy burden of energy costs for local authorities.

In this context, the search for sustainable energy solutions, particularly the application of renewable energy sources such as solar and wind power, has become a priority. Projects involving the installation of wind turbines in Nha Trang, Phan Thiet, Kon Tum, Tra Vinh, and island districts like Truong Sa, Son Cha, Tran Island, and Phu Quy have demonstrated the significant potential of wind energy in providing electricity for daily life and public lighting.

On the other hand, many areas, including inter-provincial roads, rural regions, parks, and residential areas, still suffer from insufficient lighting at night due to budget constraints, leading to severe consequences for community life and safety. This highlights an urgent need to explore and implement effective and economical public lighting solutions that are suitable for socio-economic conditions.

For these reasons, this study focuses on the application of small-capacity wind turbines—a potential and cost-effective solution—for public lighting. Specifically, we investigate the use of Quiet-Revolution/GB (Gorlov) type wind turbines as a suitable option for Vietnam's wind conditions, aiming for sustainable development, cost reduction, and enhanced safety for the public.

## 2. RESEARCH METHODS

### 2.1 Proposed design parameters for the wind-powered lighting pole system

*2.1.1 Installation requirements for the wind-powered lighting pole system*

*- Wind speed:*

In the Mekong Delta, the predominant wind patterns include the Southwest Monsoon and the North-Northeast wind. From June to October, the Southwest Monsoon, originating from the Indian Ocean, brings an average wind speed of 3.6 m/s, intensifying in August to an average of 4.5 m/s. Conversely, the North-Northeast wind, blowing from the East Sea, prevails during the dry months from November to February, with an average wind speed of 2.4 m/s. Additionally, trade winds from the South-Southeast contribute from March to May, when the average wind speed reaches 3.7 m/s (Quiet Revolution, 2017).

*- Lighting requirements:*

According to current Vietnamese construction standards and regulations for public lighting poles, the following standards apply:

According to "Standards for Artificial lighting design for roads, Streets, Squares, and Urban areas" (TCXDVN 259:2001, Pp. 2-4), internal roads (where lighting poles are planned for installation) will have a lighting class of C (Ministry of Construction, 2001):

- Average luminance: $L_{av} \geq 0.4 - 0.6$ Cd/m$^2$
- Average illuminance: $E_{av} \geq 8 - 12$ Lx
- Total luminous flux must be 6,000 Lm or more (for diffuse light mushroom-shaped lamps), with a minimum mounting height of 3 – 4 m.

*- Lighting selection:*

The electricity supplied to the lighting poles comes from vertical-axis wind turbines, with a relatively limited power output. Therefore, we decided to select lamps with a power not exceeding 100W, suitable for the power generation capacity of small-sized vertical-axis wind turbines, which are often installed in areas with low and unstable wind speeds. Based on the analyzed luminous flux, luminance, and illuminance indices, we chose to use Dien Quang LED lamps, product code DQ LEDSL03 50765 (50 W Daylight), with a luminous flux of up to 6,000 Lm. This lamp type utilizes advanced SMD LED technology, which not only saves electricity but also provides uniform light and high luminous efficiency, thanks to quality LED chips imported from Korea and Japan. The lamp has a lifespan of up to 50,000 hours (equivalent to over 8 years), demonstrating its environmental friendliness and sustainability.

The lamp is installed at a height of 5 meters from the road surface, with the lamp arm extending 1.5 meters and tilted at a 15-degree angle, in accordance with standard (TCXDVN 295-2001), to ensure even and wide light coverage in the illuminated area.

**2.2 Design of the Twisted-blade vertical-axis wind turbine structure**

*2.2.1 Turbine design specifications*

The design of the Quiet-Revolution/GB twisted-blade wind turbine was developed for low-power applications, with specific technical requirements as follows:

Blade profile: Uses the NACA 2412 airfoil to optimize the lift and efficiency of the wind turbine.

Automatic start-up: The turbine is designed to self-start when wind speed reaches 2.5 m/s, ensuring quick response to changing wind conditions.

Output voltage: 12V, compatible with standard electrical systems for LED lights and other small devices. Power output: Reaches 50W, providing sufficient energy for lighting applications and small electrical devices.

Power storage system: Current from the dynamo is directly charged into the battery, which then powers the 12VDC LED light.

Wind direction independence: The design is independent of wind direction, allowing for stable performance under all conditions.

Turbine size: The turbine diameter does not exceed 1 meter, suitable for installation in areas with limited space.

Installation location: Planned for preliminary testing at Ho Chi Minh City University of Technology and Education, providing important data for research and development.

Operating ambient temperature: From 25°C to 40°C, ensuring the wind turbine can operate effectively within a wide temperature range.

Ambient humidity: 70% - 80%, reflecting common environmental conditions in Vietnam, especially the Mekong Delta region.

*2.2.2 Turbine blade profile design*

- *Design requirements:*
  - NACA 2412 blade profile;
  - Turbine diameter less than or equal to 1 m;
  - The wind turbine produces stable power at a wind speed of 6 m/s (the wind speed for stable turbine operation);
- *Calculation of turbine blade profile design:*

a) Determining blade parameters. From the initial selection data:

- Turbine power: PT = 50 W
- Wind speed: v = 6 m/s
- Preliminary turbine radius: R = 0.5 m
- Air density: $\rho = 1.225$ kg/m$^3$
- Power coefficient: Cp = 0.35
- Tip speed ratio: $\lambda = 3.5$
- Number of blades: n = 3
- Total blade twist angle: $\varphi = 120°$

From these, we can calculate:

- Turbine height: L = 1.08 m
- Turbine blade length: l = 1.5 m
- Twist angle of turbine blade:
  $\delta = 64.1^o$
- Chord length of turbine blade profile:
  c = 238.1 mm
- Thickness of turbine blade profile:
  t = 28.6 mm
- Maximum camber of blade:
  m = 4.8 mm
- Position of maximum camber:
  p = 95.2 mm

b) Calculation of NACA 2412 blade profile coordinates:

The parameters for the NACA 2412 blade profile are calculated as follows:

- Maximum camber on the blade:
  m = 2% x c = 0.02 x 238.1 = 4.8 (mm)
  (with chord length c = 238.1 mm).
- At the position of maximum camber:
  p = 40% x c = 0,4 x 238.1 = 95.2 mm
- Maximum thickness of the blade:
  t = 12% x c = 0,12 x 238.1 = 28.6 mm

The NACA 2412 blade profile includes parameters as shown in Figure 1.

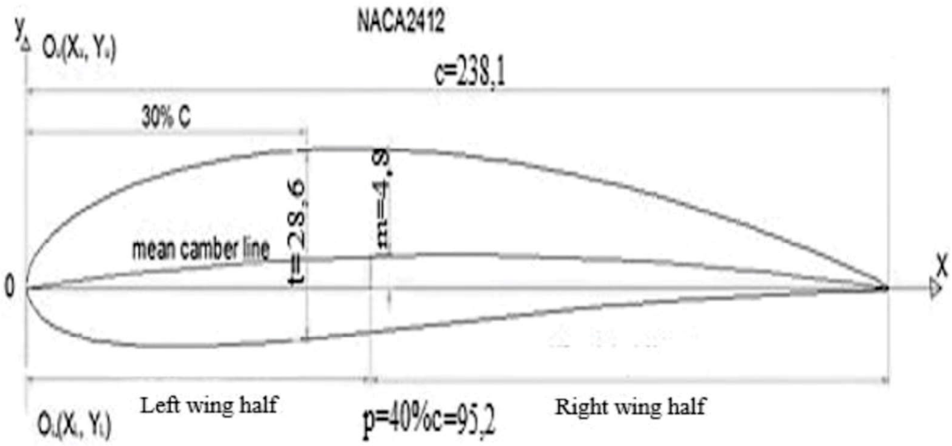



**Figure 1. Asymmetric NACA 2412 blade profile**

From the parameters m, p, and t, we can calculate the coordinates of the points on the blade profile.

