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Research Article

Improving the Design of Blade for Horizontal Axis Wind Turbine with QBlade Software

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Abstract
As climate change is instigating massive human distress globally, several nations have agreed to minimize the release of greenhouse gases through the effective use of renewable energy resources like wind power through the Paris treaty of 2015 and COP-26 organized in Glasgow, Scotland. The blade is an important part of a wind turbine and its design impacts the efficiency of a wind farm immensely. In this paper, the design optimization of an NREL 5 MW horizontal axis wind turbine has been attempted with QBlade software. The optimized blade design validates improved co-efficient of power and developed stress profile.
Keywords: Blade; Horizontal Axis; NREL; QBlade Software; Wind Turbine.

1. Introduction

Because of the unreliable supply and detrimental effect of hydrocarbon-based fuels, renewable power generation techniques can support electricity generation businesses to generate power with minimal carbon footprint [1]. Wind energy is a competent renewable power generation resource and is assisting countries to produce electricity cost-effectively [2] [3].

Several kinds of research have been aimed at boosting the efficiency of wind power generation systems [4] - [16]. Researchers looked for important features of controlling and upkeep Wind Turbines (WTs). Nearly 0.28 annual breakdowns have been estimated for the blade tip of WT [17]. The breakdown proportions of German and Danish WTs applying the Windstats consistency details and power-law technique [18]. It has been detected that the collapse frequency for German WTs was to some extent more and was expected to fall to the identical magnitude of the malfunction proportions of Danish WTs after 7 years. A three-dimensional finite element prototype for fatigue crash of a completely composite-formed WT airfoil blade has been explored [19]. Because of the arbitrariness of the air flow form, a stochastic procedure had been betrothed to plan a software scheme for emulating the current of air with randomness on the WT blade, and afterward, each load case was associated with the conforming Weibull distribution.

In a study published in 2019, a software simulation has been undertaken for a small WT (less than 1 kW) rotor blade using the Blade Element Method (BEM) for maximizing the lift and drag coefficient ratio along with the power factor [20].

The present paper aims to increase the power co-efficient and the developed stress characteristics using the QBlade software for a 5 MW WT.

2. Problem Design

The current research has been performed for a horizontal axis WT. The power co-efficient of a WT can be calculated as per Eq. (1) [20].

$$C_p = \frac{P_{actual}}{P_{wind}} \tag{1}$$

where P_{actual} denotes the actual generated electrical power and P_{wind} signifies the available power flowing through the wind at a certain speed.

The process of WT design employing the QBlade software can be described as follows.

a) Design of the WT blade.
b) Modeling of the WT rotor,
c) Simulation of the entire WT.

In this current work, a National Renewable Energy Laboratory (NREL) 5 MW WT has been deemed. At first, the airfoil has been designed for a WT blade of 43.05 m.

The WT blade for standard NREL 5 MW WT has been shown in Fig. 1.

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Figure 1. *Standard NREL 5 MW WT Blade*

