Development of Graphical User Interface (GUI) for the Calculation of Wind Turbine Output Power using Different Blade Radius

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Abstract – **This project presents the development of graphical user interface (GUI) which is discussed about calculation of the output power of wind turbine using different blade radius. The wind turbine output power is evaluated by looking at the blade radius and wind speed to supply electricity. GUI is a graphical user interface that interfaced with a program that can make program easier to use with intuitive control such as pushbutton, sliders, menus, axes and so forth. It is used as a platform to simulate the output power of wind turbine system. This project investigates the effect of wind turbine output power using different blade radius. Two types of wind turbine involved in developing the output power are Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Depending on the wind turbine's characterizations, the most reliable wind turbine used will be determined. As a result, by developing the GUI, the blade radius is proportional to the output power produced for different usage such as outdoor light, individual houses, island and others.**

***Key Words:** Wind energy, Matlab GUI, Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT).*

I. INTRODUCTION

Wind power is the conversion of wind energy into more useful forms such as electricity using wind turbines. Most modern wind power is generated in the form of electricity by converting the rotation of turbine blades into electrical current by means of electrical generator. The wind is a clean and sustainable fuel source, it does not create pollution and it will never run out. Wind energy technology is developing fast and turbines are becoming cheaper and more powerful, bringing the cost of renewably-generated electricity down.

Wind energy has its own advantages and disadvantage on the surrounding environment, and the general reliability of wind turbine. One of the advantages of wind energy system is clean and independent energy. It is 100% clean, renewable, and independent source of energy [1]. It is also cheaper compare to other sources. As the wind is free, more and more power of this free wind energy can be produced.

The main disadvantage of wind energy system is locations, where not every location is suitable for a wind turbine. Only selected locations have sufficient wind blowing regularly enough to make the turbines useful. In Malaysia, the average wind speeds that are required to move the blades lie between 2 m/s to 13 m/s. In Malaysia, locations that have sufficient wind speed are Kuala Terengganu, Kota Bharu, Mersing and Kota Kinabalu [2].

Wind turbine works by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical that can be supplied. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine. Wind energy conversion system has great potential on resort islands in Malaysia especially on the East Coast in South China Sea [3].

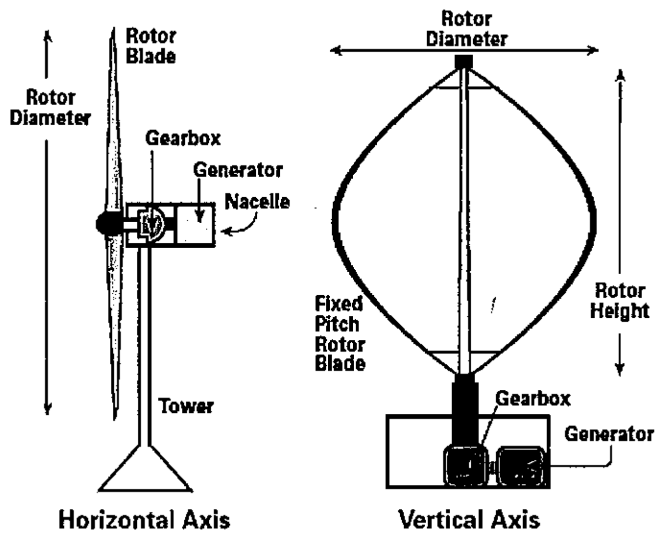

Figure 1: Type of Wind Turbine Horizontal and Vertical Axis

There are two types of wind turbine : Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) as shown in Figure 1. Horizontal axis Wind Turbine (HAWT) is more common, these turbines have blades spinning perpendicular to the ground. Both vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT) generate electricity from wind power. However, the VAWT is less efficient, less strong and does not work as well as the HAWT [4]. All wind systems consist of a wind turbine, a tower, wiring, and the "balance of system" components: controllers, inverters, and batteries [5]. Home wind turbines consist of a rotor, a generator mounted on a frame, and a tail. Through the spinning blades, the rotor captures the kinetic energy of the wind and converts it into rotary motion to drive the generator.