From the existing equations for calculating blade profile coordinates, we use Microsoft Excel to find the desired parameters through the following calculation tables:

**Table 1. NACA 2412 blade profile coordinates - Left half**

| 25 đoạn | Xc | Yc | Xc/238,1 | (Xc/238,1)^2 | (Xc/238,1)^3 | (Xc/238,1)^4 | Yt | Xu | Yu | dYc/dx | Đêta | Sin(Đêta) | Cos(Đêta) | XL | YL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0,00 | 0,00 | 0,00 | 0E+00 | 0E+00 | 0,00 | 0 | 0,00 | 0,10 | 0,06 | 0,06 | 1,00 | 0 | 0,00 |
| 1 | 3,69 | 0,36 | 0,02 | 0,00 | 0E+00 | 0E+00 | 4,99 | 3,39 | 5,35 | 0,10 | 0,06 | 0,06 | 1,00 | 3,99 | -4,63 |
| 2 | 7,38 | 0,72 | 0,03 | 0,00 | 0E+00 | 0E+00 | 6,87 | 6,97 | 7,59 | 0,09 | 0,06 | 0,06 | 1,00 | 7,79 | -6,15 |
| 3 | 11,07 | 1,05 | 0,05 | 0,00 | 0E+00 | 0E+00 | 8,21 | 10,58 | 9,26 | 0,09 | 0,06 | 0,06 | 1,00 | 11,56 | -7,16 |
| 4 | 14,76 | 1,37 | 0,06 | 0,00 | 0E+00 | 0E+00 | 9,27 | 14,2 | 10,64 | 0,09 | 0,06 | 0,06 | 1,00 | 15,32 | -7,90 |
| 5 | 18,45 | 1,68 | 0,08 | 0,01 | 0E+00 | 0E+00 | 10,14 | 17,94 | 11,82 | 0,08 | 0,05 | 0,05 | 1,00 | 18,96 | -8,46 |
| 6 | 22,14 | 1,97 | 0,09 | 0,01 | 0E+00 | 0E+00 | 10,87 | 21,6 | 12,84 | 0,08 | 0,05 | 0,05 | 1,00 | 22,68 | -8,90 |
| 7 | 25,83 | 2,25 | 0,11 | 0,01 | 0E+00 | 0E+00 | 11,49 | 25,37 | 13,74 | 0,07 | 0,04 | 0,04 | 1,00 | 26,29 | -9,24 |
| 8 | 29,52 | 2,52 | 0,12 | 0,02 | 0E+00 | 0E+00 | 12,02 | 29,04 | 14,54 | 0,07 | 0,04 | 0,04 | 1,00 | 30 | -9,50 |
| 9 | 33,21 | 2,76 | 0,14 | 0,02 | 0E+00 | 0E+00 | 12,47 | 32,71 | 15,23 | 0,07 | 0,04 | 0,04 | 1,00 | 33,71 | -9,71 |
| 10 | 36,90 | 3,00 | 0,15 | 0,02 | 0E+00 | 0E+00 | 12,86 | 36,39 | 15,86 | 0,06 | 0,04 | 0,04 | 1,00 | 37,41 | -9,86 |
| 11 | 40,59 | 3,22 | 0,17 | 0,03 | 0E+00 | 0E+00 | 13,19 | 40,06 | 16,41 | 0,06 | 0,04 | 0,04 | 1,00 | 41,12 | -9,97 |
| 12 | 44,28 | 3,43 | 0,19 | 0,03 | 1E-02 | 0E+00 | 13,46 | 43,88 | 16,89 | 0,05 | 0,03 | 0,03 | 1,00 | 44,68 | -10,03 |
| 13 | 47,97 | 3,62 | 0,20 | 0,04 | 1E-02 | 0E+00 | 13,69 | 47,56 | 17,31 | 0,05 | 0,03 | 0,03 | 1,00 | 48,38 | -10,07 |
| 14 | 51,66 | 3,80 | 0,22 | 0,05 | 1E-02 | 0E+00 | 13,88 | 51,24 | 17,68 | 0,05 | 0,03 | 0,03 | 1,00 | 52,08 | -10,08 |
| 15 | 55,35 | 3,96 | 0,23 | 0,05 | 1E-02 | 0E+00 | 14,03 | 54,93 | 17,99 | 0,04 | 0,03 | 0,03 | 1,00 | 55,77 | -10,07 |
| 16 | 59,04 | 4,11 | 0,25 | 0,06 | 2E-02 | 0E+00 | 14,15 | 58,62 | 18,26 | 0,04 | 0,03 | 0,03 | 1,00 | 59,46 | -10,04 |
| 17 | 62,73 | 4,24 | 0,26 | 0,07 | 2E-02 | 0E+00 | 14,23 | 62,45 | 18,47 | 0,03 | 0,02 | 0,02 | 1,00 | 63,01 | -9,99 |
| 18 | 66,42 | 4,36 | 0,28 | 0,08 | 2E-02 | 1E-02 | 14,28 | 66,13 | 18,64 | 0,03 | 0,02 | 0,02 | 1,00 | 66,71 | -9,92 |
| 19 | 70,11 | 4,47 | 0,29 | 0,09 | 3E-02 | 1E-02 | 14,30 | 69,82 | 18,77 | 0,03 | 0,02 | 0,02 | 1,00 | 70,4 | -9,83 |
| 20 | 73,80 | 4,56 | 0,31 | 0,10 | 3E-02 | 1E-02 | 14,30 | 73,66 | 18,86 | 0,02 | 0,01 | 0,01 | 1,00 | 73,94 | -9,74 |
| 21 | 77,49 | 4,63 | 0,33 | 0,11 | 3E-02 | 1E-02 | 14,27 | 77,35 | 18,90 | 0,02 | 0,01 | 0,01 | 1,00 | 77,63 | -9,64 |
| 22 | 81,18 | 4,70 | 0,34 | 0,12 | 4E-02 | 1E-02 | 14,22 | 81,04 | 18,92 | 0,01 | 0,01 | 0,01 | 1,00 | 81,32 | -9,52 |
| 23 | 84,87 | 4,74 | 0,36 | 0,13 | 5E-02 | 2E-02 | 14,14 | 84,73 | 18,88 | 0,01 | 0,01 | 0,01 | 1,00 | 85,01 | -9,40 |
| 24 | 88,56 | 4,78 | 0,37 | 0,14 | 5E-02 | 2E-02 | 14,05 | 88,42 | 18,83 | 0,01 | 0,01 | 0,01 | 1,00 | 88,7 | -9,27 |
| 25 | 92,25 | 4,80 | 0,39 | 0,15 | 6E-02 | 2E-02 | 13,94 | 92,25 | 18,74 | 0,00 | 0,00 | 0,00 | 1,00 | 92,25 | -9,14 |
| 26 | 95,20 | 4,80 | 0,40 | 0,16 | 6E-02 | 3E-02 | 13,83 | 95,2 | 18,63 | 0,00 | 0,00 | 0,00 | 1,00 | 95,2 | -9,03 |