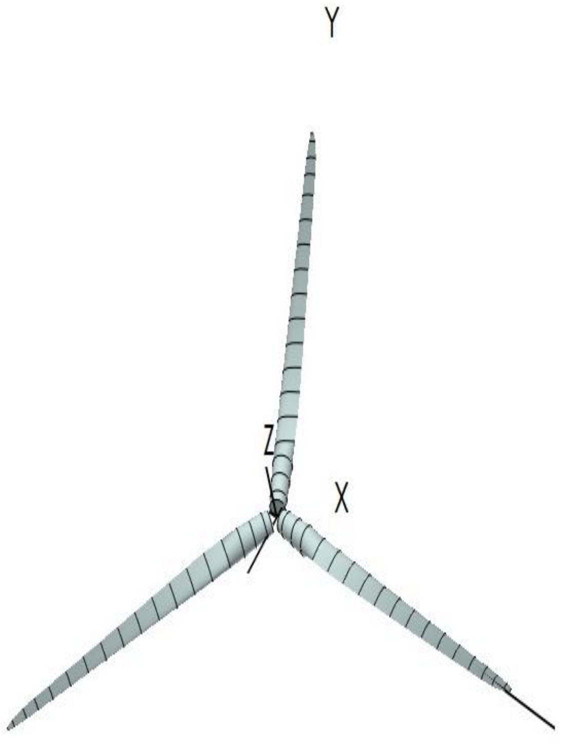

Figure 2. *Rotor View of Standard NREL 5 MW WT Blade*

Table 1. *Standard NREL 5 MW WT Blade Data*

Position (m)	Chord (m)	Twist	Foil
0	3.2	13.08	Circular Foil 0.5
1.36	3.54	13.08	Circular Foil 0.5
4.1	3.85	13.08	Circular Foil 0.5
6.83	4.67	13.08	Circular Foil 0.35
10.25	4.55	13.08	DU99W405LM
14.35	4.652	11.48	DU99W350LM
18.45	4.458	10.16	DU99W350LM
22.55	4.249	9.011	DU97W300LM
26.65	4.007	7.795	DU91W225LM
30.75	3.748	6.544	DU91W225LM
34.85	3.502	5.361	DU93W210LM
38.95	3.256	4.188	DU93W210LM
43.05	3.01	3.125	NACA64618

The simulated wind field with a mean airspeed of 13 m/s has been shown in Fig. 3.

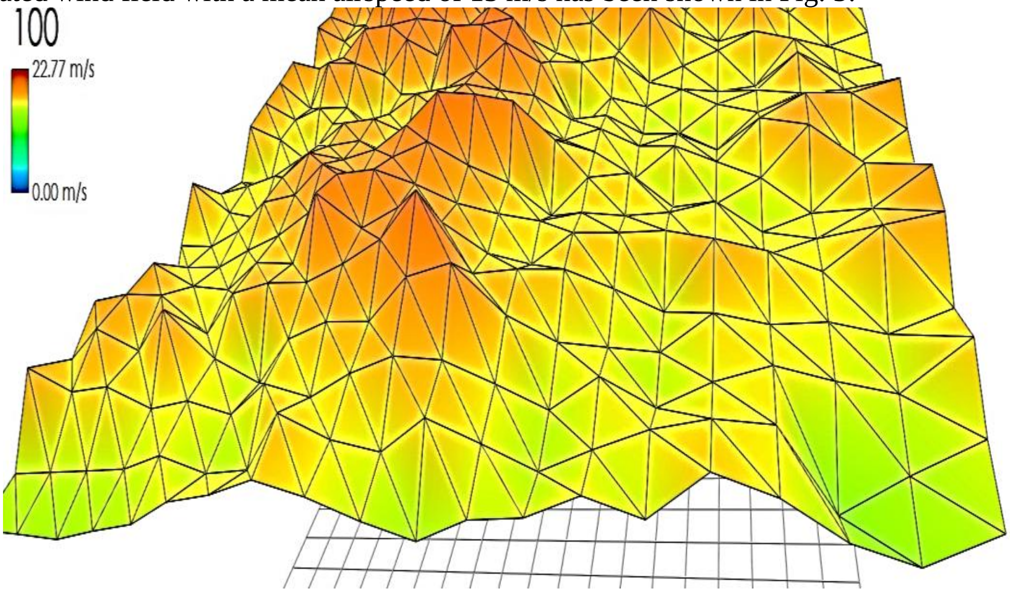

Figure 3. *Considered Wind Field*

The power simulation of standard NREL 5 MW WT has been shown in Fig. 4.

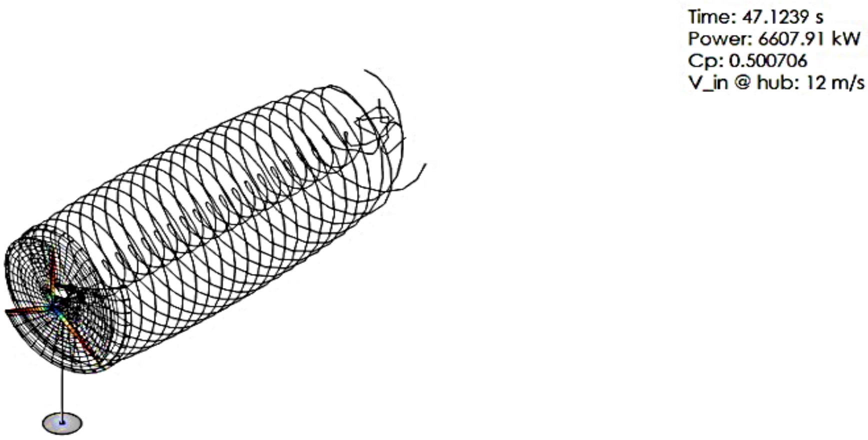

Figure 4. *Power Simulation Using Standard NREL 5 MW WT*

The loading condition on the WT blade has been presented in Table 2.

