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International Journal of Research Publications

Design and Construction of Horizontal Wind Turbine

Odinikuku Ejenavi William

Department of Mechanical Engineering, Petroleum Training Institute, Effurun, Nigeria

Abstract

This research work is focused on the design and construction of a horizontal wind turbine. This present work is aimed at substantiating the generation of electricity from wind and proffering solution to drawbacks associated with non-renewable energy. A wind turbine is an electric generator moved by the action of the wind. Energy generation in wind turbine occur in two phases. In the first phase, the wind turbine blades convert wind energy to mechanical energy. In the second phase, the rotor converts the mechanical energy to electrical energy. The horizontal wind turbine consists of the following major parts; stanchion, yaw mechanism, hub, blade, nacelle, shaft, generator, tail boom, fasteners and joiners. The designed and constructed horizontal wind turbine was used to drive the generator. The principle of faraday law of electromagnetic induction was adopted. The results obtained shows that according to Betz's Law, only 34% of all the mechanical energy developed by the wind will be converted to electrical energy for usage. The speed of the turbine was obtained as 2182rpm, and rotor speed of the turbine as 228rad/s. The torque effect at the tip speed was obtained as 12.5N/m. It was determined that the maximum stress of the wind turbine blade was in tension (5.69KN/m^2), and the minimum stress in compression (3.73KN/m^2).

Keywords: Horizontal wind turbine, design, constructure, electromagnetic induction, torque, stress

1. Introduction

Energy has a major impact on every aspect of our socio-economic life. It plays a vital role in the economic, social and political development of any nation (Global Energy Network Institute 2014; Orhorhoro et al., 2016). Despite the abundance of energy resources in Nigeria, the country is still in short supply of electrical power. Only about 40% of the nation's over 150 million inhabitants have access to grid electricity (Sambo, 2006). The electricity supply to the consumers that are connected to the grid is erratic. Therefore there is the need to harness renewable energy potentials for reliable power supply in this country (ECN, 2012; WEC, 2013). Besides, the concern of global warming and continued apprehensively of nuclear power necessitated the strong demand for wind generation. The main advantages of electricity generation from renewable energy sources, such as wind, are the absence of harmful emissions, very clean and almost infinite availability of the wind energy that is convertible into electricity (Brady, 2009).

Wind generation has been described to be one of the mature and less cost effective resources among different renewable energy technologies. Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface (Mohamed, 2011). Wind is a classic example of a stochastic variable. Due to this stochastic nature, wind energy cannot be controlled, but can be managed. This is because wind power is available only when the wind speed is above a certain threshold (Akinbami, 2001). Most wind turbines start generating electricity at wind speeds of around 3-4 metres per second (m/s) (or 6.71-8.95km/hr.). They generate maximum 'rated' power at around 15 m/s (or 33.6 km/hr.); and shut down to prevent storm damage at 25 m/s (or 55.92km/hr.) (Okafor and Uzuegbu, 2010).

The connection of wind generators to the grid possess new challenges to engineers as these have been a significant impact on the system and equipment operations in terms of steady state and dynamic operations in terms of steady state and dynamic operations, reliability, power quality, stability, and safety for both the utility and customers. Mostly, the stability and reliability studies are carried out whenever wind power is connected to power system to predict severe consequences on the power system being studied.

It is very important to state here that it is not just enough to say that the wind turbines should be connected to the grid because there are sufficient wind speeds to drive the wind turbine, but the wind turbine generators must be able to connect with the existing grid. Mostly, stability and reliability studies must be carried out whenever wind power is to be connected to the power system to predict severe consequences on the power system to which the wind generators will be connected. This present work is aimed at the designed and construction of a horizontal wind turbine that will produce power, basically electricity by utilizing the potential and kinetic energy of flowing wind. The design is custom because it will operate under a specific head to generate a specific power of 200watts.