**Table 2. NACA 2412 blade profile coordinates - Right half**

| 40 đoạn | Xc | Yc | Xc/238,1 | (Xc/238,1)^2 | (Xc/238,1)^3 | (Xc/238,1)^4 | Yt | Xu | Yu | dYc/dx | Bêta | Sin(Bêta) | Cos(Bêta) | XL | YL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 95,20 | 4,80 | 0,40 | 0,16 | 6E-02 | 3E-02 | 13,83 | 95,2 | 18,63 | 0,00 | 0,00 | 0,00 | 1,00 | 95,2 | -9,03 |
| 2 | 98,80 | 4,79 | 0,41 | 0,17 | 7E-02 | 3E-02 | 13,69 | 98,8 | 18,48 | 0,00 | 0,00 | 0,00 | 1,00 | 98,8 | -8,90 |
| 3 | 102,40 | 4,77 | 0,43 | 0,18 | 8E-02 | 3E-02 | 13,53 | 102,54 | 18,30 | -0,01 | -0,01 | -0,01 | 1,00 | 102,26 | -8,76 |
| 4 | 106,00 | 4,74 | 0,45 | 0,20 | 9E-02 | 4E-02 | 13,36 | 106,13 | 18,10 | -0,01 | -0,01 | -0,01 | 1,00 | 105,87 | -8,62 |
| 5 | 109,60 | 4,69 | 0,46 | 0,21 | 1E-01 | 4E-02 | 13,17 | 109,73 | 17,86 | -0,02 | -0,01 | -0,01 | 1,00 | 109,47 | -8,48 |
| 6 | 113,20 | 4,62 | 0,48 | 0,23 | 1E-01 | 5E-02 | 12,97 | 113,33 | 17,59 | -0,02 | -0,01 | -0,01 | 1,00 | 113,07 | -8,35 |
| 7 | 116,80 | 4,55 | 0,49 | 0,24 | 1E-01 | 6E-02 | 12,76 | 116,93 | 17,31 | -0,02 | -0,01 | -0,01 | 1,00 | 116,67 | -8,21 |
| 8 | 120,40 | 4,46 | 0,51 | 0,26 | 1E-01 | 7E-02 | 12,53 | 120,65 | 16,99 | -0,03 | -0,02 | -0,02 | 1,00 | 120,15 | -8,07 |
| 9 | 124,00 | 4,35 | 0,52 | 0,27 | 1E-01 | 7E-02 | 12,29 | 124,25 | 16,64 | -0,03 | -0,02 | -0,02 | 1,00 | 123,75 | -7,94 |
| 10 | 127,60 | 4,23 | 0,54 | 0,29 | 2E-01 | 8E-02 | 12,04 | 127,96 | 16,27 | -0,04 | -0,03 | -0,03 | 1,00 | 127,24 | -7,81 |
| 11 | 131,20 | 4,10 | 0,55 | 0,30 | 2E-01 | 9E-02 | 11,79 | 131,55 | 15,89 | -0,04 | -0,03 | -0,03 | 1,00 | 130,85 | -7,69 |
| 12 | 134,80 | 3,95 | 0,57 | 0,32 | 2E-01 | 1E-01 | 11,52 | 135,15 | 15,47 | -0,04 | -0,03 | -0,03 | 1,00 | 134,45 | -7,57 |
| 13 | 138,40 | 3,79 | 0,58 | 0,34 | 2E-01 | 1E-01 | 11,24 | 138,74 | 15,03 | -0,05 | -0,03 | -0,03 | 1,00 | 138,06 | -7,45 |
| 14 | 142,00 | 3,62 | 0,60 | 0,36 | 2E-01 | 1E-01 | 10,95 | 142,33 | 14,57 | -0,05 | -0,03 | -0,03 | 1,00 | 141,67 | -7,33 |
| 15 | 145,60 | 3,43 | 0,61 | 0,37 | 2E-01 | 1E-01 | 10,65 | 145,92 | 14,08 | -0,05 | -0,03 | -0,03 | 1,00 | 145,28 | -7,22 |
| 16 | 149,20 | 3,22 | 0,63 | 0,39 | 3E-01 | 2E-01 | 10,34 | 149,61 | 13,56 | -0,06 | -0,04 | -0,04 | 1,00 | 148,79 | -7,12 |
| 17 | 152,80 | 3,01 | 0,64 | 0,41 | 3E-01 | 2E-01 | 10,03 | 153,2 | 13,04 | -0,06 | -0,04 | -0,04 | 1,00 | 152,4 | -7,02 |
| 18 | 156,40 | 2,77 | 0,66 | 0,43 | 3E-01 | 2E-01 | 9,70 | 156,79 | 12,47 | -0,07 | -0,04 | -0,04 | 1,00 | 156,01 | -6,93 |
| 19 | 160,00 | 2,53 | 0,67 | 0,45 | 3E-01 | 2E-01 | 9,37 | 160,37 | 11,90 | -0,07 | -0,04 | -0,04 | 1,00 | 159,63 | -6,84 |
| 20 | 163,60 | 2,27 | 0,69 | 0,47 | 3E-01 | 2E-01 | 9,03 | 163,96 | 11,30 | -0,07 | -0,04 | -0,04 | 1,00 | 163,24 | -6,76 |
| 21 | 167,20 | 2,00 | 0,70 | 0,49 | 4E-01 | 2E-01 | 8,68 | 167,63 | 10,68 | -0,08 | -0,05 | -0,05 | 1,00 | 166,77 | -6,68 |
| 22 | 170,80 | 1,71 | 0,72 | 0,51 | 4E-01 | 3E-01 | 8,33 | 171,22 | 10,04 | -0,08 | -0,05 | -0,05 | 1,00 | 170,38 | -6,62 |
| 23 | 174,40 | 1,41 | 0,73 | 0,54 | 4E-01 | 3E-01 | 7,96 | 174,88 | 9,37 | -0,09 | -0,06 | -0,06 | 1,00 | 173,92 | -6,55 |
| 24 | 178,00 | 1,09 | 0,75 | 0,56 | 4E-01 | 3E-01 | 7,59 | 178,46 | 8,68 | -0,09 | -0,06 | -0,06 | 1,00 | 177,54 | -6,50 |
| 25 | 181,60 | 0,76 | 0,76 | 0,58 | 4E-01 | 3E-01 | 7,21 | 182,03 | 7,97 | -0,09 | -0,06 | -0,06 | 1,00 | 181,17 | -6,45 |
| 26 | 185,20 | 0,42 | 0,78 | 0,61 | 5E-01 | 4E-01 | 6,83 | 185,61 | 7,25 | -0,10 | -0,06 | -0,06 | 1,00 | 184,79 | -6,41 |
| 27 | 188,80 | 0,06 | 0,79 | 0,63 | 5E-01 | 4E-01 | 6,44 | 189,19 | 6,50 | -0,10 | -0,06 | -0,06 | 1,00 | 188,41 | -6,38 |
| 28 | 192,40 | -0,31 | 0,81 | 0,65 | 5E-01 | 4E-01 | 6,04 | 192,82 | 5,73 | -0,11 | -0,07 | -0,07 | 1,00 | 191,98 | -6,35 |
| 29 | 196,00 | -0,70 | 0,82 | 0,68 | 6E-01 | 5E-01 | 5,63 | 196,39 | 4,93 | -0,11 | -0,07 | -0,07 | 1,00 | 195,61 | -6,33 |
| 30 | 199,60 | -1,10 | 0,84 | 0,70 | 6E-01 | 5E-01 | 5,22 | 199,97 | 4,12 | -0,11 | -0,07 | -0,07 | 1,00 | 199,23 | -6,32 |
| 31 | 203,20 | -1,51 | 0,85 | 0,73 | 6E-01 | 5E-01 | 4,80 | 203,58 | 3,29 | -0,12 | -0,08 | -0,08 | 1,00 | 202,82 | -6,31 |
| 32 | 206,80 | -1,94 | 0,87 | 0,75 | 7E-01 | 6E-01 | 4,37 | 207,15 | 2,43 | -0,12 | -0,08 | -0,08 | 1,00 | 206,45 | -6,31 |
| 33 | 210,40 | -2,38 | 0,88 | 0,78 | 7E-01 | 6E-01 | 3,93 | 210,71 | 1,55 | -0,12 | -0,08 | -0,08 | 1,00 | 210,09 | -6,31 |
| 34 | 214,00 | -2,83 | 0,90 | 0,81 | 7E-01 | 7E-01 | 3,49 | 214,28 | 0,66 | -0,13 | -0,08 | -0,08 | 1,00 | 213,72 | -6,32 |
| 35 | 217,60 | -3,30 | 0,91 | 0,84 | 8E-01 | 7E-01 | 3,03 | 217,84 | -0,27 | -0,13 | -0,08 | -0,08 | 1,00 | 217,36 | -6,33 |
| 36 | 221,20 | -3,79 | 0,93 | 0,86 | 8E-01 | 7E-01 | 2,57 | 221,43 | -1,22 | -0,14 | -0,09 | -0,09 | 1,00 | 220,97 | -6,36 |
| 37 | 224,80 | -4,29 | 0,94 | 0,89 | 8E-01 | 8E-01 | 2,11 | 224,99 | -2,18 | -0,14 | -0,09 | -0,09 | 1,00 | 224,61 | -6,40 |
| 38 | 228,40 | -4,80 | 0,96 | 0,92 | 9E-01 | 9E-01 | 1,63 | 228,55 | -3,17 | -0,14 | -0,09 | -0,09 | 1,00 | 228,25 | -6,43 |
| 39 | 232,00 | -5,32 | 0,97 | 0,95 | 9E-01 | 9E-01 | 1,14 | 232,1 | -4,18 | -0,15 | -0,09 | -0,09 | 1,00 | 231,9 | -6,46 |
| 40 | 235,60 | -5,86 | 0,99 | 0,98 | 1E+00 | 1E+00 | 0,65 | 235,66 | -5,21 | -0,15 | -0,09 | -0,09 | 1,00 | 235,54 | -6,51 |
| 41 | 238,10 | -6,25 | 1,00 | 1,00 | 1E+00 | 1E+00 | 0,30 | 238,13 | -5,95 | -0,15 | -0,09 | -0,09 | 1,00 | 238,07 | -6,55 |

