Design a Smart Turbines for Power Generation

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Abstract This project focuses on designing a weather station and controllable wind turbine to harness the advantages of wind energy, which is one of the most important renewable energy sources in the world. The weather station is an Arduino-based tool and mobile App that measures temperature, humidity, wind speed and direction, and pressure. The methodology used is data analysis to give data and wind turbine control. The weather station provides the proper reads for the owner to steer the turbine in the right direction. Despite the physical, technical, and programming difficulties, both the weather station and mobile App perform well, achieving the project's objectives successfully. The accuracy of the results approaches 80%, with limitations highlighted in the thesis. Recommendations for further improvements and upgrades to the project are also discussed.

Keywords Smart wind turbine · Weather station · Controllable wind turbine

1 Introduction

The use of wind as a renewable source of energy has a long history, dating back to ancient times with the use of sailing ships and windmills. In modern times, wind turbines have become a popular means of generating electricity on a large scale, with wind farms being used to feed national power grids. Additionally, small-scale wind turbines are being used to provide electricity in remote areas. This is all possible because wind energy is a clean, renewable and abundant resource that is readily available. Therefore, the use of wind energy is a sustainable solution to meeting the

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increasing demand for electricity while reducing carbon emissions and mitigating climate change [1].

Wind energy is abundant, renewable, widely distributed, cleans, and mitigates the greenhouse effect if it is used to replace fossil-fuel-derived electricity [2–4], so in this project-weather station-we using a variety of sensor, to sensing the surrounding environment (temperature, humidity, pressure, wind direction and speed) and connected with Arduino, and we use the wind turbine to generate the electrical power and save the output voltage in battery, and we control with turbine direction with direction sensor to follow the wind and make the turbine more effect, and in the advantage in this project that combines many techniques we will be explained in this project.

It is significant to watch the weather all year round. Thereby, the Ministry of Transportation in Palestine has been built the weather station most of the cities.

Weather stations often incorporate a range of sensor types, each designed to sense a certain sort of weather variable. The signal is received by the Arduino, then the Arduino sends an order to the turbine to follow wind direction, and the Arduino eventually sends data to the App.

Necessity is the mother of invention, and regardless of the current excess of oil, humanity will ultimately be obliged to resort to new types of energy to run civilization's machinery. Solar, wind, geothermal, and other sources of natural power will someday be used to generate heat and light, as well as propulsion and movement. Humanity, ever flexible, has already started developing and producing alternate energy sources, but has yet to completely invest in the future.

The urge for innovation is more appealing in less developed countries. Places with poor or non-existent infrastructure are already looking to alternative energy to meet their requirements, and a number of organizations are supporting with these endeavors.

Almost any site with adequate wind may benefit from using wind turbines to meet at least some of its energy demands. According to the United Nations, one in every five people globally is energy poor [4]. Most people who fit that description reside in locations that aren't financially capable of building or installing full-scale wind turbines, but the partnership's tiny version is a different story.

The main goals of our project are listed as follow:

- To design a wind energy investment.
- To reach the maximum efficiency of the transformed energy.
- To design a smart Monitor system for weather changes.

The motivations to conduct this project include:

- There is no similar machine in the local market to the best of our knowledge.
- This station is smart.
- The turbine is turning at 3600 rpm, and this advantage is not available in other projects.
- This project benefits the whole society and helps the university to build its own weather station.

The problems identified in this project include, but not limited to:

- Reviving the local market with necessary machines and needed detectors.
- Encouraging local industry to produce home-made products
- Introduction

2 Methodology

The project is intended to be an Arduino-based weather station for monitoring weather changes. The various project components are joined together, and the Wind Turbine + Weather Station are successfully connected together, as illustrated in Fig. 1.

The technique in this project is based on measuring the temperature, humidity, air speed, and air direction, and controlling by the turbine angle, utilizing unique sensors and analyzing data in the microcontroller, and we employ a data-driven strategy to address this difficulty. Figure 1 depicts a schematic (block diagram) of the weather station design process.

As a result, this study provides a comprehensive technique for wind turbine design. It covers every area of project development and feasibility analysis. This method makes use of long-term wind data derived from on-site observations. The collected data is statistically examined.