Table 2. *Loading Condition on the WT Blade*

Radial Position (m)	Normal Loading (N)	Tangential Loading(N)
0	4.65125	-4.31069
1.36	22.3584	-22.2077
4.1	43.0771	-62.938
6.83	64.9657	-102.651
10.25	366.223	53.4711
14.35	480.349	81.7205
18.45	474.401	53.9021
22.55	611.256	57.682
26.65	945.007	77.0227
30.75	1341.61	81.3494
34.85	1825.48	69.0401
38.95	2202.58	54.3237
43.05	2483.5	48.0438

3. Results and Discussion

The stress profile generated for the standard NREL 5 MW WT rotor blade using the loading condition of Table 2 has been shown in Fig. 5.

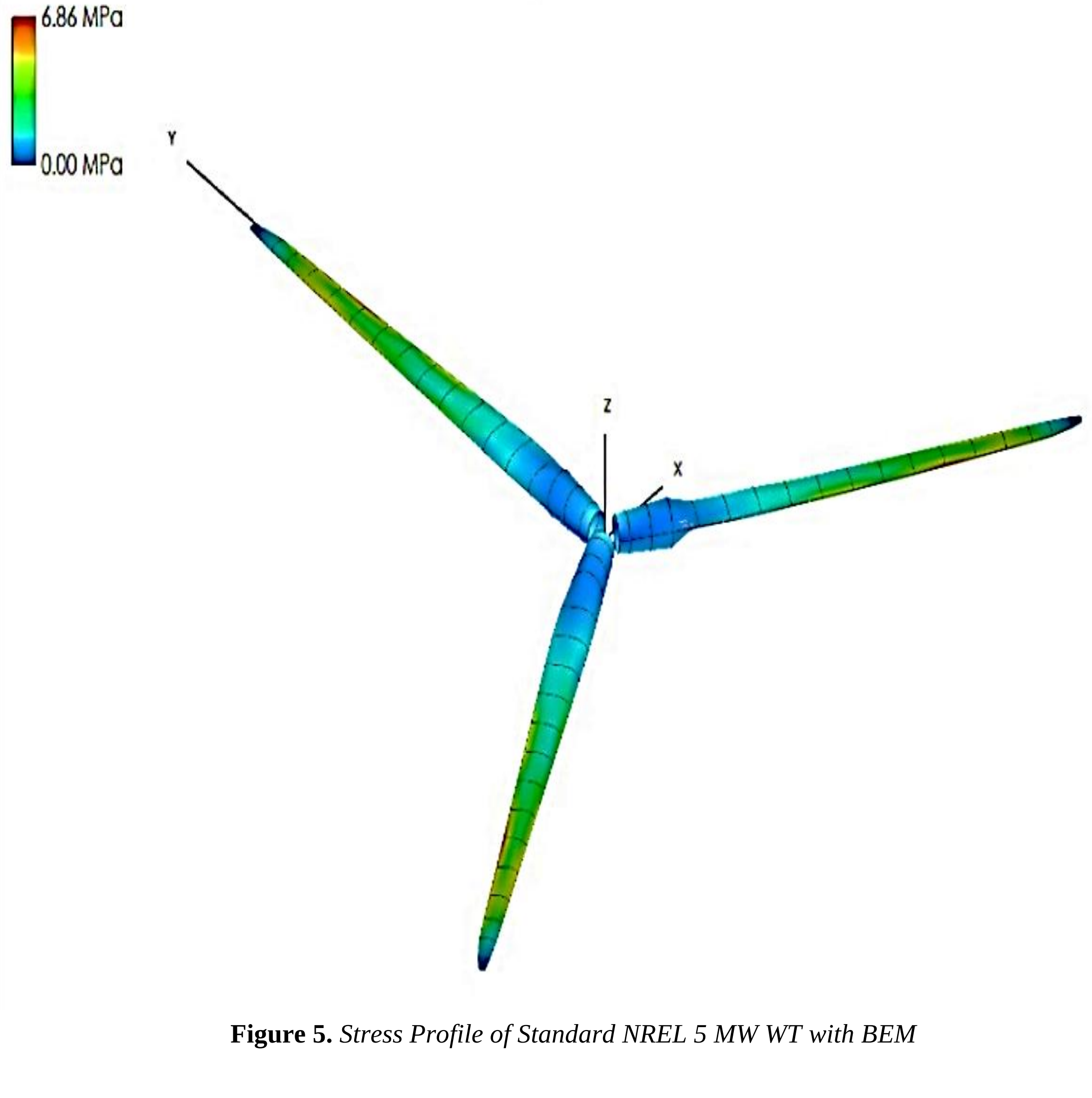

Figure 5. *Stress Profile of Standard NREL 5 MW WT with BEM*

Table 3. *Optimized NREL 5 MW WT Blade Data*

Position (m)	Chord (m)	Twist	Foil