2. Methodology

2.1 Part Design

The horizontal wind turbine consists of the following major parts:

i. Stanchion
ii. Yaw Mechanism
iii. Hub
iv. Blade
v. Nacelle
vi. Shaft
vii. Generator
viii. Fasteners and Joiners
ix. Tail Boom

2.1.1 The Stanchion

This is connected with 40mm diameter steel pipe with a total length of 600mm. To achieve the needed power, the rotor height should be of similar height because above that height the wind speeds would be higher by wind shear phenomenon and could cause damage to the generator. For the above mentioned reasons, I used the height is 600mm. Tower of such height was best suited because it was well over height of all other surroundings, thus no obstruction of the wind path towards the turbine. The foundation is prepared from concrete that is reinforced with steel struts. The foundation is constructed with square base area of (60mmx60mm) small sized rocks are introduced into pits and a mixture of sand. Cement and water is poured into the pit. Steel struts are also introduced into the pit and sand mixture of small sized rocks. Cements, sand and water is used to fill the pit up to surface.

2.1.2 Yaw Mechanism

The yaw mechanism ensured that the turbine faces the most suitable wind direction. It also turns the blades 90degrees from prevailing wind under high wind to reduce stress on blades and internal components and consequently avoid over speed condition which can lead to overloading of the generator which can lead to damage of the generator windings.

2.1.3 Hub

Hub connects the blades to the main rotor shaft of the wind turbine. The hub transmits and withstands all loads. The hub controller that is usually in direct communication with the nacelle controller is used to moves the blades. There are three types of blades

i. Rigid hubs
ii. Teetering hubs
iii. Hubs from hinged blades.

2.1.3.1 Rigid Hubs

Have all major parts fixed. Approximate for wind turbines with three or more blades. A hub on the pitch controlled turbine must provide for bearing and pitching mechanism. Pitching mechanism may use a pitch rod passing through the main shaft together with hub linkage. The pitch rod is driven by the motor mounted on the main part of the turbine. Another method is to mount electric gear motors on the hub. This can be done with slip rings or rotary rings.

2.1.3.2 Teetering Hub

Used in almost all two bladed wind turbine. This is because a teetering hub can reduce loads due to aerodynamic imbalances or load due to dynamic effect

2.1.3.3 Hinged Hub

It crosses between rigid and a teetering hub

2.1.5 Blade

A blade is now being made on the HAWT due to dominance in the wind turbine industry. HAWT are very sensitive to changes in blade profile and design. The blades (the Parts that look like fan) catch the wind. Sitting at a slight angle to the direction of the wind, the blade are pushed in a circle as the wind blows against them.

2.1.6 Nacelle

The nacelle houses the generator and also adds some weight to the shaft of the generator and the shaft of the turbine.

2.1.7 Shaft or Axis

The shaft connects the turbine to the generator and transmits load, torque and energy from the blade of the turbine to the generator.

2.1.8 Generator

This component converts rotary motion to electrical energy. Induction generators are most commonly used type of generators because they do not require an exciting field current generator. They are continuously being developed for wind turbines with research centered to producing high electrical power at low speed. The wind turbine pulses current, or alternating current. It does so by passing strong magnets over coils of fine wire. For every time a magnet passes over a coil, the coil energized wire electricity. With the four coils connected together in series, the result is a quadrupling of voltage, and this is the simplest and possibly most efficient way to generate electricity, and is equally the basic principle used in almost all wind turbines, even large scale commercial ones. Usually, electricity from wind turbine is converted from alternating current to direct current, which can be used for battery charging.

2.1.9 Fasteners and Joiners

These are bolts and nuts clamps and clips that are used to join each part to another to make up the entire mechanism for proper operation.

2.1.10 Tail Boom

The tail boom aids the entire turbine to turn in the direction of the wind in other to protect the parts from damaging due to high wind speed and sudden change in wind direction.

2.2 Material Requirements and Selection

The selection of a proper material, for engineering purposes, is one of the most difficult problems for the designer. The following factors should be considered while selecting the material:

i. Availability of the material
ii. Suitability of the material for the working conditions in service
iii. The cost of the material desired objective at the minimum cost

The materials used for this project are as follows:

2.2.1 Steel

For all the parts such as the tower, hub, nacelle that require toughness, ductility, weldability and high temperature strength etc.

2.2.2 Alluminum

This is for mainly the tail boom and part of the yaw mechanism; aluminium is used for the tail boom because it is light weighed, high resistance to corrosion, and possess high strength etc.

2.2.3 Mild Steel Plate

The mild steel plate is used for the construction of the turbine blades. The summary of materials selected, dimensions, and quantities used are shown in Table 1.