II. METHODOLOGY

A. Wind Turbine Power Equation

In designing wind turbine, the output power needs to be calculated. Each type of wind turbine produced different output power. The factors that contributed to the power produced are speed and swept area. The definition of various variable used in wind turbine model are as below [6]:

E = Kinetic Energy (J)	ρ = Density (kg/m3)
m = Mass (kg)	A = Swept Area (m^2)
V = Wind Speed (m/s)	P = Power (Watt)
C_p = Power Coefficient	r = radius (m
$\frac{dm}{dt}$ = Mass flow rate (kg/s)	x = Distance (m)
$\frac{dE}{dt}$ = Energy Flow Rate (J/s)	t = Time (s)

Under constant acceleration, the kinetic energy of an object having mass, *m* and velocity, *v* is equal to the work done *W in* displacing that object from rest to a distant *S* under a force.

$$E = Fs$$

According to Newton's Law:

$$F = ma$$

Hence,

$$E = mas \ldots\ldots (1)$$

Using the equation of motion:

$$V^2 = U^2 + 2as$$

So that,

$$a = \frac{(V^2 - U^2)}{2s}$$

Since the initial velocity of object is zero, U = 0:

$$a = \frac{V^2}{2s}$$

Substituting it in equation (1) that the kinetic energy of a mass in motion is:

$$E = \frac{1}{2} mV^2 \ldots\ldots (2)$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2}V^2 \frac{dm}{dt} \ldots\ldots (3)$$

As mass flow rate is given by :

$$\frac{dm}{dt} = \rho A \frac{dx}{dt}$$

And the rate of change of distance is given by:

$$\frac{dx}{dt} = V$$

So that,

$$\frac{dm}{dt} = \rho AV$$

$$Air\ Density, \rho = 1.23\ kg/m^3$$

Hence, from equation (3), the power can be defined as:

$$P = \frac{1}{2}\rho AV^3 \ldots\ldots (4)$$

Betz Limit or Betz Law state that no wind turbine can convert more than 59.3% of kinetic energy into mechanical energy. The theoretical maximum power efficiency of any design of wind turbine is 0.59 and called power coefficient [7].

$$C_{p(\text{maximum})} = 0.59$$

At maximum value of coefficient power, wind turbine cannot operate at this limit. This is because in real design, coefficient power is between 0.35 – 0.45 which is the best in designing wind turbine. So that, the value of coefficient power is:

$$C_p = 0.4$$

Hence, the power coefficient needs to be factored in equation (4) and the extractable power from the wind is given by:

$$P = \frac{1}{2}\rho AV^3 C_p$$

B. Progress of Work

This project involves the development of GUI in MATLAB for calculation of the output power using different blade radius. Graphical User Interface (GUI) is an interface to a program. The development tool included with MATLAB is called GUIDE which stands for Graphical User Interface Development Environment. GUIDE allows the user to easily construct the GUI design. GUIDE also allows user to manage properties with Property Inspector and automatically generating M-file code for GUI. A GUI provides the user with an environment which to work. The environment contains pushbuttons, list boxes, sliders, text boxes, toggle buttons, menus and so forth. GUI should behave in an understandable and predictable manner, so that user knows what to expect when performs an action [8].

Figure 2 shows the flowchart for wind turbine output power calculation using MATLAB GUI.

