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Computational Investigation of Wind Turbine with Winglets

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***Abstract*— Wind energy is became vital and ecofriendly. The development of the wind turbine is an evolution and presently 3 blade single rotor wind turbines are commonly used around the world. These types use mega structures (> 50 tons) for producing 1 to 6 MW power in off and on shore areas. The 3 blade single rotor wind turbines play main role in the wind power generation, however it may have some weak points.**

Lift is an useful component to produce more power. Induced drag is one kind of drag which arises during production of lift in the form of tip vortices in wind turbine blade. These vortices travel over turbine blade during operation and collapse the flow and lead to reduction in lift force. In aircrafts, same problem is solved by providing winglets and this is tried in this project for wind turbine.

In present work, design and analysis of wind turbine with winglet is proposed. Winglet height is varied from 10mm to 40 mm in increment of 10mm and cross section varied as NACA 0012 and 0018. Computational investigation of conventional rotor and modified rotor is done. Ultimately, experimental investigation will be done.

II. MATERIALS AND METHODS

2.1 DESIGN THEORY

In wind turbine blade pitch is very large. Interactions between blades can be neglected in theoretical design. Wind turbine is one of the only in turbo machinery where one of the blade can be considered in isolation. Consider turbine shown below, speed of all blade will be same and assuming that wind velocity does not vary over the area of machine. Therefore, an analysis needs to be conducted on single blade.

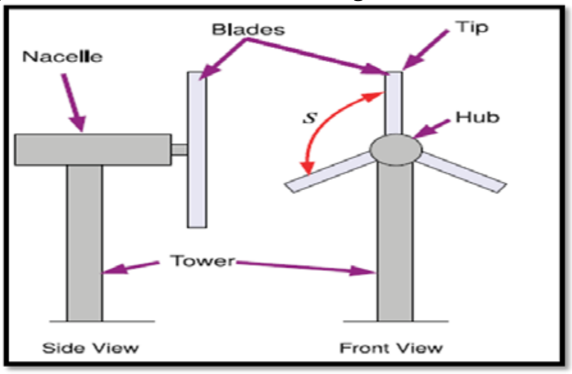

Fig. 2.1 Wind Turbine Views

Using blade element method, wind turbine is designed. In blade element method, small section of blade is considered. Tangential and axial forces can be calculated for this section. Then, it is integrated to full blade length.

2.2 INPUT PARAMETERS

i.	Air velocity	-	5 m/s
ii.	Air density	-	1.23 kg / m^3
iii.	Speed	-	500 rpm
iv.	Chord length	-	50 mm
v.	Blade length	-	300 mm
vi.	Hub radius	-	75mm

This is based on the wind tunnel parameters available.

2.3 DESIGN CALCULATION

Lift L = $C_l \times 0.5 \times \text{density} \times W^2 \times c$

Where,

C_l	-	Lift co-efficient
W	-	Relative velocity
c	-	Chord length

NACA 0012 airfoil is selected because it is tiny wind turbine. NACA 0012 is symmetrical and thin airfoil.