The wind resources are then calculated, and the best-fitting wind turbines are selected. Using SOLIDWORKS and MATLAB, an ideal design for wind turbines is given. The primary contribution of this thesis is to assess the accuracy of this

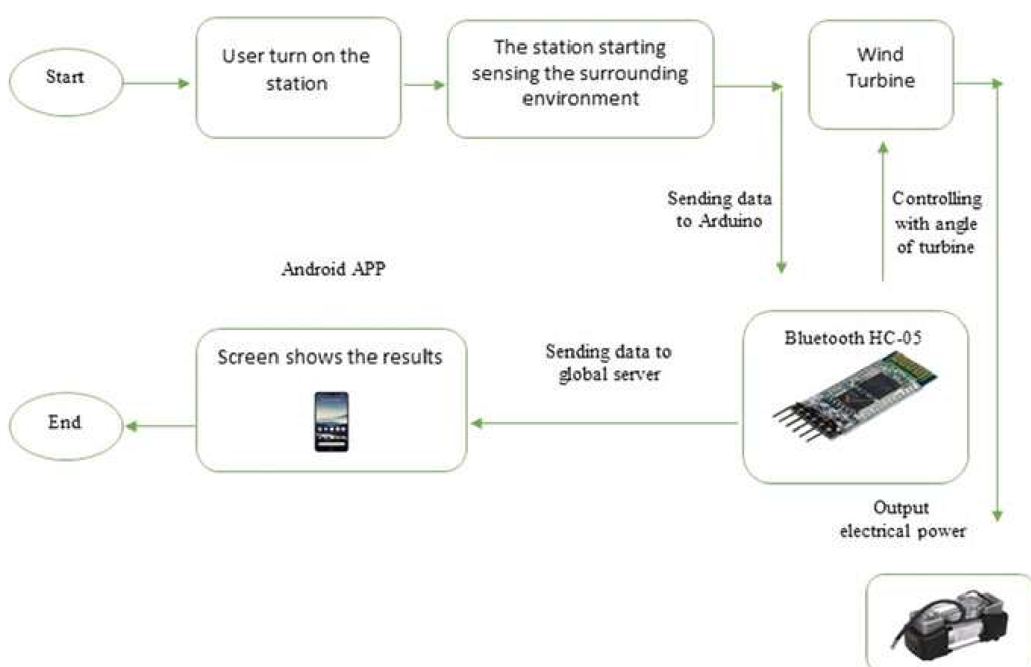

Fig. 1 A schematic (block diagram) of the designing process of the weather station

technique in estimating the future yearly energy output of wind farms. To accomplish this goal, the approach was developed wind micro turbine to a specific place that already has a wind turbine installed. The test case wind turbine is located in PTUK's Tullkarem.

The evaluation is carried out by comparing the estimated energy production with the wind turbine's real-time operation database. Finally, the thesis discusses the possibility of upgrading wind turbines in order to make better use of the local wind resource.

The wind is produced as a result of the Sun heating the Earth and causing convection currents to form in the Earth's atmosphere. So, using the wind as a source of electricity is not a novel concept. It has been used in sailing ships driven by the wind for thousands of years and windmills that ground maize using the force of the wind.

The blade we have been designed in SOLIDWORKS software, in Figs. 2 and 3 show the deigned blade and turbine to send the software to 3D printer to print it.