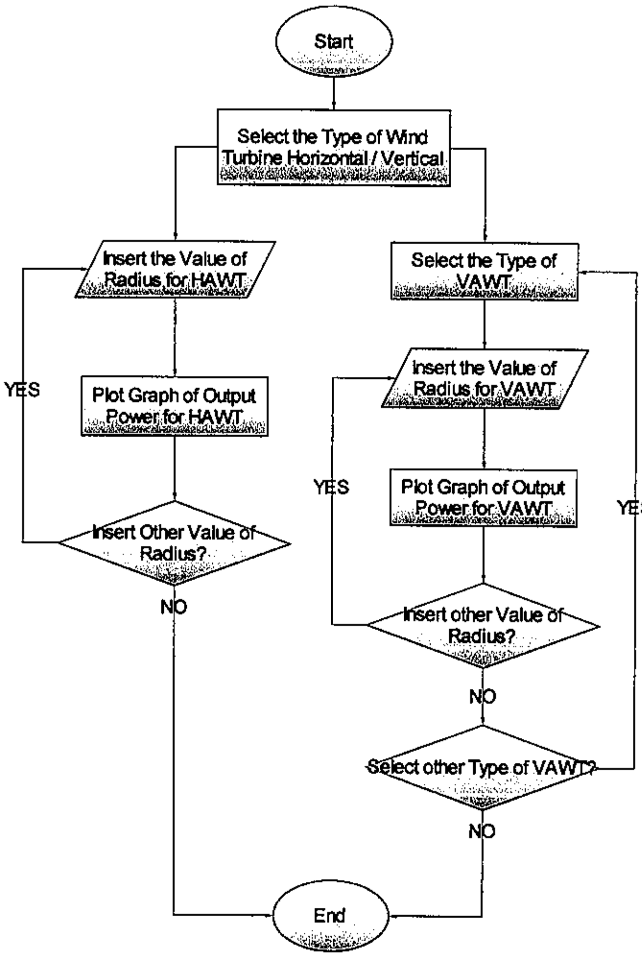

Figure 2 : Flowchart of Wind Turbine Output Power

The step-by step procedure is described as follows: Figure 3 shows the window that user needs to click to select which type of wind turbine. When user chooses one of the pushbutton, new windows will be appear.

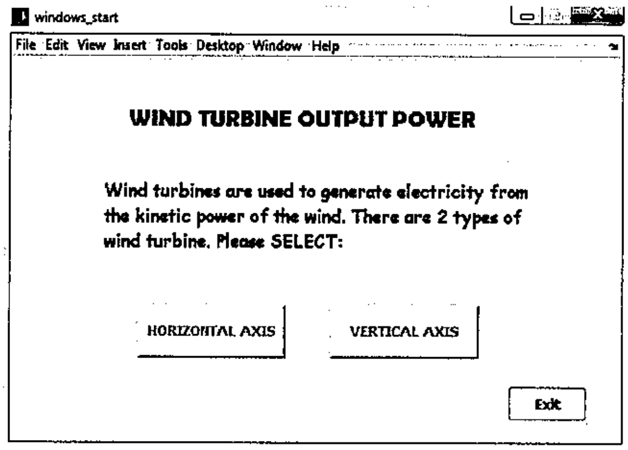

Figure 3: Start Windows

For the next window as Figure 4, user can insert the value of radius between 1m to 50m and then click the run pushbutton to get the graph. The graph shows the output power of wind turbine versus wind speed. From the graph, it can be seen that as radius getting bigger, output power became higher. If user wishes to end the system, user should click the end button. Clicking the back button will bring user to the start window and choose the other type of wind turbine that is VAWT.

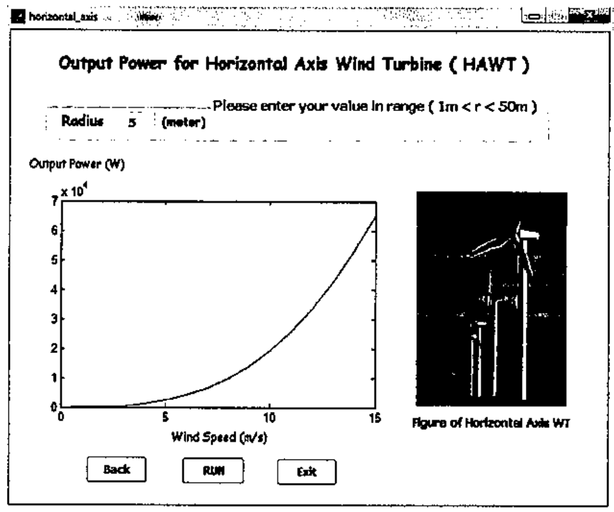

Figure 4: Horizontal Axis Wind Turbine

For the vertical axis wind turbine (VAWT) at Figure 5, it consists of three other types which are H-rotor VAWT, Darrieus VAWT and Savonius VAWT. Each type of wind turbine produced different output power. The user chooses either one of the pushbutton and new window will appear. Then user need to enter the value of radius.