0	3.2	13.08	Circular Foil 0.5
1.36	3.54	13.08	Circular Foil 0.5
4.1	3.85	13.08	Circular Foil 0.5
6.83	4.167	13.08	Circular Foil 0.35
10.25	10.4399	13.08	DU99W405LM
14.35	6.44813	11.48	DU99W350LM
18.45	6.69132	10.16	DU99W350LM
22.55	6.4402	9.011	DU97W300LM
26.65	5.33015	7.795	DU91W225LM
30.75	4.8217	6.544	DU91W225LM
34.85	4.10463	5.361	DU93W210LM
38.95	3.61205	4.188	DU93W210LM
43.05	3.4957	3.125	NACA64618

The optimized NREL 5 MW WT has been presented in Figs. 6 and 7.

Figure 6. *Optimized NREL 5 MW WT Blade*

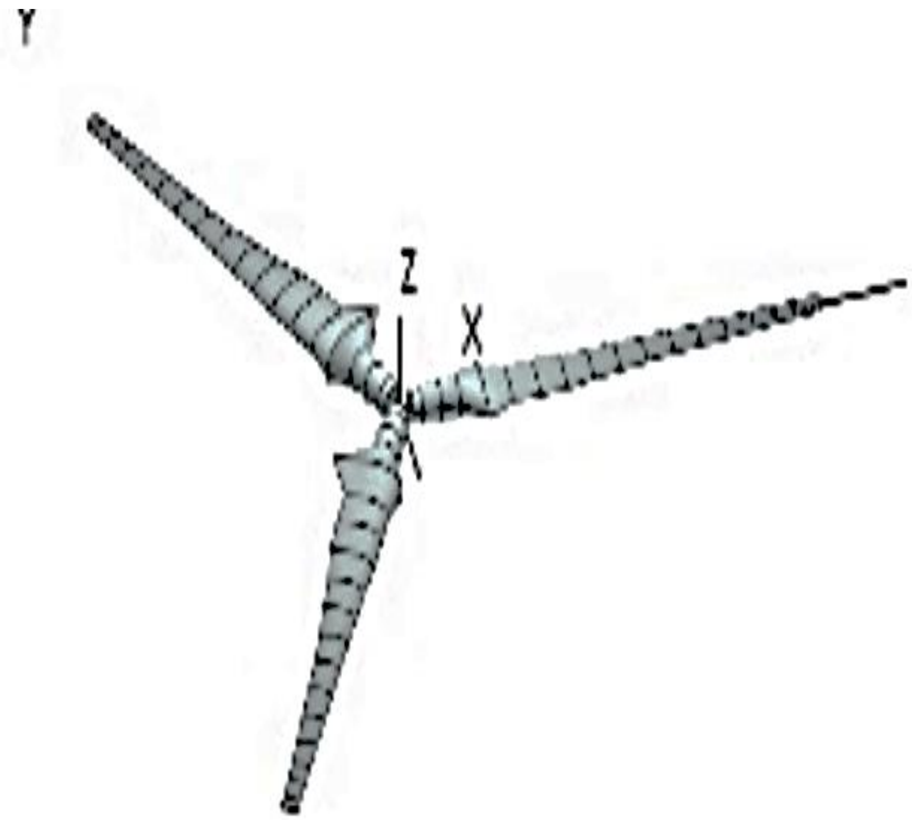

Figure 7. *Rotor View of the Optimized NREL 5 MW WT*

The simulated power co-efficient and BEM stress analysis has been shown in Figs. 8 and 9 respectively.