From the coordinates in Table 1 & 2, the actual NACA 2412 blade profile coordinates can be plotted in Excel.

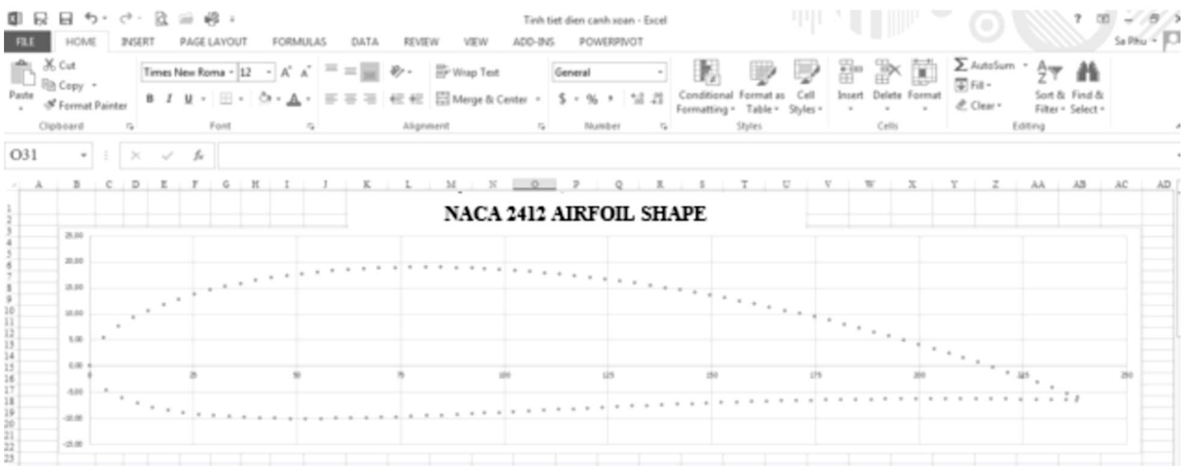



**Figure 2. NACA 2412 blade profile plotted in Excel**

The NACA 2412 blade profile was also drawn using SolidWorks software.

*2.2.3 Design of the Quiet – Revolution wind turbine structure*

*- Design requirements:*

- The turbine must be vertical-axis, 3-bladed, and rigid;

- Lightweight materials should be used in the turbine design.

- The turbine should operate stably without vibration and with low noise.

*- Turbine structure design:*

The turbine was designed using Solidworks 2016 software and its operation was simulated with ANSYS 15. Figure 3 presents the overall structure of the turbine in SolidWorks software.