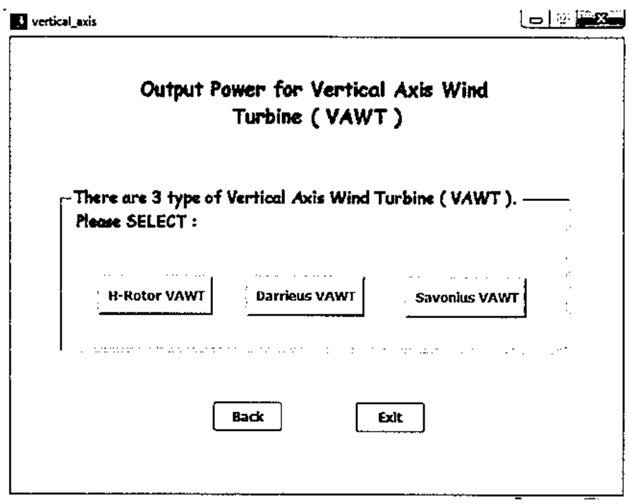

Figure 5: Vertical Axis Wind Turbine

Using the above procedure, calculation for wind turbine output power is conducted for each type of wind turbine and for different blade radius. Results for each calculation were tabulated and discussed in the next section.

III. RESULT AND DISCUSSION

In this section, the following table is to explain the result between 5 m to 50 m radius blade. For the maximum radius, the power produced by HAWT is 6520.8 kW.

Table 1: Output power for HAWT

Wind Speed(m/s)	4	8	10	12	15
Power(kW) r = 5 m	1.237	9.892	19.32	33.386	65.208
Power(kW) r = 10 m	4.95	39.6	77.3	133.55	260.83
Power(kW) r = 15 m	11.13	89.0	173.9	300.48	586.87
Power(kW) r = 20 m	19.78	158.2	309.1	534.18	1043.3
Power(kW) r = 30 m	44.5	356.1	695.5	1201.9	2347.5
Power(kW) r = 40 m	79.1	633.1	1236.5	2136.7	4173.3
Power(kW) r = 50 m	123.7	989.2	1932.1	3338.6	6520.8

The following table explained the result between 5 m to 50 m radius blade. For the maximum radius, the power produced by H-Rotor VAWT is 4151.3 kW.

Table 2: Output power for H-Rotor VAWT

Wind Speed (m/s)	4	8	10	12	15
Power(kW) r = 5 m	7.87	62.98	123.00	212.55	415.13
Power(kW) r = 10 m	15.74	125.95	246.0	425.09	830.25
Power(kW) r = 15 m	23.62	188.93	369.0	637.63	1245.5
Power(kW) r = 20 m	31.49	251.9	492.0	850.18	1660.5
Power(kW) r = 30 m	47.23	377.86	738.0	1275.3	2490.7
Power(kW) r = 40 m	62.98	503.81	1309.7	2161.9	3321.0
Power(kW) r = 50 m	78.72	629.76	1230.0	2125.4	4151.3

The tabulated table below explained the result between 5 m to 50 m radius blade. For the maximum radius, the power produced by Darrieus VAWT is 2698.3 kW.

Table 3: Output power for Darrieus VAWT

Wind Speed (m/s)	4	8	10	12	15
Power(kW) r = 5 m	5.12	40.93	79.95	138.15	269.83
Power(kW) r = 10 m	10.23	81.87	159.90	276.31	539.66
Power(kW) r = 15 m	15.35	122.80	239.85	414.46	809.49
Power(kW) r = 20 m	20.47	163.74	319.80	552.61	1079.3
Power(kW) r = 30 m	30.70	245.61	479.70	828.92	1619.0
Power(kW) r = 40 m	40.9	327.5	639.6	1105.2	2158.7
Power(kW) r = 50 m	51.2	409.3	799.5	1381.5	2698.3

The following table is to explain the result between 5 m to 50 m radius blade. For the maximum radius, the power produced by Savonius VAWT is 2075.6 kW.