Table 1. Material Selection

S/N	Description	Dimension	Quantity
1.	Galvanized pipe	50 x 6.3mm	2 length
2.	Bolts and nuts(mild steel)	M16 x 20mm	3pcs
3.	Bolts and nuts(mild steel)	M14 x 15mm	9 pcs
4.	Bolts and nut	M22 x 40mm	3pcs
5.	Mild steel plate	50mm x90mm	3pcs
6.	Mild steel plate	70mm x 70mm	3pcs
7.	Generator	Normal	1set
8.	Electrode	250 x2mm	1pcs
9.	Bearing	40 x 40mm	2set
10.	Cutting disk	250 x 2mm	1pcs
11.	Grinding disk	250 x 6mm	1pcs
12.	Paint	Normal	1thin
13.	Connecting cable	2mm wire	10yards

2.3 The Wind Turbine System

The wind turbine is an electric generator moved by the action of the wind. In the first case, the blades represents the change from the wind energy to the mechanical energy, in the second case, the turn of a rotor inside of a generator represents the change from the mechanical energy to electrical energy.

2.4 Design Calculations

The design calculation for the wind turbine includes;

i. Power output
ii. Turbine blade diameter
iii. Swept area of the blade
iv. Stanchion length
v. Rated output volt
vi. Rated output current

2.4.1 Power in the Wind

Power in the wind is the total energy generated mechanically and converted to electrical energy. Given mathematically as;

$$P_w = ½\delta A V_w{}^3 \qquad (1)$$

where

$\delta = 1.125 kg/m^3$

A = Area

A »» swept area of the blade

And r »» radius of the blade

2.4.2 Power Coefficient (Cp)

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of wind into mechanical energy turning a rotor. To this day, this is known as the Betz limit or Betz's law. The theoretical maximum power efficiency of any design of wind turbine is (0.59) (i.e no more than 59% 0f the energy carried by the wind can be exerted by a wind turbine). This is called the "power coefficient" and is defined as;

$$Cp_{max} = 0.59 \quad (2)$$

where;
P = Power available
P_w = Wind power

Wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine such as strength and durability in particular, the real world limit is well below the Betz limit with values of 0.35-0.59 common even in the best designed wind turbines. Therefore to calculate for the power coefficient in this design,

$$C_p = \frac{p}{pw} \quad (3)$$

P = 200w and P_w = 558 watts (as calculated)

2.4.3 Speed of the Turbine

This is the rate of rotation of the turbine at a velocity from the wind angle of attack. Mathematically, given by;

$$N = \frac{V \times TRS \times 60}{2\pi r} \quad (4)$$

where;
TSR = Tip ratio of the turbine blade

$$\text{Given as *TSR} = \frac{TIP\ SPEED\ OF\ BLADE}{WIND\ SPEED}\ OR\ \frac{4\pi}{n} \quad (5)$$

where,
n = number of blades.

$$TSR = \frac{4\pi}{3} = \frac{12.3}{3} = 4.2 \approx 4$$

The speed of the turbine is given by Equation (6)

$$N = \frac{V \times TRS \times 60}{2\pi r} \quad (6)$$

To determine the tip speed of the blade;

$$U_{tip} = \omega r \quad (7)$$

The tip speed is the actual distance the blades travel in one revolution per time per second.

$$T_w = \frac{p}{\omega} \quad (8)$$

2.4.5 Chord length of the Blades

To determine the chord length of the blade, Equation was used

$$L_{chord} = \frac{4D}{TRS^2 B} \quad (9)$$

where,
D= Blade swept diameter and
B = Number of blades

2.4.6 Tower Calculation
Stanchion Height (H) = 6000mm
Outer Diameter (D) = 10mm
Outer Radius (R) = 50mm
Inner Diameter (d) = 8mm
Inner radius (r) = 4mm
Thickness (t) = 2mm
The volume of the pipe is given by Equation (10)

$$V \frac{\pi H(D^2 - d^2)}{4} \quad (10)$$

2.4.7 Maximum and Minimum Intensity of Stress at the Stanchio
Height of the tower = 6000m

2.4.8 Direct Stress

$$\sigma_d = \frac{W}{A} \quad (11)$$

Where W is the weight of the tower, and given as:

