OPTIMIZATION OF SMALL HORIZONTAL AXIS WIND TURBINE BLADE USING COMPUTATIONAL FLUID DYNAMIC ANALYSIS

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Abstract - *World is moving towards the renewable sources of clean energy for the energy requirements of today and tomorrow faster. One of the key component of the system is wind turbine blades. In this work we propose to optimize the aerodynamic shape through parametric study on the general small wind turbine blade geometry. This work will optimize the chord length and twist angles of the blade at the different locations based on the CFD study performed on the blade using varying parameters. Analysis results will be used to select the best suited three different options.*

Key Words: Renewable Sources, Clean Energy, Turbine .Aerodynamic, Optimize, CFD

1. INTRODUCTION

Since early recorded history, people have harnessed the energy of the wind. Wind energy propelled boats along the Nile River as early as 5000 B.C. By 200 B.C., simple windmills in China were pumping water, while vertical-axis windmills with woven reed sails were grinding grain in Persia and the Middle East. New ways of using the energy of the wind eventually spread around the world. By the 11thcentury, people in the Middle East used windmills extensively for food production. Returning merchants and crusaders carried this idea back to Europe. The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches and later to generate electricity for homes and industry.

American colonists used windmills to grind wheat and corn, to pump water and to cut wood at sawmills. With the development of electric power, wind power found new applications in lighting buildings remotely from centrally generated power. Throughout the 20th century, small wind plants, suitable for farms and residences, and larger utility-scale wind farms that could be connected to electricity grids were developed.

During World War II, the largest wind turbine known in the 1940s, a 1.25-megawatt turbine that sat on a Vermont hilltop known as Grandpa's Knob, fed electric power to the local utility network. Wind electric turbines persisted in Denmark into the 1950s but were ultimately sidelined due to the availability of cheap oil and low energy prices.

The oil shortages of the 1970s changed the energy picture for the U.S. and the world. It created an interest in alternative energy sources, paving the way for the re-entry of the wind turbine to generate electricity.

From 1974 through the mid-1980s, the U.S. government worked with industry to advance the technology and enable development and deployment of large commercial wind turbines. Large-scale research wind turbines were developed under a program overseen by the National Aeronautics and Space Administration to create a utility-scale wind turbine industry in the United States. With funding from the National Science Foundation and later the U.S. Department of Energy, 13 experimental turbines were put into operation using four major wind turbine designs. This research and development program pioneered many of the multi-megawatt turbine technologies in use today. The large wind turbines developed under this program set several world records for diameter and power output.

In the 1980s and early 1990s, low oil prices threatened to make electricity from wind power uneconomical. But in the 1980s wind energy flourished in California partly because of federal and state tax incentives that encouraged renewable energy sources. These incentives funded the first major use of wind power for utility electricity. The turbines, clustered in large wind resource areas such as Altamont Pass, would be considered small and uneconomical by modern wind farm development standards.

While wind energy's growth in the U.S. slowed dramatically after tax incentives ended in the late 1980s, wind energy continued to grow in Europe, in part due to a renewed concern for the environment in response to scientific studies indicating potential changes to the global climate if the use of fossil fuels continues to increase.

Today, wind-powered generators operate in every size range, from small turbines for battery charging at isolated residences to large, near-giga watt-size offshore wind farms that provide electricity to national electric transmission systems.

Fig. 1.1:- Wind Turbine

BENEFITS OF WIND ENERGY:-

ECONOMIC BENEFITS

- Local economic impacts of wind power are derived from temporary and permanent employment in construction, engineering, transportation, manufacturing, and operations; local economic activity resulting from wind construction; and increased revenues from land lease payments and tax revenue.
- Attracting more than $100 billion in private investment to the US since 2008
- Supporting a manufacturing supply chain of more than 500 factories across 43 states
- By the end of 2016, approximately 102,500 individuals were employed directly in the U.S. wind industry. In the 39 states with utility-scale wind deployment, wind plants create permanent jobs for site operations and provide local tax and lease payments. Globally, an estimated 834,000 direct and indirect jobs were tied to wind in 2013.
- The value of wind project development flows toward the local community through annual land lease payments. With over 98% of all wind energy projects on private land, wind energy projects deliver at least $245 million every year in land lease payments to landowners. Other local benefits include property tax payments, payments in lieu of taxes, and increased local spending plus its associated tax revenue. These local benefits are often used toward community development such as schools, libraries and hospitals.

ENVIRONMENTAL BENEFITS

- Wind deployment delivers public health and environmental benefits today, including reduced greenhouse gas (GHG) emissions, reduced air pollutants, and reduced water consumption and withdrawals.
- In 2016, wind energy avoided an estimated 159 million metric tons of CO2—the equivalent of reducing power sector CO2 emissions by around 9%, or 33.7 million cars' worth of carbon emissions.
- The 10,432 megawatts (MW) of wind power capacity under construction at the end of 2016 is expected to reduce another 24.2 million metric tons of CO2 per year when it is operational — the equivalent of reducing power-sector CO2 emissions by another 1%. This would bring total emissions reductions from U.S. wind generation to around 183 million metric tons of carbon dioxide per year.
- On average, wind generation today will avoid roughly 0.69 metric tons (1,500 pounds) of CO2 for every MWh of wind generation. A typical new wind turbine will avoid over 4,200 metric tons of CO2 annually, the equivalent of nearly 900 cars worth of carbon emissions.
- In 2016, wind energy generation reduced water consumption at existing power plants by approximately 87 billion gallons of water – the equivalent of roughly 266 gallons per person in the U.S. or conserving the equivalent of 657 billion bottles of water.