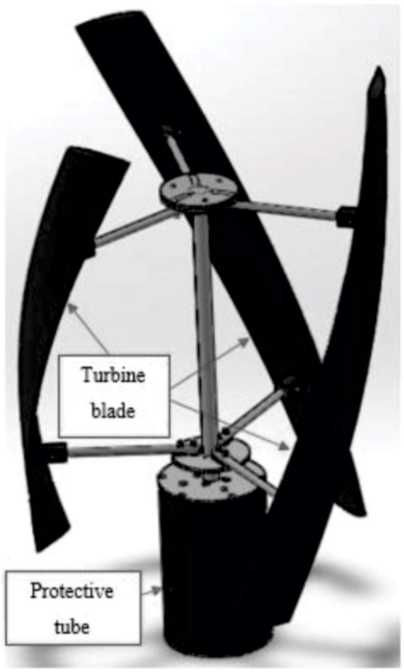
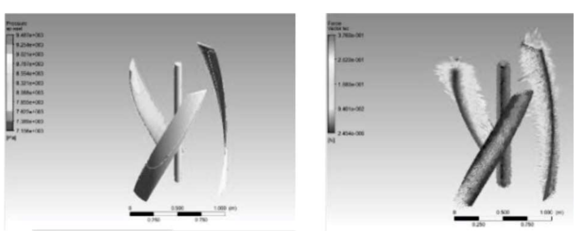



**Figure 3. Overall turbine model designed with SolidWorks 2016**

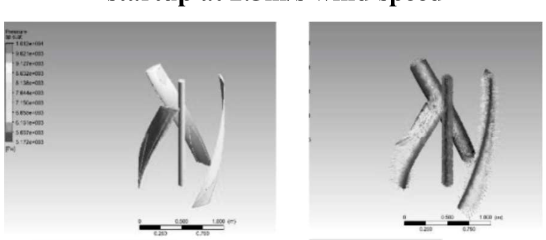
- *Simulation of pressure and force acting on turbine blades:*

From the 3D model built using SolidWorks 2016, meshing and simulation were performed with ANSYS 15 (Fluent). The simulation results for pressure distribution on the blades and force distribution on the blades are presented in Figures 4, 5, 6, and 7.



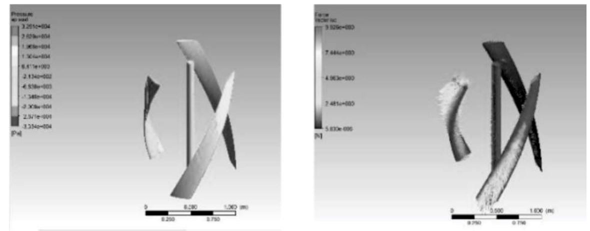
*a) Pressure Distribution* *b) Force Distribution*

**Figure 4. Pressure and force on blades at startup at 2.5m/s wind speed**



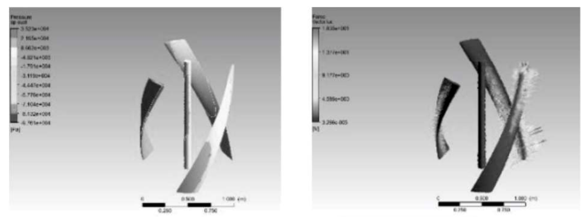
*a) Pressure distribution* *b) Force distribution*

**Figure 5. Pressure and force on blades at startup at 4.5 m/s wind speed**



*a) Pressure distribution* *b) Force distribution*

**Figure 6. Pressure and force on blades at startup at 6.5 m/s wind speed**



*a) Pressure distribution* *b) Force distribution*

**Figure 7. Pressure and force on blades at startup at 15.0 m/s wind speed**

As wind speed increases, the pressure and air force acting on the blades increase, and the rotation speed becomes faster, thus generating more electricity. Specifically, the maximum pressure and force values are shown in Table 3.

**Table 3. Simulation results**

| Wind speed (m/s) | 2.5 | 4.5 | 6.5 | 15.0 |
|---|---|---|---|---|
| Max pressure on blade (Pa) | 9.487 $x10^3$ | 1.012 $x10^4$ | 3.291 $x10^4$ | 3.523 $x10^4$ |
| Max force on blade (N) | 3.760 | 9.160 | 9.926 | 18.350 |

Conclusion:

- A suitable structure for the Quiet-Revolution wind turbine with 50W, 12VDC power has been selected.

- Simulation results using ANSYS 15 software show that the turbine structure is sufficiently durable and operates safely even at a wind speed of 15.0 m/s.

*2.2.4 Electrical system design*

- *General requirements for the wind turbine electrical system:*

- The battery system should be chosen to sufficiently power a 50W lamp for 6 hours;

- A charge control circuit is needed to manage the charging and discharging process;

- There should be a display screen showing the voltage, current, and power generated.

- *Calculation of energy storage capacity:*

a) Power consumption for a 50W lamp for 6 hours:

The power consumption of a 50W lamp is determined as follows:

$Q_{6h} = 50 \times 6 = 300$ (Wh)

b) Battery system capacity for energy storage:

The battery capacity for energy storage in the system is the amount of battery sufficient to continuously power a 50W lamp for 6 hours.

Battery capacity:

$$\frac{E_{out}.D}{V.\eta_b.DOD} = \frac{300\times1}{12\times0{,}95\times0{,}7} = 37{,}6 \text{ Ah}$$

Therefore, we chose a 40 Ah battery system for lamp energy storage.

c) Selecting the energy storage battery System:

In the field of energy storage, LiFePo4 batteries are currently the most popular choice of lithium battery due to their outstanding advantages, including: reduced risk of fire and explosion, significant lifespan of over 1,000 charge and discharge cycles, along with sustainable quality. Notably, LiFePo4 batteries have been applied to the Quiet-Revolution wind turbine's energy storage system. Each LiFePo4 battery cell has a nominal voltage of 3.2 V, maintaining this stable voltage throughout the discharge process until the energy is depleted, eliminating the need for a voltage regulation circuit. Therefore, a system integrating 4 LiFePo4 battery cells will provide a nominal voltage of 12.8 V, effectively serving the system's power needs.

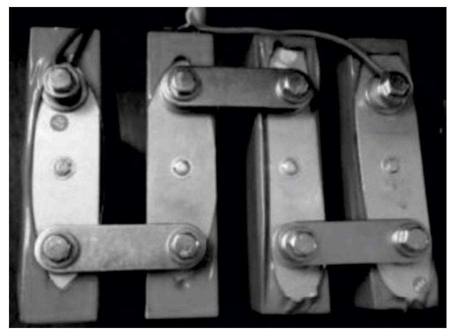


**Figure 8. Wiring diagram of 4 LiFePo4 battery cells**

- *Selecting a charge controller for the energy storage battery system:*

The charge controller is a device that regulates charging for the battery system, protecting it from overcharging and excessive discharge to extend its lifespan. Additionally, the charge controller indicates the charging status from the dynamo to the battery system and helps users control loads. We chose the Hybrid Controller MPPT 300W – auto 12/24V.

**Figure 9. Wind hybrid controller MPPT 300W**

**2.3 Fabrication – Testing**

*2.3.1 Fabrication of the Quiet – Revolution wind turbine*

*- Fabrication of the Quiet – Revolution wind turbine:*

Based on theoretical research, operating principles, suitable mechanisms, and necessary calculations for the turbine's mechanical system, the author designed a model of the small-scale Quiet-Revolution/GB (Gorlov) wind turbine as shown in Figure 10. This model illustrates the entire wind turbine system.