Table 4: Output power for Savonius VAWT

Wind Speed (m/s)	4	8	10	12	15
Power(kW) r = 5 m	3.94	31.49	61.50	106.27	207.56
Power(kW) r = 10 m	7.87	62.98	123.0	215.54	415.13
Power(kW) r = 15 m	11.81	94.46	184.5	318.82	622.69
Power(kW) r = 20 m	15.74	125.95	246.0	426.09	830.25
Power(kW) r = 30 m	23.62	188.93	369.0	637.63	1245.4
Power(kW) r = 40 m	31.48	251.9	492.0	850.18	1660.5
Power(kW) r = 50 m	39.36	314.88	615.0	1062.7	2075.6

From the tabulated output power, the blade radius can be classified into different types of wind turbine. Figure 6 shows the blade radius, r = 5 meter. H-Rotor VAWT has the highest value of output power compared to other types of Vertical Axis Wind Turbine. The HAWT produced the lowest value of output power; it shows that the HAWT is not suitable to produce a higher output power when the radius blade is small.

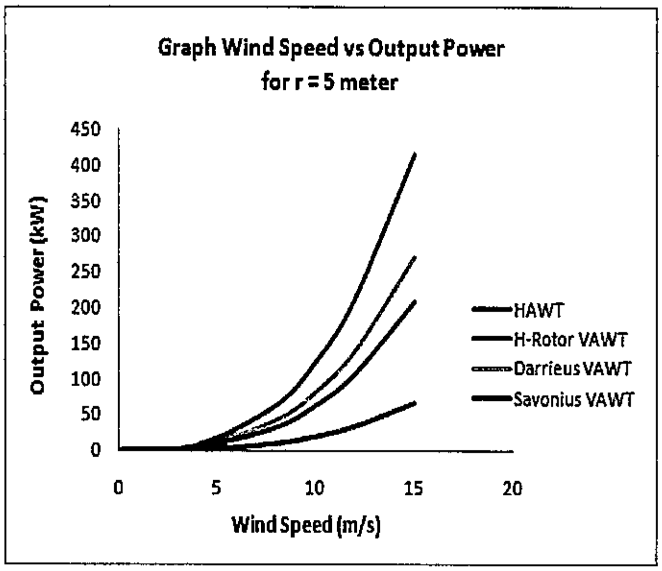

Figure 6: Graph for radius = 5 meter.

When blade radius, r = 10 meter, all type of VAWT are at higher power than the HAWT. VAWT is commonly used to produce power for farm or house without grid connection. The H-Rotor VAWT delivers more power rather than Darrieus and Savonius VAWT. This is because H-Rotor is more efficient like the blade of helicopter. The Darrieus VAWT rotor can move by itself without need other mechanism because the blade is lighter and need only small wind speed to generate output. Therefore Darrieus VAWT produced more the output power than Savonius.

Figure 7 show that the Savonius VAWT is smaller in delivering power rather than the others. The Savonius VAWT is effective for residential area as it is extremely quiet, easy to build, simplest and more economical. For that, it only produced small amount of power such as outdoor light, pumping water and electrical gate.