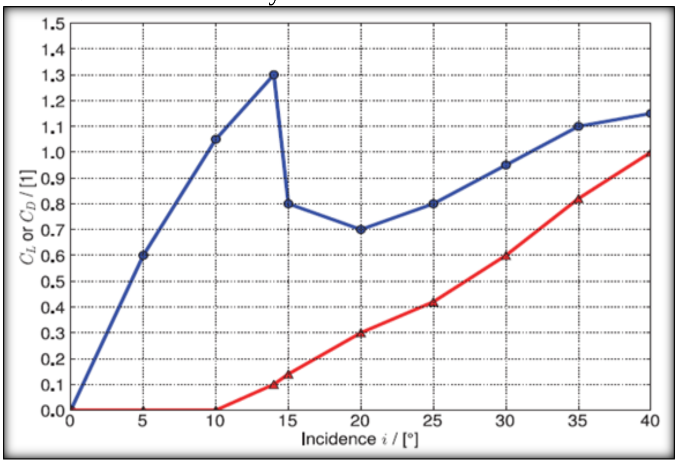

Fig. 2.2 Airfoil data for NACA 0012

ISSN 2348 – 7968

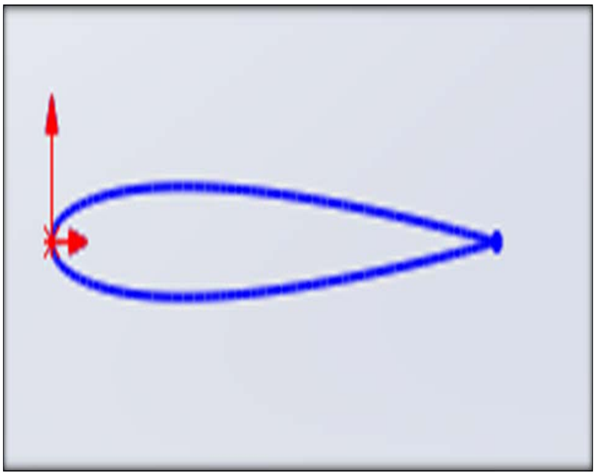

Fig. 2.3 NACA 0012

C_l and C_d data for NACA 0012

C_l = 1.05 for optimum angle attack of 10°
W = $(V^2 + U^2)^{0.5}$
Where,
U - Rotor linear velocity
V - Air velocity or Absolute velocity
R - Radius
Ω - Angular velocity
U = r × ω
ω = (2×3.14×N) / 60
= 52.33 rad / s
U = 0.375 × 52.33
= 19.625 m / s
W = 20.25 m / s
L = 13.24 N / m
F = L cos β
Where,
F – Tangential force
B – Relative flow angle
P – Power
β = $\tan^{-1}$ (U/V) = 75
F = 3.43 N / m
P = F × U
= 67. 26 W / m
Power for 300mm blade:
P_{300} = 20.18 W

Table 2.1 Theoretical Power Vs Velocity

Velocity	Relative angle	Angle of attack	Power
5 m/s	75°	10°	20W
10m/s	63°	10°	41.87W
15m/s	52.6°	10°	70.45W

2.4 Cad Models of Single Rotor

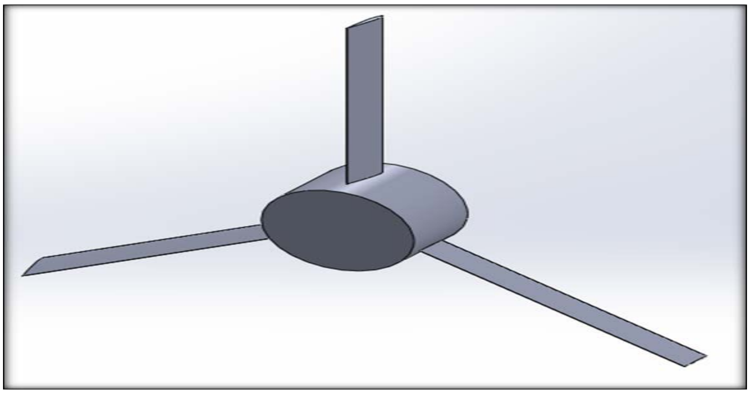

Fig. 2.4 Single Rotor

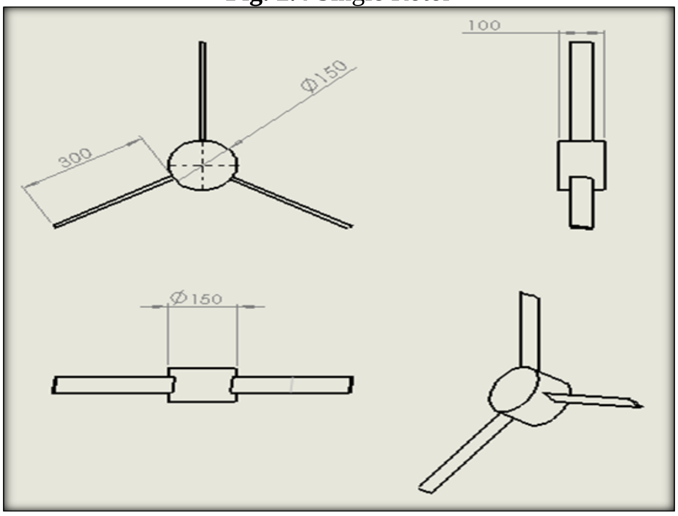

Fig. 2.5 Dimensions of Single Rotor

2.5 MODIFIED ROTOR WITH WINGLETS OF DIFFERENT HEIGHTS

Winglets are provided to control tip vortices and to avoid downwash which affects lift. Lift is a useful component of force to produce power in wind turbine. Therefore, designed conventional rotor is modified with winglet of different heights and cross-section. Winglet heights are 10mm, 20mm, 30mm, 40mm. Cross-sections are NACA 0012 and NACA 0018.