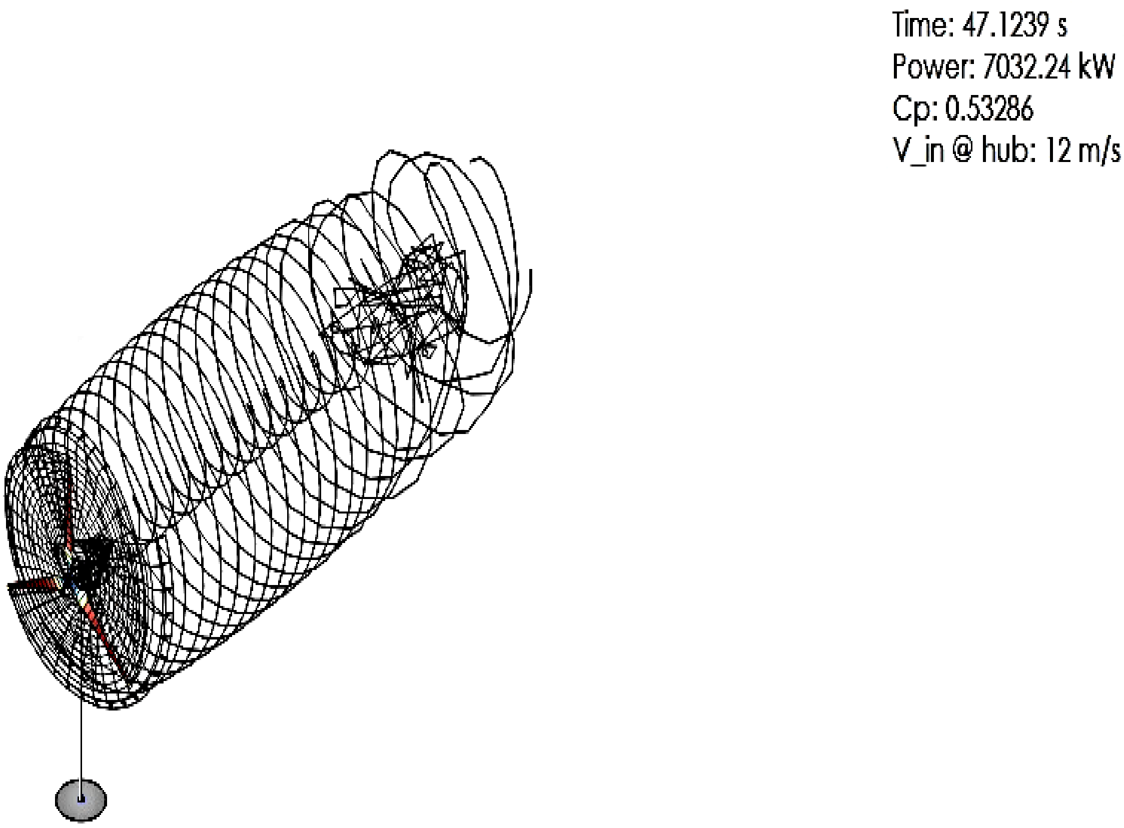

Figure 8. *Power Simulation of the Optimized NREL 5 MW WT*

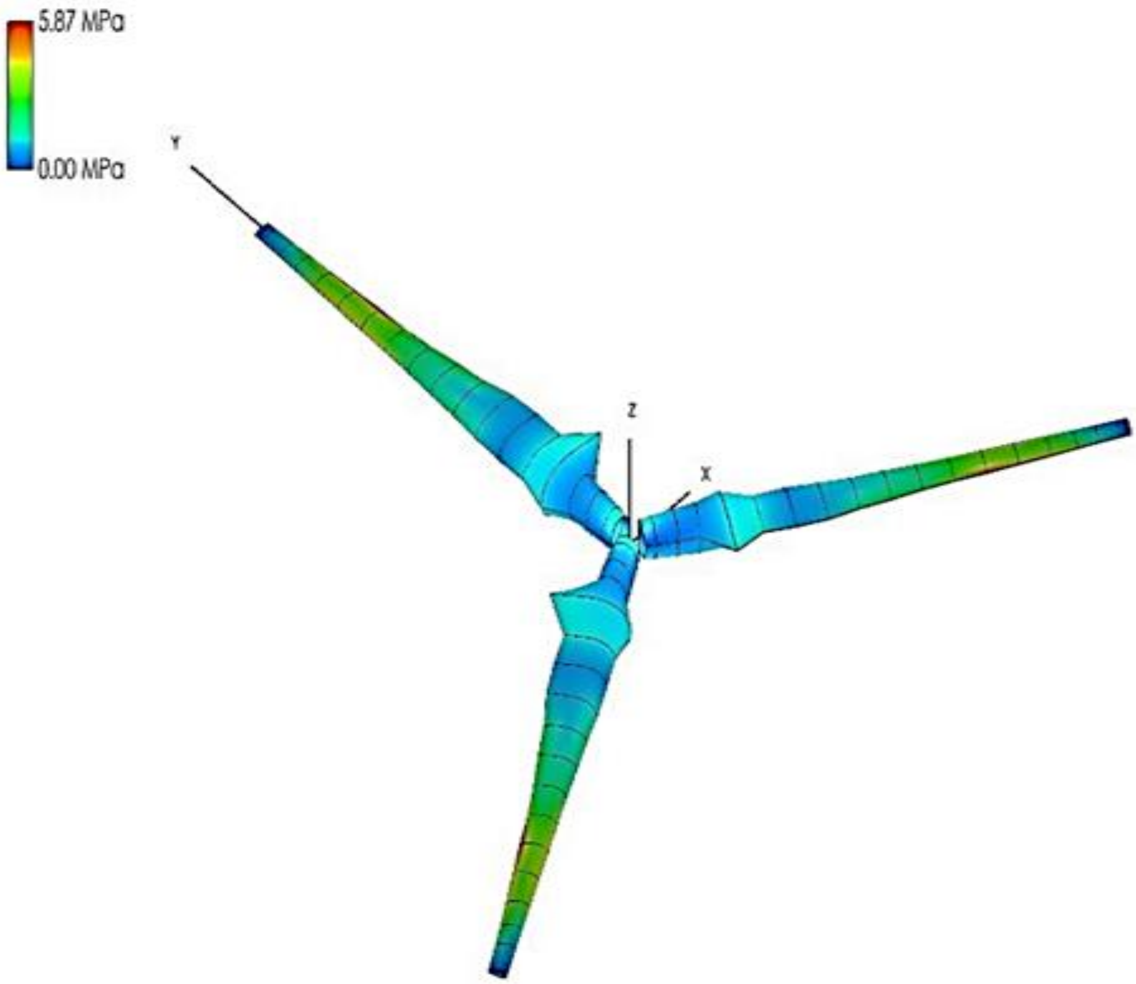

Figure 9. *Stress Profile of Optimized NREL 5 MW WT with BEM*

The power co-efficient and maximum generated stress for both the blade patterns have been presented in Table 4.

Table 4. *Comparative Analysis of Blade Profiles*

Blade Profile	**Power Co-efficient (C_p)**	**Maximum Developed Stress (σ_{max})**
Non-Optimized Standard NREL 5MW WT Rotor Blade	0.500706	6.86 MPa
Optimized NREL 5MW WT Rotor Blade	0.53286	5.87 MPa

The analysis validates the superiority of the optimized blade profile over the non-optimized standard NREL 5 MW WT rotor blade for presenting higher power co-efficient and lower maximum developed stress.

4. Conclusion

Wind power is being utilized transnationally for curbing the carbon footprint of the electricity generation sector. WT rotor blade design is an influential factor in optimizing the wind power generation system performance. In this paper, the design of the NREL 5 MW WT rotor blade has been enhanced to increase the power co-efficient and curtail the developed stress profile. This research can initiate novel prospects for wind power generation design improvement procedures.

Declaration of Interest

The authors declare that there is no conflict of interest.

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