2.4.9 Moment of Inetia

$$I = \frac{\pi}{64}(10^4 - 8^4) \quad (12)$$

2.4.10 Section Modulus

$$Z = \frac{I}{y} \quad (13)$$

The pressure intensity concentrated at the projected area is given by Equation (14)

$$P = K\varphi A_p \quad (14)$$

2.4.11 Bending Moment at the Base

$$M = P\,\frac{H}{2} \quad (15)$$

2.4.12 Bending Stress

$$\sigma_b = \frac{M}{Z} \quad (16)$$

2.4.13 Maximum Stress

$$\sigma_{max} = \sigma_d + \sigma_b) \quad (18)$$

2.4.14 Minimum Stress

$$\sigma_{min} = \sigma_d - \sigma_b \quad (19)$$

3. Result and Discussion

The results obtained showed that the following determined values are required for effectiveness and better performance of the turbine.

i. Power output = 200watts
ii. Turbine blade diameter = 60mm
iii. Swept area of the blade =140mm
iv. Stanchion length = 600mm
v. Rated output volt =12V
vi. Rated output current =12A

The results also confirmed that only 34% of all the mechanical energy developed by the wind will be converted to electrical energy for usage. The number of blades used in this design was determined as 3 and the tip ratio of the turbine blade were obtained as 4. The speed of the turbine was obtained as 2182rpm, and rotor speed of the turbine as 228rad/s. The torque effect at the tip speed was obtained as 12.5N/m. A chord length of 0.0011m was used. The pressure intensity concentrated at the projected area was determined as 19.2N, the direct stress as 4.71KN/m^2, moment of inertial as 295.2mm^4, and section modulus as 59.04mm^3. Furthermore, the bending moment at the base was obtained as 57.7KNm, and the bending stress as 0.98KN/m^2. It was determined that the maximum stress was in tension (5.69KN/m^2), and the minimum stress in compression (3.73KN/m^2).

Moreover, the wind turbine was tested by attaching the base to the stanchion with the help of bolts and nuts. After which the top component (comprising the generator, turbine blade) were mounted on the stanchion through the connections of two bearings of different sizes, the top component was then extended to a height of 6000mm above ground level, where sufficient wind can get to it for rotation of the blades. The device was tested by mounting the wind turbine to a height of 6000mm after which it was observed that the blade began to rotate and as a result of that, the 200 watts bulb was being lit. Table two and Figure 1 show the results obtained from performance test. The minimum and maximum tests time duration were 5minutes and 10 minutes respectively. It was observed that time was directly proportional to the amount of power generated with highest amount of power generated (200watts) at 20minutes and minimum power generated (170 watts) at 5minutes.

Table 2 Performance Test Result

Electrical power (watts)	Time (minutes)
170	5
180	10
195	15
200	20

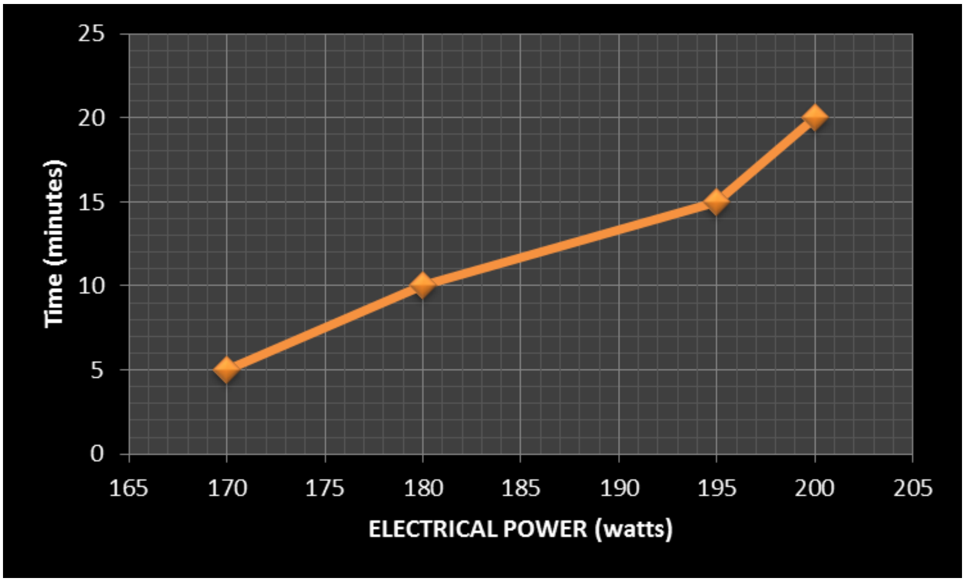

Fig. 1 Plot of Time (minutes) against Electrical Power (watts)