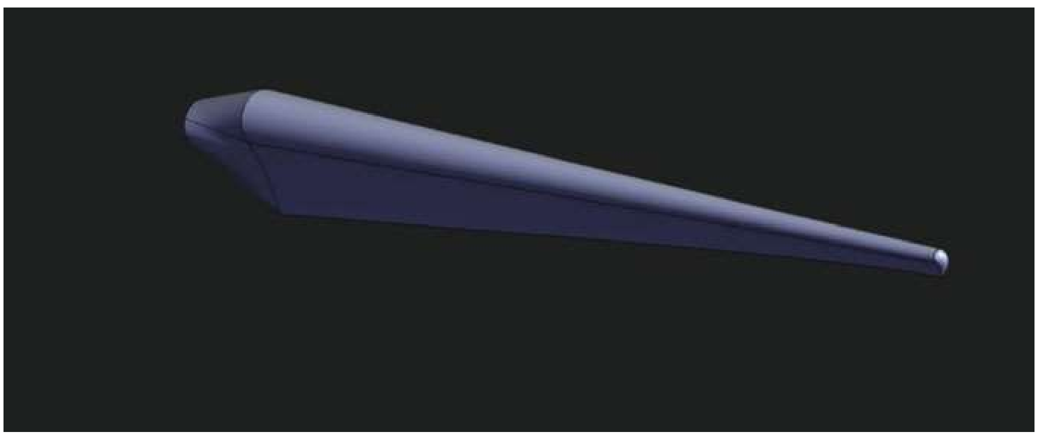

Fig. 2 The deigned blade SOLIDWORKS

Fig. 3 The deigned wind turbine SOLIDWORKS

SOLIDWORKS: a solid modeling computer-aided design (CAD) and computeraided engineering (CAE) computer program published by Dassault Systèmes, that runs primarily on Microsoft Windows. While it is possible to run SOLIDWORKS on an Intel-based Mac with Windows installed, the application's developer recommends against this [9].

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file (SOLIDWORKS file). The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the object is created. We designed the blades on the solid work program and printed them on a 3D printer from the EAC brand (see Fig. 4) and used PVA material (Polyvinyl Alcohol) due to its good quality and very affordable price.

Figure 5 shows the design of the weather station using Fritzing, this is an open-source initiative to develop amateur or hobby CAD software for the design of electronics hardware, to support designers and artists ready to move from experimenting with a prototype to building a more permanent circuit [5].

Fig. 4. 3D printer from the EAC brand

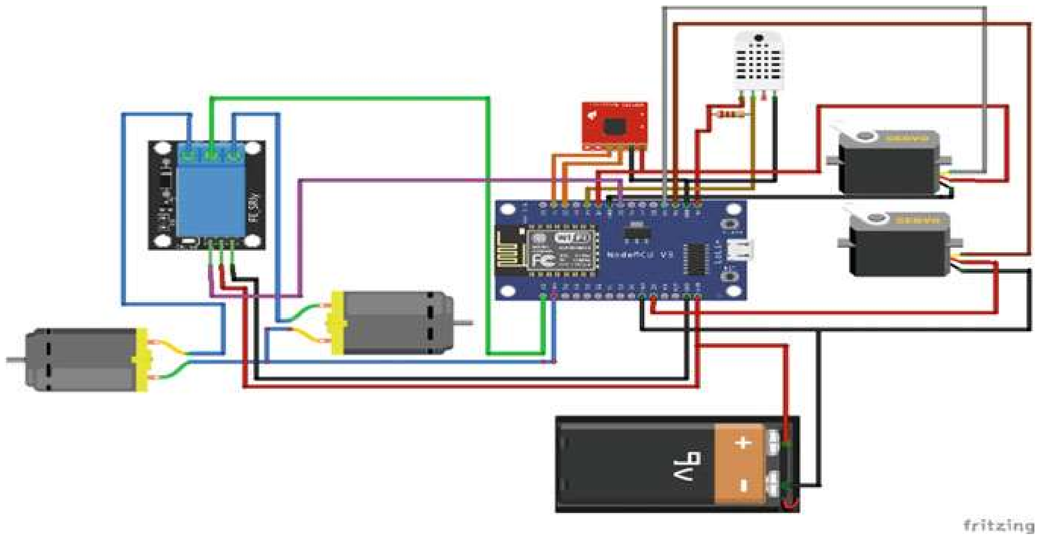

Fig. 5 The design of the weather station using Fritzing

3 Results

An application was created to simulate the behavior of a wind generating system using the Wind Turbine models provided before. The simulator was created in MATLAB/ Simulink® and was used to compare waveforms with the emulator, which was also created for experimental analysis.

MATLAB has been used to simulate the wind turbine with PMDC generator and we use spur gear (n = 1:6) to increase the input torque in the generator to get more input rotational speed to the generator, Fig. 6 shows the simulation of wind turbine with PMDC generator using MATLAB.