2.6 CAD MODELS OF MODIFIED ROTOR

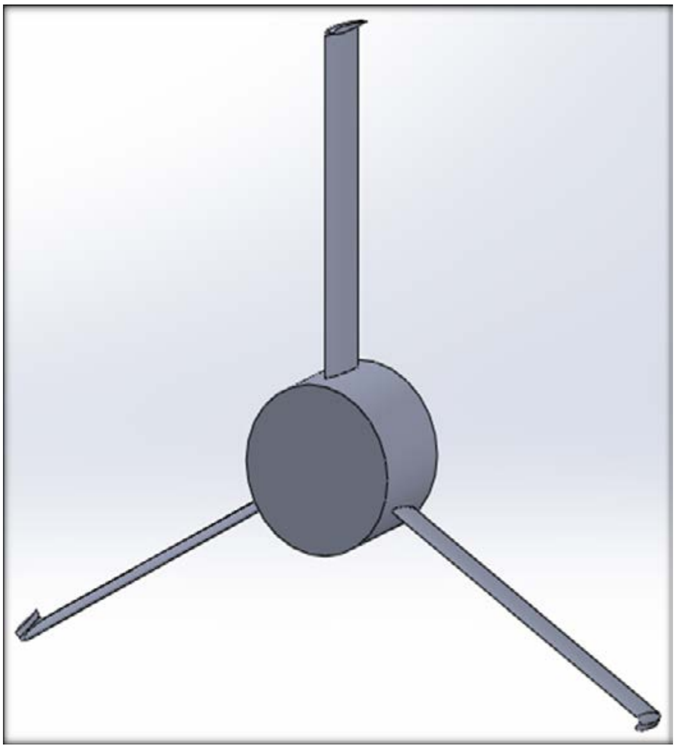

Fig.2.6 Winglet with 10mm

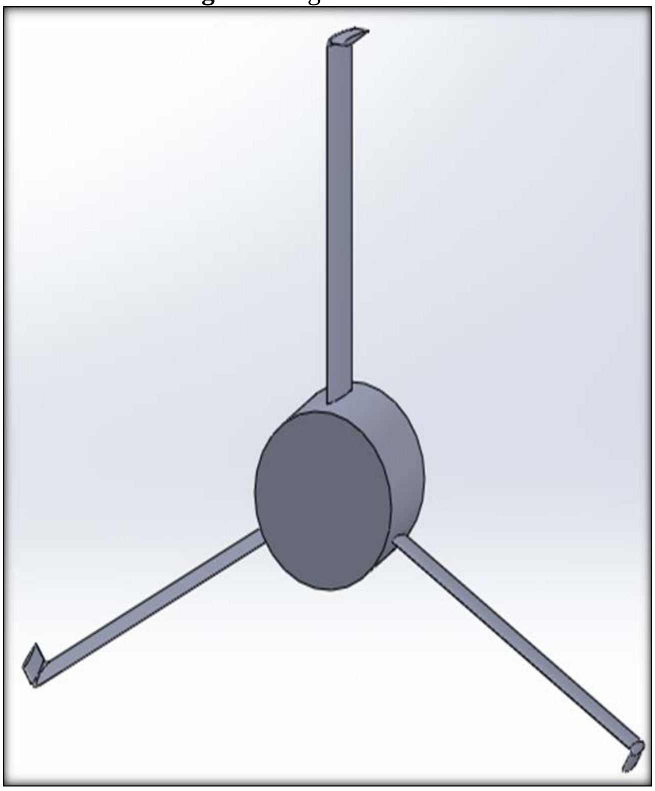

Fig.2.7 Winglet with 20mm

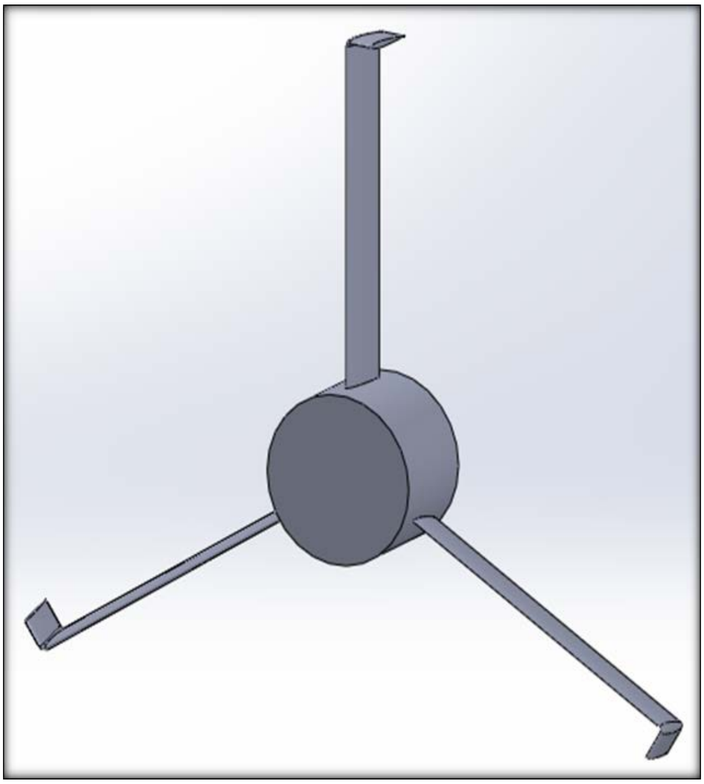

Fig.2.8 Winglet with 30mm

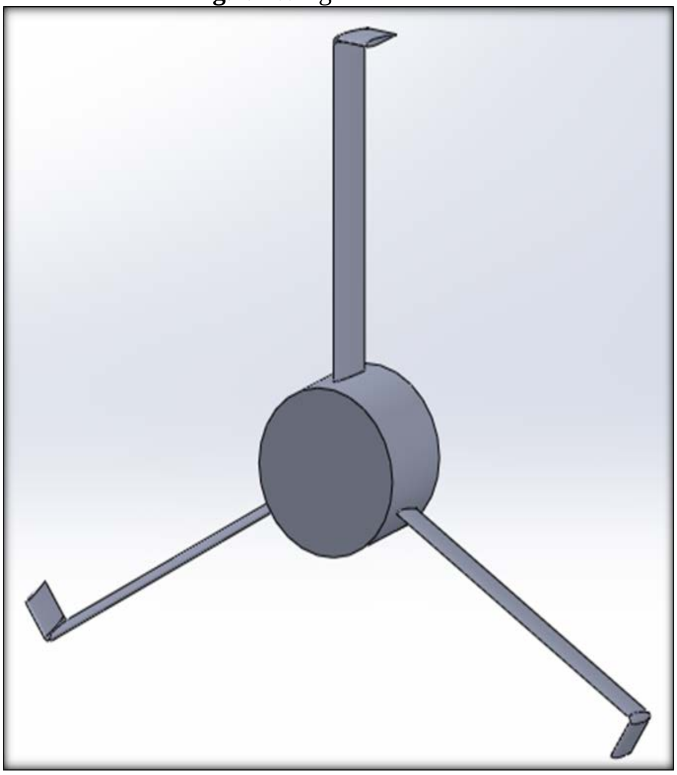

Fig.2.9 Winglet with 40mm

ISSN 2348 – 7968

2.7 SIMULATION PARAMETERS

Type of analysis	–	External flow
Boundary condition	–	Free stream velocity (5, 10, 15)
Initial Pressure	-	Atmospheric pressure
Initial Temperature	-	293K
Air Density	-	1.23 Kg/m
Turbulence Model	-	K-epsilon