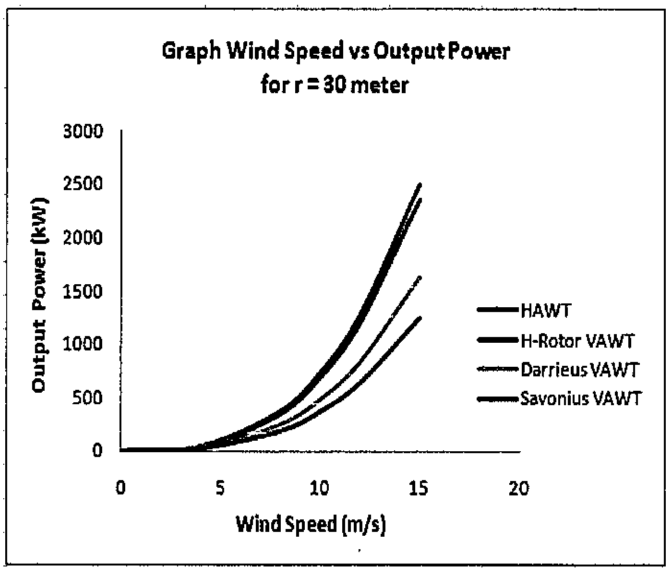

Figure 7: Graph for radius = 30 meter.

Figure 8 shows the HAWT is the highest value of output power when the blade radius, r = 50 meter. It shows that the HAWT is more convenience to design wind turbine compare to others. All types of VAWT are design to use for small and simple wind rotor. It is not suitable for generating electricity due to low speed and low power coefficient [9]. HAWT is able to convert more wind into power for greater efficiency and better power even though HAWT can cost hundreds dollar more than VAWT. Due to highly cost, HAWT is designed to deliver electricity to bigger load [10]. Therefore, HAWT is commonly used to convert mechanical energy to electrical energy.

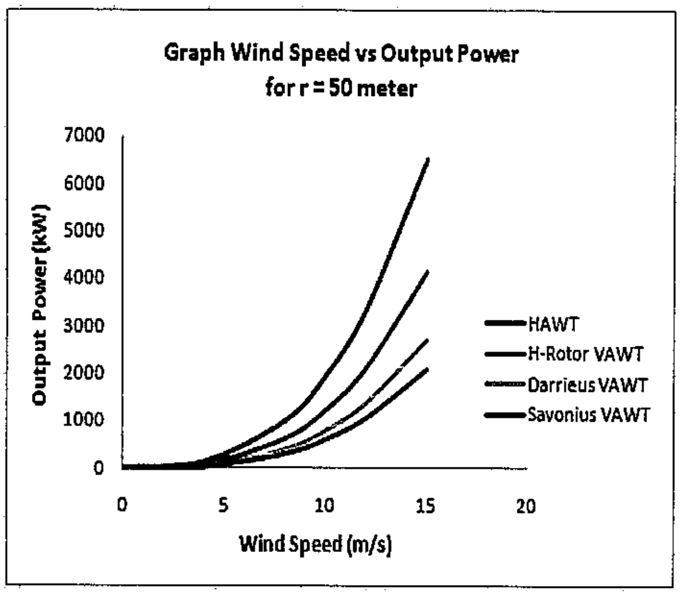

Figure 8: Graph for radius = 50 meter

IV. CONCLUSION

This thesis presents the development of GUI for calculating wind turbine output power using different blade radius. The GUI has been successfully developed and the effect of wind turbine output power using different blade radius has been successfully investigated. From the GUI system, the output power is varied according to the blade radius used. The bigger the blade radius, more output power will be obtained. GUI automatically displays the graph of output power to user. The output power displayed to user using MATLAB Graphical User Interface (GUI) is successful. Using GUI, it is easy to analyze each type of wind turbine by inserting the different value of blade radius. The characterization of the type of wind turbine has been determined. HAWT will produce bigger electricity especially for larger electrical supply used such as to supply a whole island. As the power produced is low for VAWT such as H-Rotor, Darrieus and Savonius; it is more suitable for personal usage such outdoor light, individual houses, and others. Among all types of VAWT, H-Rotor has the better performance due to output power produced by a certain swept area design. As a result, even though H-Rotor has better performance but when compared to HAWT, HAWT has more capability in producing bigger output power. For future recommendation, it is suggested that other than GUI, methods such as MATLAB Simulink and PSCad can be used. Besides, the output power from combination of two types of wind turbine such as combination of Darrieus VAWT and Savonius VAWT can be developed by improving the GUI system. Other than that the maximization of the output power can also be obtained from the combination with other renewable energy such as wind turbine and solar panel.

V. REFERENCE

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