After running the model in MATLAB and enter variable values of pitch angel (β) and wind speed (V) we get the results as shown in Table 1:

Figure 7 depicts a block schematic of a Wind Turbine's dynamic behavior. The aerodynamic stage receives user inputs such as wind velocity and pitch angle. The power co-efficient and turbine torque are calculated using these inputs, as well as the rotor speed. The rotor speed is calculated using the turbine torque and generator torque. The electrical model then use the load characteristic to calculate voltages, currents, and generator torque.

The project has been run and recorded the data in different conditions and compared them with the theoretical values and expected values taken from reliable observatories. Table 2 displays the electrical energy resulting from the Wind Turbine that designed with a diameter of 14 cm, where we changed the beta of the turbine and entered different speeds of air the results, Fig. 8 shows its geometrical shape, dimensions and specification. It is a vertical mini wind turbine with diameter of blade of 14 cm. Rated output at wind speed of 10 m/s is 2.11 W, but it can stand up to 40 m/s of wind speed. Since the wind speed was measured at 10 m height;

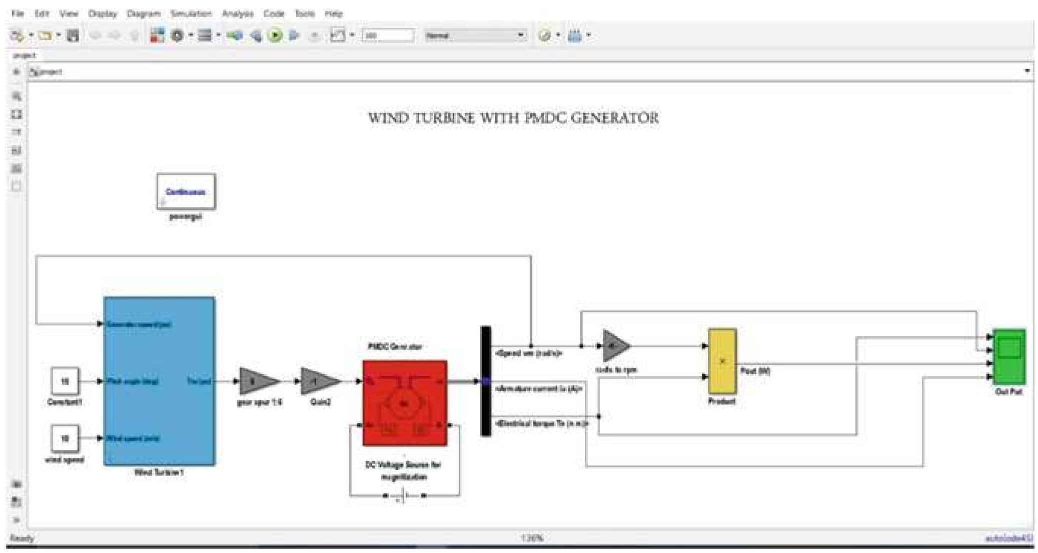

Fig. 6 The simulation of wind turbine with PMDC generator using MATLAB

Table 1 The output power from wind turbine in MATLAB with variable inputs

Wind speed (m/s)	Pitch angel β (°)	Output power (w)
1.4	0	0
1.4	10	0.01
1.4	12	0.220
1.4	15	0.412
10	0	4.149
10	10	4.278
10	12	4.546
10	15	4.879

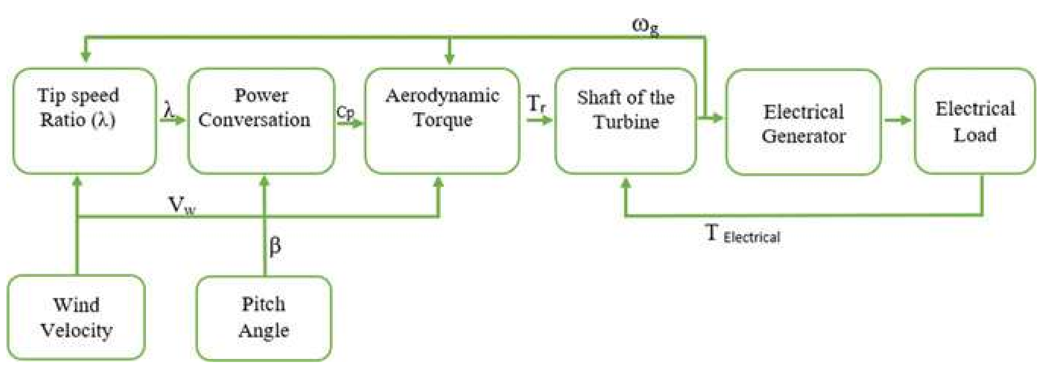

Fig. 7 Block diagram of the wind turbine mathematical model for simulation implementation