Solver - Solid works-COSMOS FLOW WORKS

2.8 Simulation Results of Conventional Rotor

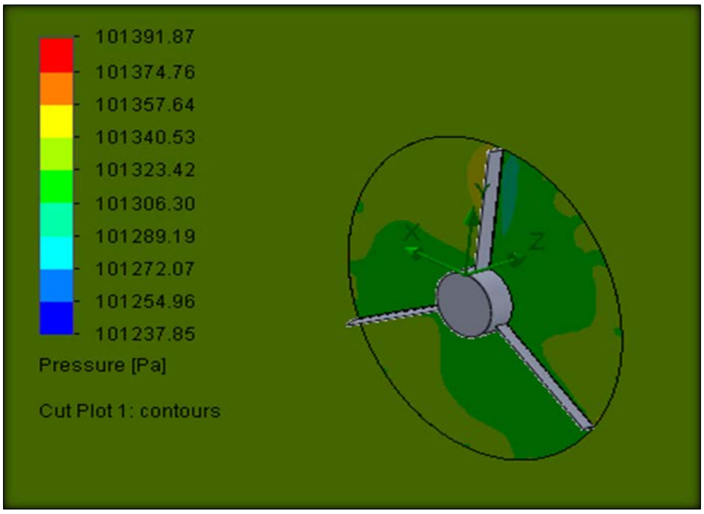

Fig.2.10 Cut Plot Of Pressure-Conventional Rotor 5 M/S

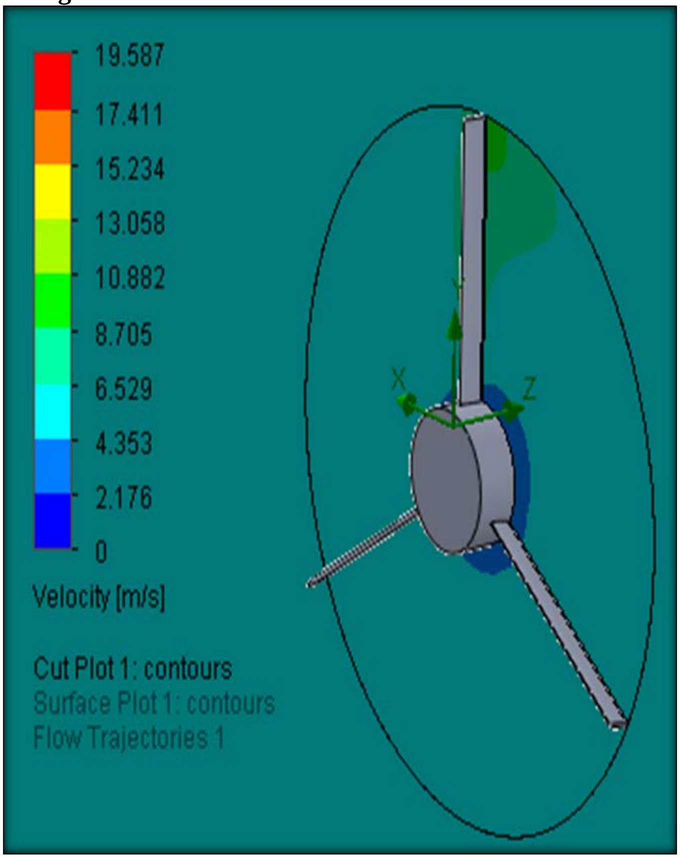

Fig.2.11 Cut plot of velocity-Conventional Rotor 5 m/s