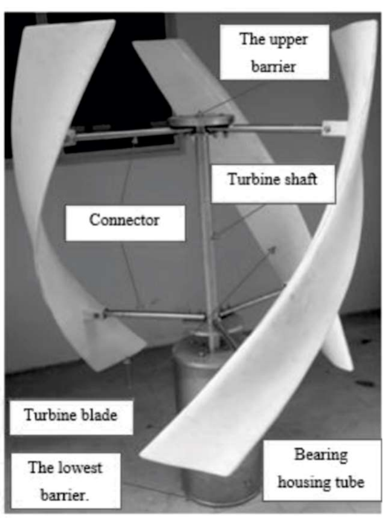
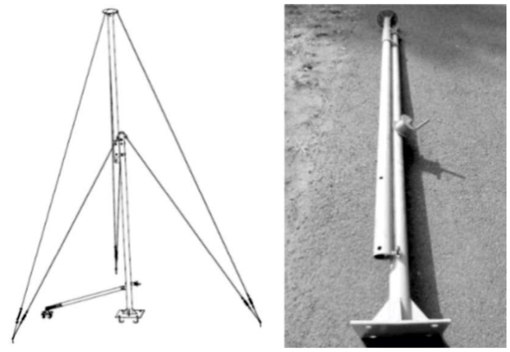



**Figure 10. Model of the Small-Scale quiet-revolution/GB wind turbine**

*- Design of public lighting pole system using wind power:*

Technical specifications: Pole height: 5 m; Pole diameter: Ø114 mm.



*a) Design* *b) Fabrication*

**Figure 11. Lighting pole with wind turbine**

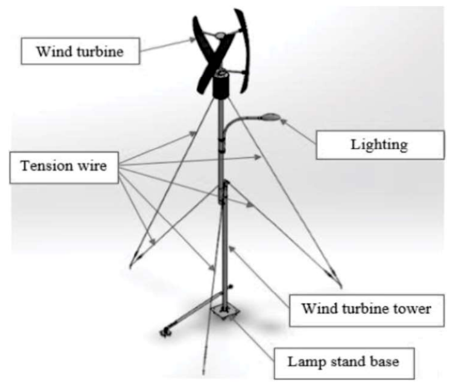



**Figure 12. Preliminary design of public lighting pole**

*2.3.2 Preliminary testing of the Twisted-Blade vertical-axis wind turbine*

*- Evaluation of the Wind Turbine's mechanical structure through testing:*

Manual turbine rotation test: To check the alignment between the shaft and bearings, the turbine was manually rotated to assess whether the assembled joints were machined coaxially as designed. The results showed that the turbine rotated smoothly, with no signs of misalignment or obstruction.

Operational test under wind impact: The turbine was tested under varying wind pressure, with wind speed gradually increased from 1 m/s to 11 m/s, to record and evaluate the turbine's operational parameters:

The turbine began operating when the wind reached a speed of 2.5 m/s, consistent with the designed start-up parameter.

No vibrations were detected during operation, and the turbine stand remained stable, indicating that the turbine was well-balanced.

The turbine operated with low noise, demonstrating the effective reduction of noise impact during operation.

Conclusion: The wind turbine met the requirements for mechanical structure and rigidity as designed, proving its stable and efficient operational capability.

*3.2.2 Results of No-Load turbine operation test*

Connecting the dynamo's wires to the measuring instruments (voltage meter, ammeter, power meter) to measure and update the parameters into Table 4.

**Table 4. No-Load operational parameters**

| Test No. | Wind Speed (km/h) | Wind Speed (m/s) | Rotational Speed (rpm) | Voltage (V) |
|---|---|---|---|---|
| 1 | 4.0 | 1.1 | 0.0 | 0.00 |
| 2 | 5.0 | 1.4 | 0.0 | 0.00 |
| 3 | 5.4 | 1.5 | 0.0 | 0.00 |
| 4 | 6.5 | 1.8 | 0.0 | 0.00 |
| 5 | 7.6 | 2.1 | 0.0 | 0.00 |
| 6 | 8.3 | 2.3 | 14.0 | 3.95 |
| 7 | 9.0 | 2.5 | 24.0 | 4.31 |
| 8 | 10.1 | 2.8 | 31.0 | 4.35 |
| 9 | 11.2 | 3.1 | 47.0 | 4.44 |
| 10 | 11.9 | 3.3 | 55.0 | 4.53 |
| 11 | 12.6 | 3.5 | 67.0 | 4.83 |
| 12 | 13.7 | 3.8 | 79.0 | 5.19 |
| 13 | 14.4 | 4.0 | 89.0 | 5.80 |
| 14 | 15.1 | 4.2 | 98.0 | 6.23 |
| 15 | 15.8 | 4.4 | 109.0 | 6.94 |
| 16 | 17.3 | 4.8 | 120.0 | 7.72 |
| 17 | 18.4 | 5.1 | 130.0 | 8.44 |
| 18 | 19.1 | 5.3 | 144.0 | 9.48 |
| 19 | 19.8 | 5.5 | 153.0 | 10.13 |
| 20 | 20.9 | 5.8 | 164.0 | 10.94 |
| 21 | 21.6 | 6.0 | 177.0 | 11.88 |
| 22 | 22.3 | 6.2 | 188.0 | 12.71 |
| 23 | 23.4 | 6.5 | 199.0 | 13.53 |
| 24 | 24.5 | 6.8 | 210.0 | 14.34 |
| 25 | 25.6 | 7.1 | 221.0 | 15.20 |
| 26 | 26.3 | 7.3 | 230.0 | 15.74 |
| 27 | 27.0 | 7.5 | 243.0 | 16.78 |
| 28 | 27.7 | 7.7 | 253.0 | 17.49 |
| 29 | 28.8 | 8.0 | 265.0 | 18.36 |
| 30 | 29.5 | 8.2 | 275.0 | 19.13 |
| 31 | 30.6 | 8.5 | 287.0 | 19.93 |
| 32 | 31.7 | 8.8 | 296.0 | 20.64 |
| 33 | 32.8 | 9.1 | 309.0 | 21.63 |
| 34 | 33.5 | 9.3 | 318.0 | 22.24 |
| 35 | 34.6 | 9.6 | 332.0 | 23.27 |
| 36 | 35.3 | 9.8 | 339.0 | 23.76 |
| 37 | 36.4 | 10.1 | 353.0 | 24.87 |
| 38 | 37.1 | 10.3 | 361.0 | 25.43 |
| 39 | 37.8 | 10.5 | 373.0 | 26.31 |
| 40 | 38.9 | 10.8 | 381.0 | 26.87 |

From Table 4, we can plot a graph showing the relationship between wind speed, dynamo rotational speed, and output voltage as follows:

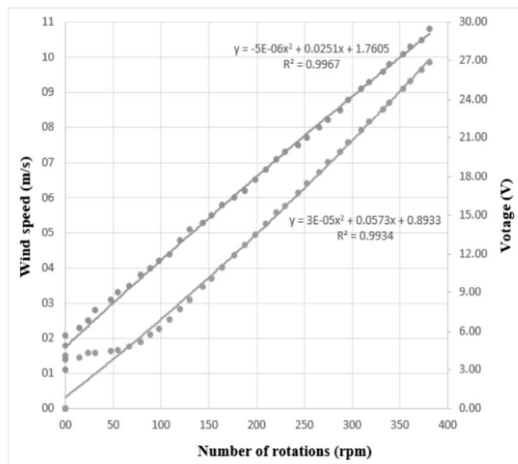



**Figure 13. Relationship between wind speed, rotational speed, and voltage**

Remarks:

- From the graph showing the relationship between wind speed, dynamo rotational speed, and output voltage in Figure 13, it can be observed that the turbine's rotational speed and output voltage are quite linear with wind speed; meaning, as wind speed increases, the turbine rotates faster, and the output voltage increases.

- When the wind speed reaches 6 m/s, the turbine rotates at 177 rpm, and the dynamo generates approximately 12V.