Figure 2 shows the dimensioned view of the horizontal wind turbine.

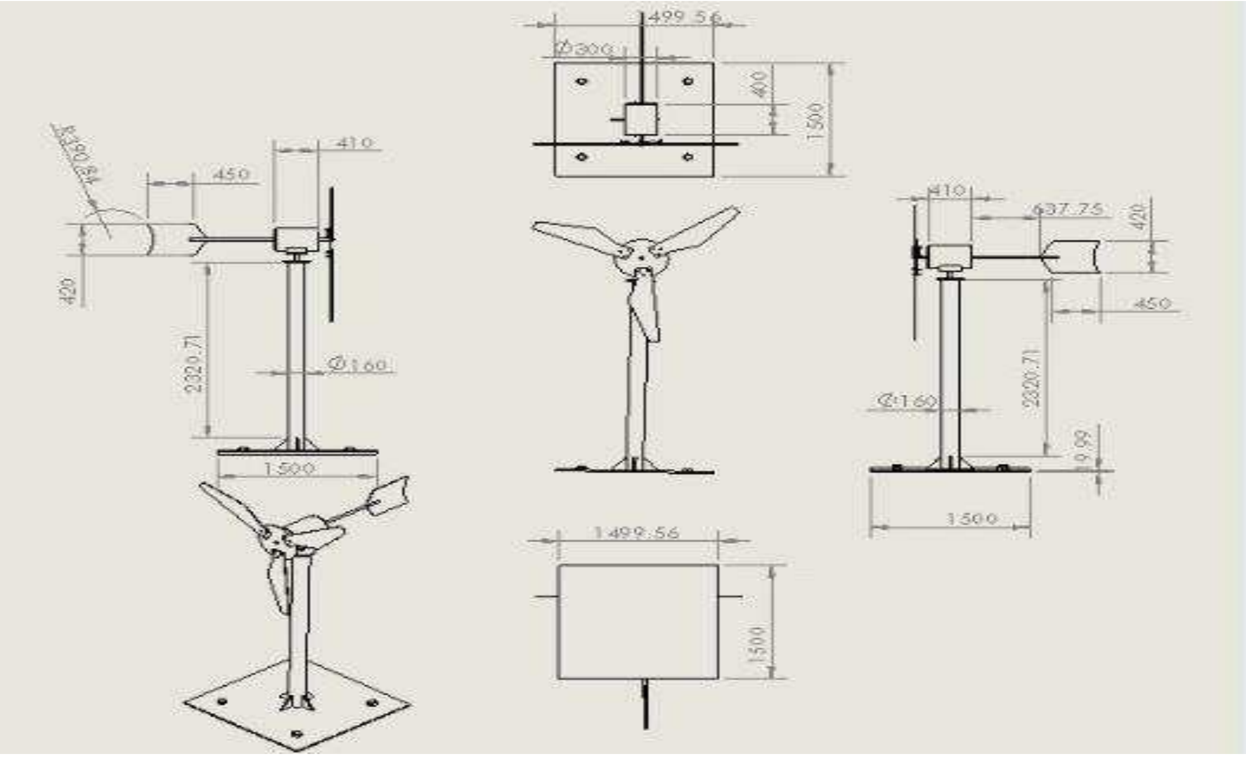

Fig. 2 Dimensioned view of Horizontal Wind Turbine

Figure 3 shows the isometric view of the of the horizontal wind turbine.