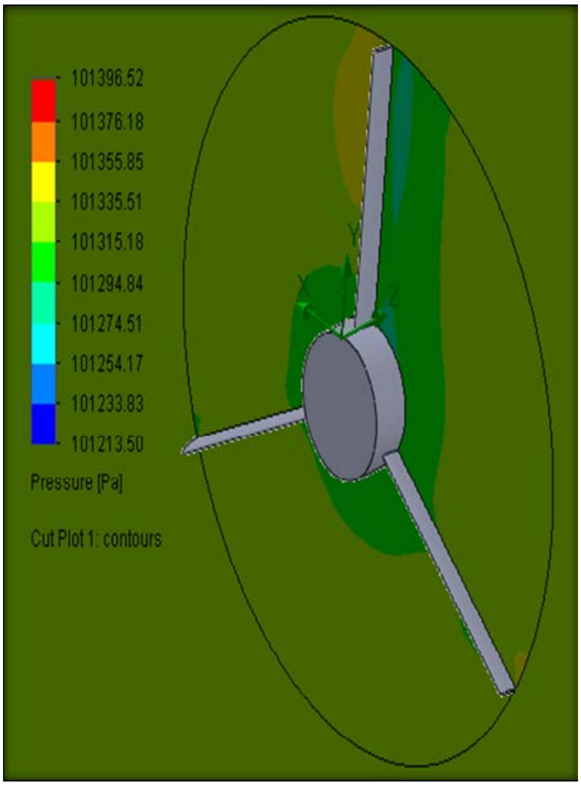

Fig.2.12 Cut Plot of Pressure-Conventional Rotor 10 m/s

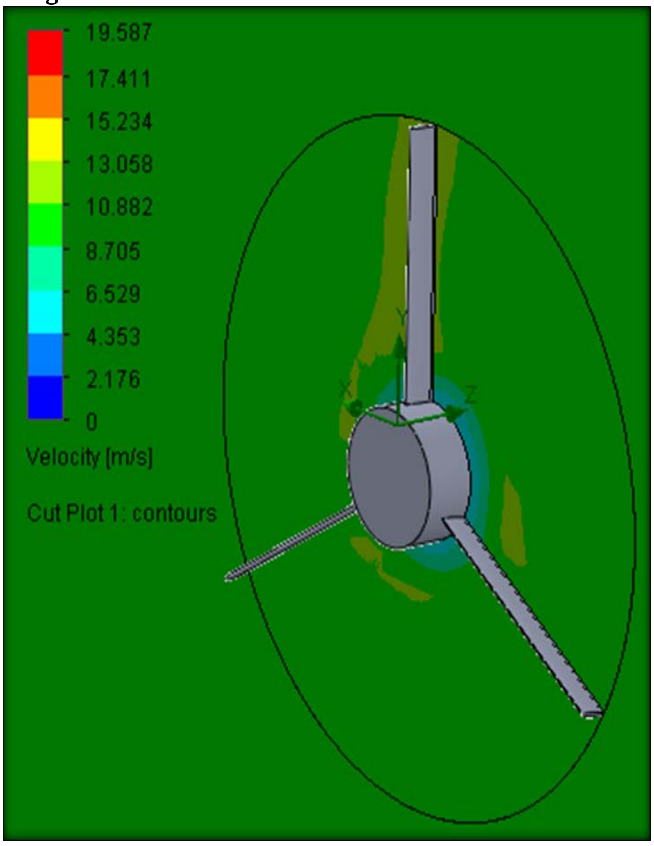

Fig.2.13 Cut plot of velocity-Conventional Rotor 10 m/s

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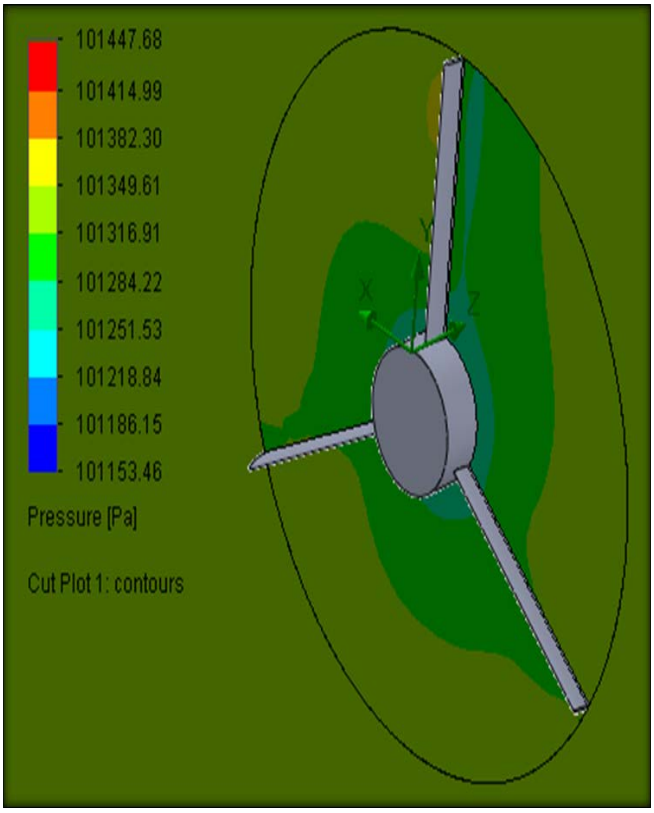