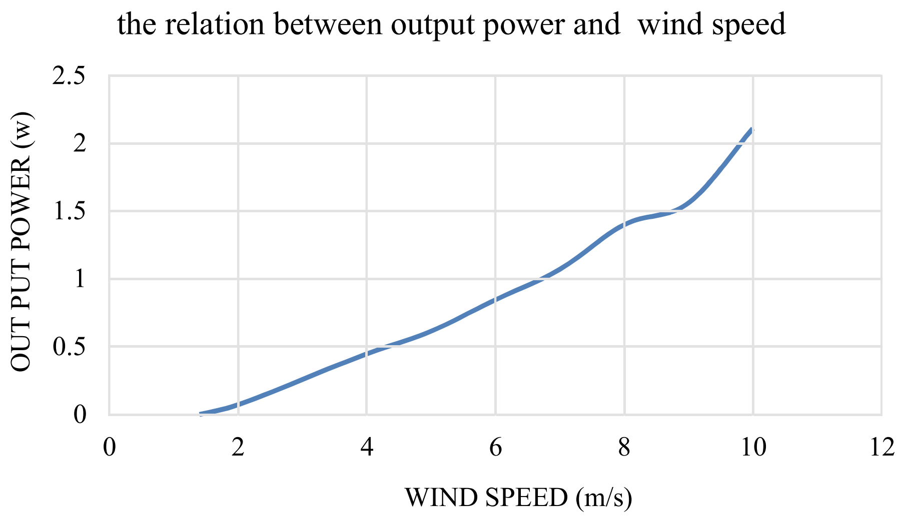

Fig. 8 The relation between wind speed and output electrical power

Table 2 Measured average monthly wind speed

Month wind	Speed (m/s)	Month wind	Speed (m/s)
Jan	2.26	Jul	1.6
Feb	2.19	Aug	1.56
Mar	2.1	Sep	1.44
Apr	1.6	Oct	1.33
May	1.4	Nov	1.3
Jun	1.5	Dec	1.8

the wind turbine was also considered to be elevated up to that height, from the data, average monthly wind speed is presented in Table 2.

Table 3 shows that the highest point of monthly average wind speed was 2.26 m/s and it was recorded on Jan 2020, whereas the lowest wind speed was 1.3 m/ s that was recorded on Nov and Dec. However, the range of average hourly, wind speed throughout 2020 was in the range of 0–8.7 m/s. Since the wind speed was measured at 10 m height, many values of electrical quantities have been measured by multimeter, Table 3 shows the outputs of the generator from variable wind speeds, the data values from the project are represented in a graph, Fig. 8 shows the relation between wind speed and output electrical power.

As for the weather station, we obtained the following results in the Table 4, and we compared them with the weather readings from the Ministry of Communications, and the percentages were very close, as shown in the following table, this data was collected in Dec 2022 at 6 pm.

As we have noticed in the table above, the values taken from the station are very close to the values taken from the official and reliable resources, and the error rate is close to zero, so the station has proven its effectiveness and the accuracy of its results.