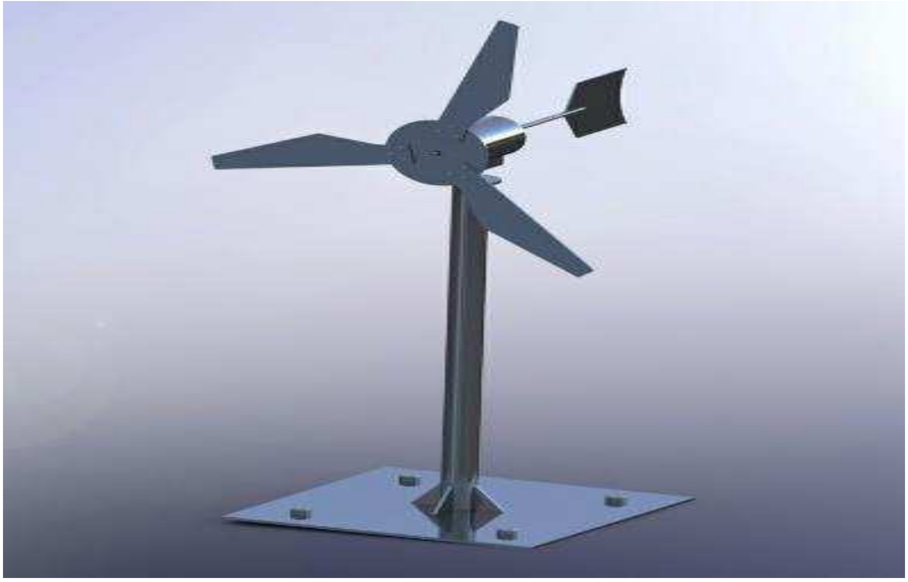

Fig. 3 Isometric view of the of the Horizontal Wind Turbine.

Figure 4 shows the exploded view of the of the horizontal wind turbine.

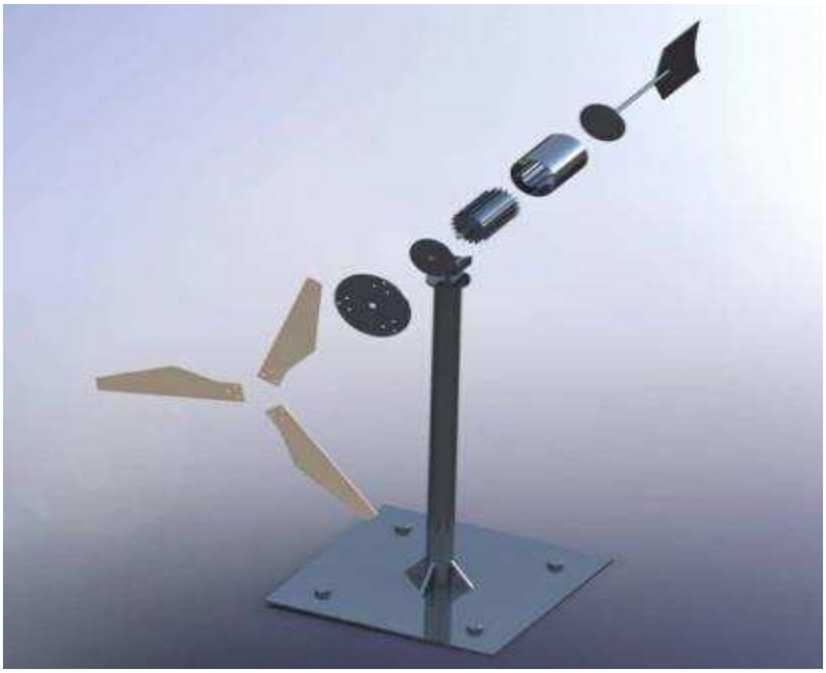

Fig. 4 Exploded View of the of the Horizontal Wind Turbine.

4. Conclusion

The horizontal wind turbine was successfully designed and constructed. From the result of performance test carried out on the constructed wind turbine, the wind turbine was able to generate electricity. Thus, it can replace non-renewable energy sources. However, as a matter of technological application of equipment, this wind turbine should be frequently put to use. Also, periodically maintained by the way of lubricating the moving parts regularly to limit friction should be practice. Besides, the horizontal wind turbine can solve some parts of Nigeria energy problem when used domestically. For commercial scale usage, the project can be scaled up for generation of large amount of power.

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