Fig.2.14 Cut Plot of Pressure-Conventional Rotor 15 m/s

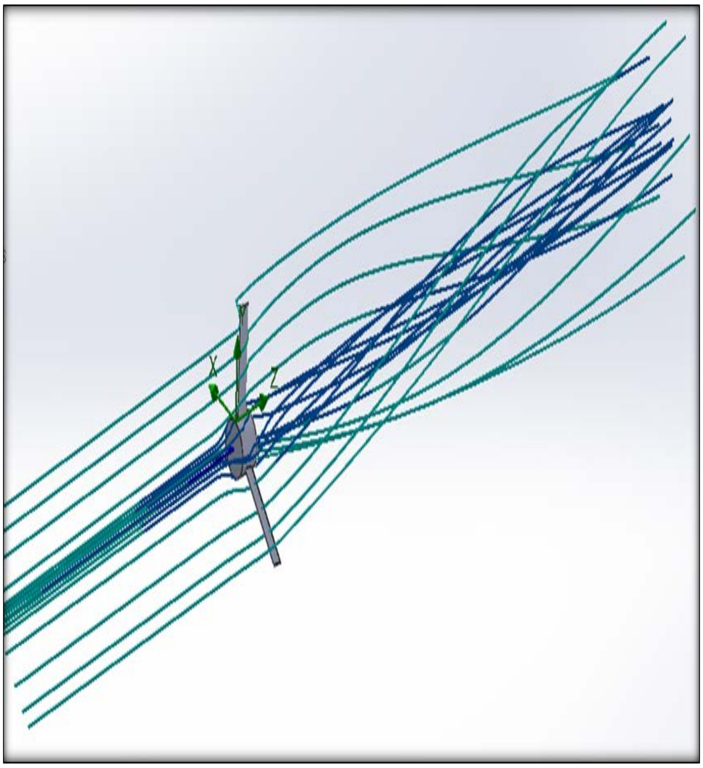

Fig.2.16 Flow Trajectories of Conventional Rotor

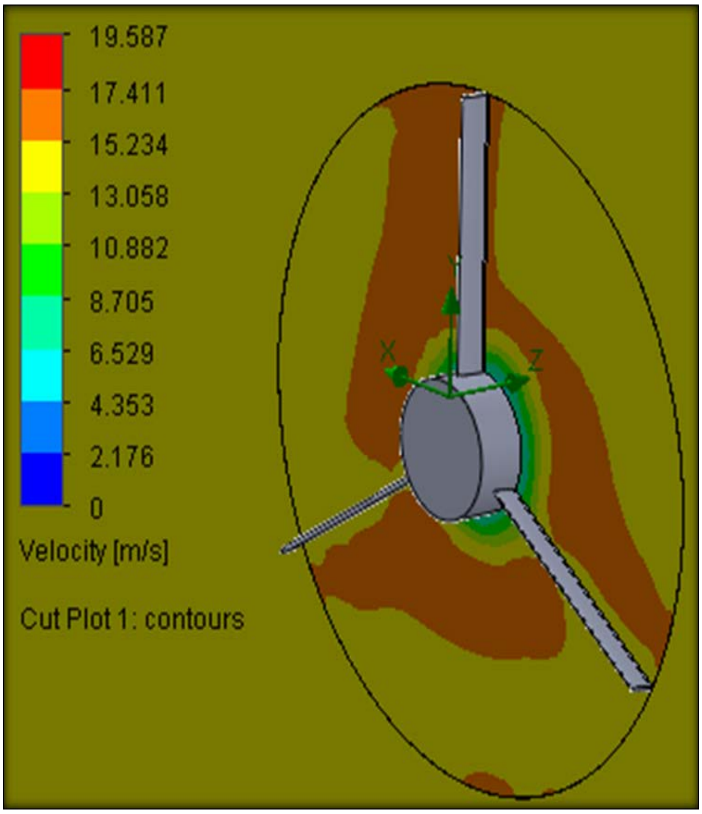

Fig.2.15 Cut plot of velocity-Conventional Rotor 15 m/s

3.9 Simulation Results of Winglets 10mm (NACA 0012)

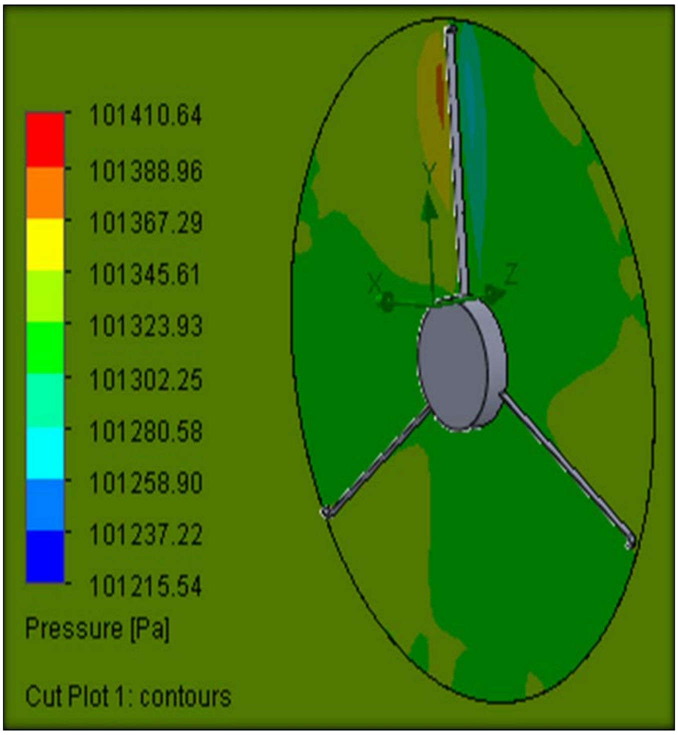

Fig.2.17 Cut Plot of Pressure- Winglet 10mm (NACA 0012) 5 m/s

III.SUMMARY AND CONCLUSION

ISSN 2348 – 7968

Table 3.1 Conventional Rotor-Power

Velocity (m/s)	Power of Conventional Rotor (W) - CFD	Power of Conventional Rotor (W) - Analytical	Variation in power (%)
5	13.54	20	32.3
10	27.65	41.87	33.96
15	55.46	70.45	21.28

Table 3.2 Conventional Rotor- Normal Force

Velocity (m/s)	Normal Force (N)
5	0.690
10	1.409
15	2.826

Power is calculated from normal force time's linear rotational velocity.

$$P = F_{normal} * U$$

Conventional rotor is designed and analyzed using CFD software COSMOS FLOW WORKS. Analytical and computational results tabulated above. Computational results are 20 to 34% below than theoretical one.