Conclusion:

- At no-load, the turbine operates to provide sufficient output voltage to charge a 12V battery system.

- *Results of turbine operation test under load:*

The MPPT charge controller was added to the turbine's electrical circuit and connected to the measuring instruments to display operational parameters such as charging voltage, charging current, and charging power during operation. Then, the MPPT charge controller was connected to the battery system to charge the 12V battery, and simultaneously, the battery system was connected to the lighting lamp (operational load).

The wind fan was then used to blow wind onto the turbine, with wind speed gradually increased from 1 m/s to 11 m/s, to test and record the operational parameters under load. These measured parameters were updated in Table 5. Since the axial flow fan did not rotate uniformly, the generated wind speed was also unstable; therefore, when recording wind speed parameters, the average value over 2 minutes was taken.

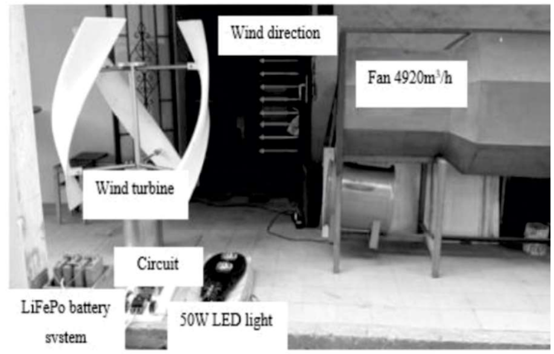



**Figure 14. Wind power generator experiment setup**

a) Relationship between wind speed and dynamo (turbine) rotational speed:

**Table 5. Operational parameters under load**

| Test no. | Wind Speed (km/h) | Wind Speed (m/s) | Rotational Speed (rpm) | Voltage (V) | Current (A) | Power (W) |
|---|---|---|---|---|---|---|
| 1 | 3.6 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 4.7 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 5.4 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 6.1 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | 7.6 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | 7.9 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | 9.0 | 2.5 | 12.0 | 12.1 | 0.0 | 0.0 |
| 8 | 9.7 | 2.7 | 22.0 | 12.1 | 0.0 | 0.0 |
| 9 | 11.2 | 3.1 | 34.0 | 12.1 | 0.0 | 0.0 |
| 10 | 12.2 | 3.4 | 46.0 | 12.1 | 0.0 | 0.0 |
| 11 | 12.6 | 3.5 | 53.0 | 121 | 0.0 | 0.0 |
| 12 | 13.7 | 3.8 | 65.0 | 12.1 | 0.0 | 0.0 |
| 13 | 14.8 | 4.1 | 78.0 | 12.1 | 0.4 | 4.3 |
| 14 | 15.5 | 4.3 | 89.0 | 12.1 | 0.3 | 3.0 |
| 15 | 16.2 | 4.5 | 99.0 | 12.1 | 0.5 | 6.1 |
| 16 | 17.3 | 4.8 | 111.0 | 12.1 | 0.4 | 4.3 |
| 17 | 17.6 | 4.9 | 121.0 | 12.1 | 0.6 | 6.7 |
| 18 | 19.1 | 5.3 | 132.0 | 12.1 | 0.8 | 9.1 |
| 19 | 20.2 | 5.6 | 143.0 | 12.2 | 0.9 | 10.5 |
| 20 | 20.9 | 5.8 | 154.0 | 12.3 | 1.2 | 15.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 21 | 21.6 | 6.0 | 165.0 | 12.3 | 1.5 | 18.3 |
| 22 | 22.7 | 6.3 | 176.0 | 12.4 | 1.9 | 23.4 |
| 23 | 23.4 | 6.5 | 187.0 | 12.5 | 2.2 | 27.0 |
| 24 | 24.5 | 6.8 | 198.0 | 12.5 | 2.4 | 30.1 |
| 25 | 25.6 | 7.1 | 209.0 | 12.6 | 2.7 | 34.5 |
| 26 | 25.9 | 7.2 | 220.0 | 12.6 | 3.0 | 37.3 |
| 27 | 27.0 | 7.5 | 231.0 | 12.7 | 3.2 | 41.1 |
| 28 | 27.4 | 7.6 | 242.0 | 12.7 | 3.6 | 45.4 |
| 29 | 28.4 | 7.9 | 253.0 | 12.8 | 3.9 | 49.8 |
| 30 | 29.2 | 8.1 | 264.0 | 12.8 | 4.1 | 53.1 |
| 31 | 30.6 | 8.5 | 275.0 | 12.9 | 4.5 | 58.4 |
| 32 | 31.3 | 8.7 | 286.0 | 12.9 | 4.8 | 62.6 |
| 33 | 32.4 | 9.0 | 297.0 | 13.0 | 5.1 | 66.5 |
| 34 | 33.5 | 9.3 | 308.0 | 13.0 | 5.5 | 72.3 |
| 35 | 34.6 | 9.6 | 319.0 | 13.1 | 5.8 | 76.2 |
| 36 | 35.3 | 9.8 | 331.0 | 13.2 | 6.2 | 81.7 |
| 37 | 36.4 | 10.1 | 341.0 | 13.3 | 6.6 | 86.9 |
| 38 | 37.1 | 10.3 | 352.0 | 13.3 | 6.8 | 90.8 |
| 39 | 38.2 | 10.6 | 363.0 | 13.4 | 7.1 | 95.2 |
| 40 | 39.2 | 10.9 | 374.0 | 13.4 | 7.3 | 97.5 |

From Table 5, we can plot a graph showing the relationship between the dynamo's rotational speed (which is also the turbine's rotational speed) and wind speed as follows:

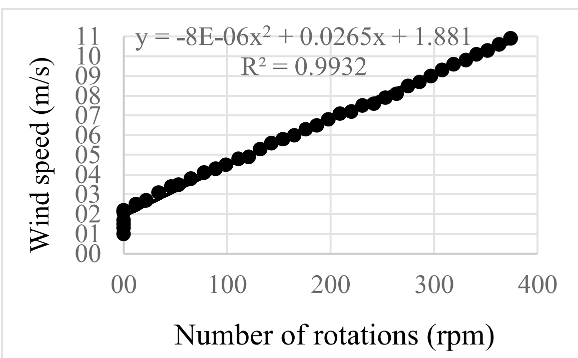



**Figure 15. Graph of the relationship between dynamo rotational speed and wind speed**

Remarks:

- The dynamo's rotational speed ranges from 50 - 150 rpm, corresponding to wind speeds from 3.2 – 5.7 m/s.

- For the dynamo to reach a rotational speed of 150 -250 rpm, the wind speed must be between 5.7 – 8.1 m/s.

b) Relationship between dynamo rotational speed and power output:

- From Table 5, we can plot a graph showing the relationship between the rotational speed of the dynamo (turbine) and the power output of the dynamo as follows:

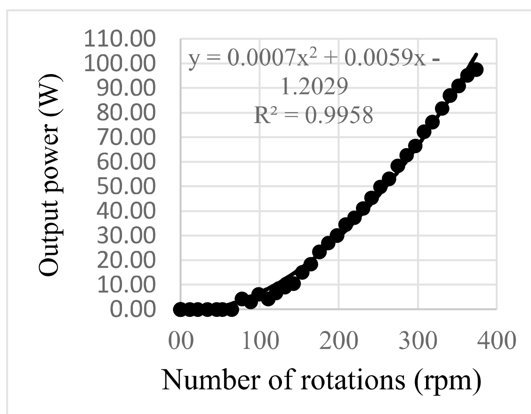



**Figure 16. Graph of the relationship between turbine rotational speed and power output**

Remarks:

- To achieve a power output from 0 – 30 W, the turbine's rotational speed must reach 25 - 200 rpm.