Table 3 Outputs of the generator from variable wind speeds

Wind speed (m/s)	V_{out} (v)	I_{out} (A)	Pout electrical (W)
1.4	0	0	0
2	0.1	0.7	0.07
3	0.274	0.91	0.259
4	0.346	1.29	0.4468
5	0.370	1.66	0.6144
6	0.412	1.711	0.846
7	0.564	1.899	1.07
8	0.736	1.909	1.4
9	0.741	2.1	1.56
10	0.879	2.4	2.11

Table 4 The result of weather station compared with readings from the Ministry of Communications

Day	Date	Temperature (c^o)		Wind speed (km/h)		Humidity (%)		Wind direction (°)		Pressure (Kpa)	
		Station	Real	Station	Real	Station	Real	Station	Real	Station	Real
Sat	5	22.5	23.5	13.9	14.2	51.5	49.2	280.9	290	99.2	100
Sun	6	23.4	23.9	14.8	15.5	56.7	54.1	260.01	278	99	101
Mon	7	22.7	22.8	15.6	15	55.0	57.0	266.1	265	99.1	100
Tus	8	24.1	25	15.2	15.5	50.1	59	270.9	277	99.02	100
Wed	9	22.0	21.9	14.7	14	70.11	72	267.4	272	99.4	100
Thru	10	22.8	23.2	13	12.5	62.4	64	288.5	290	99	100
Fri	11	23.7	24	14	13	59.9	60.9	290.1	300	99.2	100
Average		23.02	23.47	14.88	14.20	57.95	59.45	274.84	281.71	99.1	100,14
|Deference|		0.45		0.68		0.50		6.87		1.04	
%Error		0.0191%		0.478%		$8.410*10^{-3}$ %		0.0243%		0.010%	

4 Conclusion

The weather station is a vital tool for monitoring and forecasting weather conditions on land and sea, utilizing various equipment to measure temperature, atmospheric pressure, humidity, wind speed and direction. The addition of a miniature wind turbine has allowed for the exploitation of wind energy and the production of electric power, with the advantage of being connected to a control circuit that can determine wind direction. The weather station is user-friendly, requiring only basic tools such as a smartphone with good specifications to monitor weather conditions. Our project has identified several key findings, including the importance of taking wind measurements in open areas free of obstructions, and temperature and humidity measurements without exposure to direct solar radiation. We have also learned that losses decrease with increasing speed, but not all mechanical energy can be converted into electrical energy due to friction and Windage friction. The turbine requires maintenance due to the presence of the brush and the commutator, and its best power output performance occurs at steady state speed. High wind speeds can cause damage to the station and break blades. Additionally, thin cambered plates are better than conventional airfoils for high Reynolds numbers due to their relatively insensitive nature to turbulence levels. Overall, our project has successfully achieved its objectives, with the detector performing well and an accuracy rate approaching 80% compared to readings from reliable monitoring stations. While there are limitations to the project, further improvements and upgrades may lead to even better results in the future.

5 Recommendations

To further enhance the performance of the weather station and the turbine, the following recommendations are proposed:

1. It is recommended to install a gearbox to increase the speed rotation of the generator. This will lead to an increase in the output voltage, especially at the start of rotation. The gearbox will also support the increase in rotation speed of the blades.
2. Another recommendation is to add a braking operation as a protection measure from high wind speeds, storms, tornadoes, and other fast-moving weather conditions.
3. Additionally, it is suggested to design a sensor that can track the direction of the wind and program the turbine to follow it automatically. This would ensure that the turbine is always positioned optimally to capture the maximum amount of wind energy.

6 Limitations

It is important to consider the limitations of the project in any future improvement or upgrade. The following limitations have been identified:

- The PMDC generator used in the project has inherent power losses that should be minimized in order to increase the overall efficiency of the system.
- The project requires an AC voltage source to convert it to DC voltage via a power circuit. This may limit the flexibility of the project in certain applications where an AC source is not available or practical.

References

1. Johnson, G.L.: Wind energy systems. Citeseer (1985)
2. Demirbas, A.: Global renewable energy projections. Energy Sour. Part B **4**(2), 212–224 (2009)
3. Narsipur, S., Pomeroy, B., Selig, M.: CFD analysis of multielement airfoils for wind turbines. In: 30th AIAA Applied Aerodynamics Conference, p. 2781 (2012)
4. Kaygusuz, K.: Wind power for a clean and sustainable energy future. Energy Sour. Part B **4**(1), 122–133 (2009)
5. Jacobson, M.Z., Delucchi, M.A.: Providing all global energy with wind, water, and solar power, Part I: technologies, energy resources, quantities and areas of infrastructure, and materials. Energy Policy **39**(3), 1154–1169 (2011)