Table 3.3 Conventional Rotor with Winglet (NACA 0012) – Power

Velocity (m/s)	Power of 10mm winglet (W)	Power of 20mm winglet (W)	Power of 30mm winglet (W)	Power of 40mm winglet (W)
5	19.66	19	22.88275	6.77
10	33.03	32.97	42.1	24.37
15	68.66	67.18	82.31	54.81

Table 3.4 Conventional Rotor with Winglet (NACA 0012) – Normal Force

Velocity (m/s)	Normal Force of 10mm winglet (N)	Normal Force of 20mm winglet (N)	Normal Force of 30mm winglet (N)	Normal Force of 40mm winglet (N)
5	1.002	0.968	1.166	0.345
10	1.683	1.68	2.144	1.246
15	3.499	3.423	4.194	2.793

Table 3.5 Conventional Rotor with Winglet (NACA 0018) - Power

Velocity (m/s)	Power of 10mm winglet (W)	Power of 20mm winglet (W)	Power of 30mm winglet (W)	Power of 40mm winglet (W)
5	20.44	21.81	20.02	18.4
10	30.99	33.36	34.64	27.87
15	62.02	68.88	35.18	55.44

Table 3.6 Conventional Rotor with Winglet (NACA 0018) – Normal Force

Velocity (m/s)	Normal Force of 10mm winglet (N)	Normal Force of 20mm winglet (N)	Normal Force of 30mm winglet (N)	Normal Force of 40mm winglet (N)
5	1.042	1.112	1.02	0.9376
10	1.579	1.70	1.765	1.42
15	3.16	3.51	1.7925	2.825

Above tables show that rotor with winglets gives better performance than conventional rotor (rotor without winglets). Besides, we have done simulation for different winglet heights (10mm-40mm) and cross-sections. This is to find effect of winglet height and cross-section (NACA Profile) at winglet portion over performance of wind turbine. We have designed wind turbine for 5m/s free stream velocity. Most of the time throughout the year wind turbine is exposed 5m/s velocity wind only. Therefore, effects of height and cross-section are considered at design point (5m/s).

Change in cross-section (NACA 0018) at winglet portion not shows larger variation from former one (NACA 0012). Here, it can be considered effects of height at design point with NACA 0012 profile. From that, power increases till 30mm and then goes down. Therefore, we concluded that 30mm height winglet is suitable for this configuration.

This result shows good point to wind turbine with winglet related researches. There is an optimum height for every new design which we need to find out through CFD for better efficiency of wind turbine. Performance of wind turbine increases with increase in winglet height for some height after that it will reduces. Different NACA profiles at winglet portion and different configuration of wind turbine is future concern of this project.

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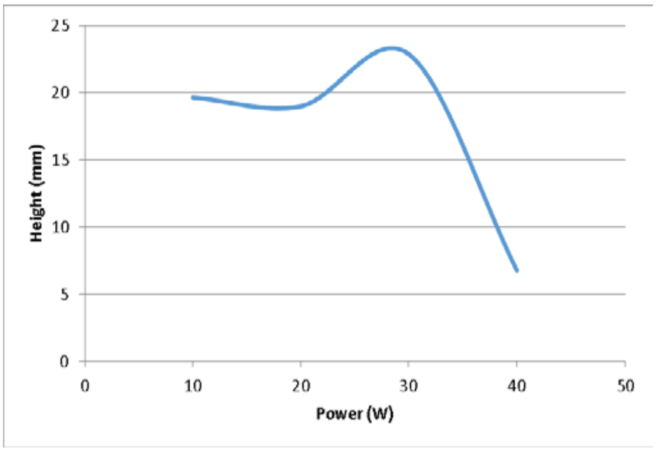

Fig.3.1 Height Vs Power- 5m/s- NACA 0012

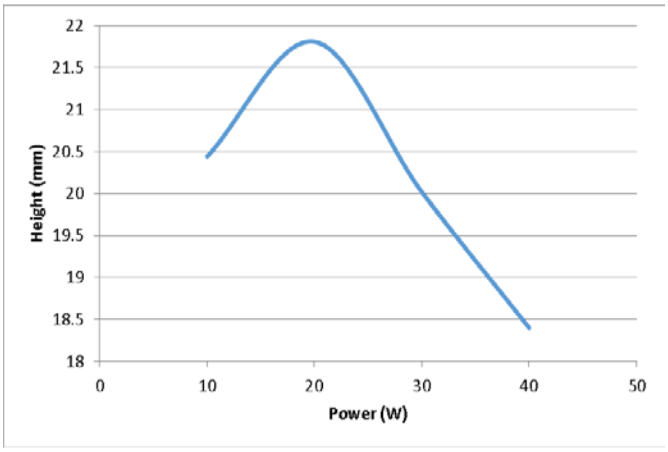

Fig.3.2 Height Vs Power- 5m/s- NACA 0018

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