- When the turbine's rotational speed reaches 200 – 260 rpm, the dynamo will generate power of 30 – 50W.

c) Relationship between wind speed and dynamo power output:

From Table 5, we can plot a graph showing the relationship between wind speed and the power output of the dynamo as follows:

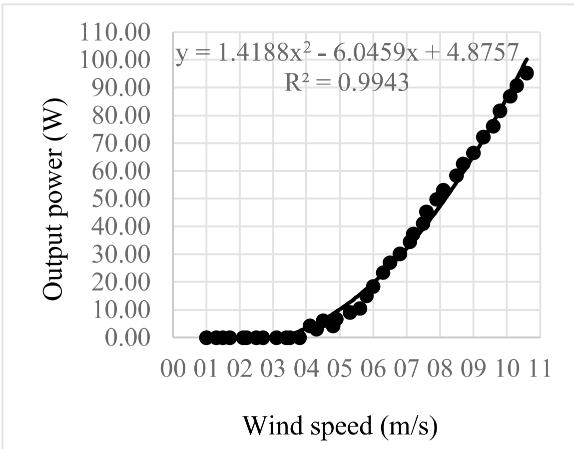



**Figure 17. Graph of the relationship between wind speed and power output**

Remarks:

- From the graph showing the relationship between wind speed and the dynamo's power output in Figure 15, we observe that the dynamo's power output is quite linear with wind speed.

- The dynamo's power output ranges from 0–30 W when the wind speed reaches 3–6.8 m/s; it reaches 30–50W when the wind speed is from 6.8 - 8.2 m/s.

*Initial field test results of the Wind-Powered lighting pole in actual operation.*

*- Test installation location:*

After studying and surveying installation locations, to facilitate experimental data collection and equipment maintenance, the author chose the internal road within the campus of Ho Chi Minh City University of Technology and Education as the installation site.

Advantages of the installation location:

- Easy to install.

- Easy to collect experimental parameters.

Challenges of the installation location:

- The campus area where the turbine was installed has many surrounding buildings, so the wind mainly consisted of swirling wind.

- The average wind speed was low, significantly affecting the turbine's operation.

*- Measured Parameters:*

a) Turbine operation:

The wind speed measured at the time of installation (August, September) was:

- Average wind speed during the experimental period: 3.3 m/s.

- Wind direction: West – Southwest.

- Highest daily wind speed at some moments of strong wind: 5.9 m/s.

b) Lighting operation:

The lamp was installed at a height of 5 m, with an arm extension of 1.5 m and an elevation angle of 15 degrees. A timer was additionally installed on the lamp for it to automatically turn on at 6 PM daily and turn off at 12 AM.

From the actual field test results of the lighting pole, it showed that:

- The wind turbine could self-operate at a wind speed of around 2.5 m/s with very little noise.

- The wind turbine began charging the battery system when the wind speed reached 4.5 m/s or more.

- The lighting achieved lighting class C (TCXDVN 259:2001) with a diffusion area diameter of 10 m, luminous flux: 6,000 Lm, and average illuminance: 10 Lx.

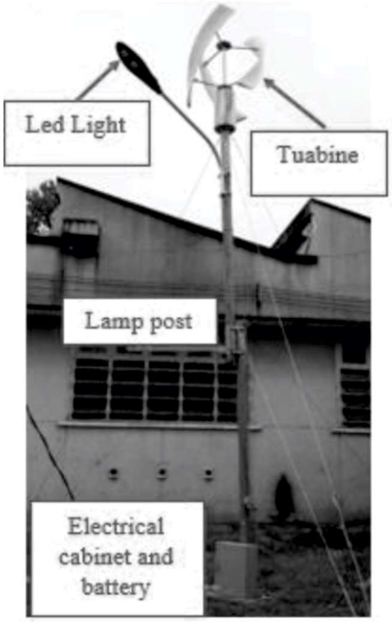



**Figure 18. Wind-Powered lighting pole fully installed**

## 3. RESULTS AND DISCUSSION

- Currently, there are not many installed wind-solar hybrid lighting pole systems, and these systems are all imported products, not yet researched and developed domestically (Vietnam Clean Energy Association, 2017; Vietnam Energy, 2017).

- Research topics and applications that have been implemented are all large-capacity horizontal-axis wind turbine systems, which are not suitable for lighting pole systems (Nguyen, 2007), (Chu, 2009).

- Some research topics have focused on selecting technology and equipment for wind power utilization, conducting surveys and evaluating power generation systems combining various forms of renewable energy for residential clusters, etc. (Nguyen, 2006; Castillo, 2011), but these have only been theoretical studies and have not been implemented in practice.

- A small-capacity vertical-axis wind turbine with automatic blade adjustment according to wind direction has been put into experimental application in practice, capable of operating at a wind speed of about 2.5 m/s, producing an electric current with a voltage of 6.89 V; 75 W (Dang & Phung, 2016). However, this system was designed for the purpose of providing electricity for household use.

- No domestic research has been found on the application of high-efficiency, small-capacity Quiet-Revolution turbines, nor is there information on research and development of small-capacity wind turbines to provide wind power for public lighting poles.

## 4. CONCLUSION AND RECOMMENDATIONS

Research on the design and fabrication of small-capacity wind turbines for public lighting purposes is an urgent issue with significant meaning, especially today as traditional energy sources are gradually being replaced by renewable energy. The report "Feasibility Study and Performance Evaluation of QUIET-REVOLUTION/GB Wind Turbines in Urban Lighting Applications" has followed this direction and achieved certain results: A comprehensive overview of public lighting systems and vertical-axis wind turbines has been conducted; the NACA profile for the twisted blade of the turbine has been successfully developed; a small-capacity Quiet-Revolution/GB twisted-blade vertical-axis wind turbine has been successfully fabricated; and a lighting pole system using energy from the Quiet-Revolution/GB twisted-blade wind turbine has been successfully designed and fabricated. Test results show that the wind turbine can operate stably at a wind speed of 2.5 m/s with low noise, and begins charging the battery system from a wind speed of 4.5 m/s. The lighting achieves lighting class C with an average illuminance of 10 Lx at a height of 5m and a wide diffusion area of 10m. During the research process, due to time and funding limitations, in addition to the achieved results, some recommendations are proposed to further expand and complete the research: Encourage broadening the scope of research to design and develop hybrid power generation systems, combining wind power with other renewable energy sources for medium and small capacities such as solar energy and hydropower. Continue researching and developing the drive system, with the goal of increasing the transmission ratio while keeping power transmission losses as low as possible. Integrate IoT technology into the wind turbine system to collect operational data and monitor the turbine's status more accurately. This technology can support flexible adjustments to the turbine's operational settings, improving system efficiency and durability.

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