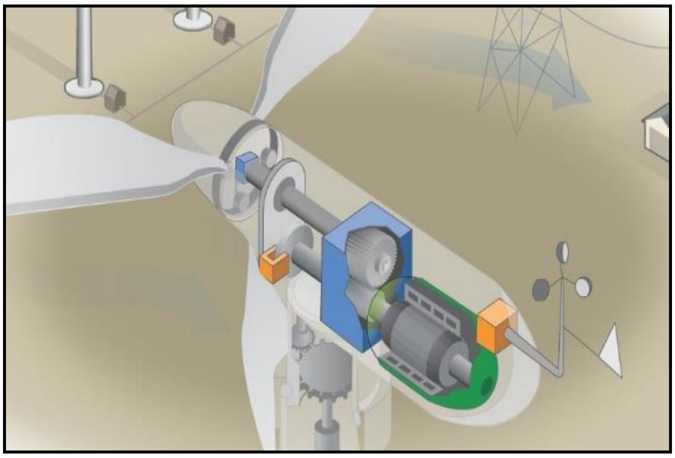

Fig. 1.2:- Sectional view of wind mill

Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. Click on the image to see an animation of wind at work.

Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

Types of Wind Turbines

Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of when we think of a wind turbine. A HAWT has a similar design to a windmill; it has blades that look like a propeller that spin on the horizontal axis.

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.

Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind. Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines.

Vertical axis wind turbines

As shortened to VAWTs, have the main rotor shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on sites where the wind direction is highly variable or has turbulent winds.

With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawbacks of a VAWT generally create drag when rotating into the wind.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and these can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

Fig. 1.3:- Vertical wind turbine

Components of Wind Mill:-

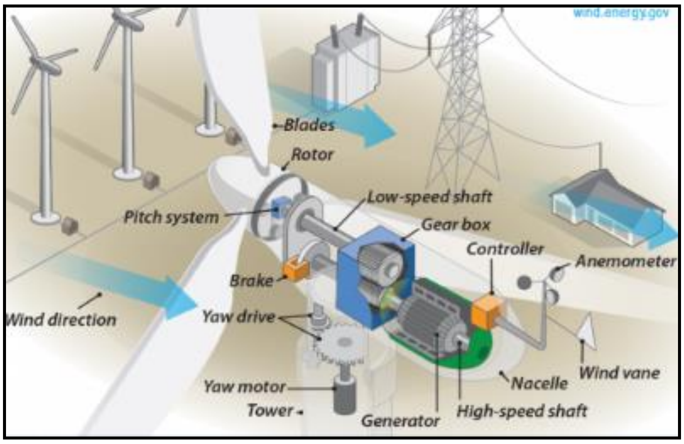

Fig. 1.4:- Components of wind mill

Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Blades: Lifts and rotates when wind is blown over them, causing the rotor to spin. Most turbines have either two or three blades.

Brake: Stops the rotor mechanically, electrically, or hydraulically, in emergencies.

Controller: Starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they may be damaged by the high winds.

Gear box: Connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30-60 rotations per minute (rpm), to about 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator: Produces 60-cycle AC electricity; it is usually an off-the-shelf induction generator.

High-speed shaft: Drives the generator.

Low-speed shaft: Turns the low-speed shaft at about 30-60 rpm.

Nacelle: Sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.

Pitch: Turns (or pitches) blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: Blades and hub together form the rotor.

Tower: Made from tubular steel (shown here), concrete, or steel lattice. Supports the structure of the turbine. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction: Determines the design of the turbine. Upwind turbines—like the one shown here—face into the wind while downwind turbines face away.

Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive: Orients upwind turbines to keep them facing the wind when the direction changes. Downwind turbines don't require a yaw drive because the wind manually blows the rotor away from it.

Yaw motor: Powers the yaw drive.

2. RESEARCH METHODOLOGY

1. Design a general wind turbine blade using BEM theory suitable for low speed application.

2. Scale down the wind turbine blade such a way that it should be suitable for manufacturing in 3 D printing and testing in wind tunnel.

3. Create scaled 3 D model using Solid works for the wind turbine blade.

4. Perform CFD flow analysis on the wind mill blade to find out the effectiveness of the blade through lift and drag forces.

5. Perform parametric study on the blade through changing chord lengths and twist angles through designed matrix to optimize them.

6. Compare the CFD results to select the best suited manufacturable and high performing wind blade geometries.

Design methods can be broadly classified as:

1. Inverse methods

2. Iterative modification methods

3. Transformed plane methods

4. Special methods.

As shown on the road map, the main characteristics of various methods are reviewed here,

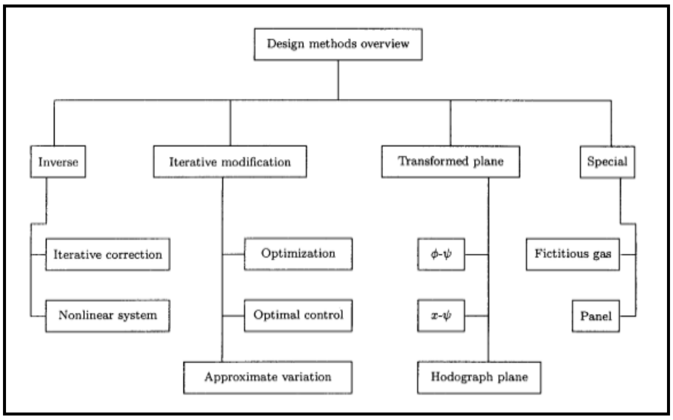

Fig. 4.1. Road map

Blade Plan Shape and Quantity

The ideal plan form of a HAWT rotor blade is defined using the BEM method by calculating the chord length according to Betz limit, local air velocities and aero foil lift. Several theories exist for calculating the optimum chord length which range in complexity, with the simplest theory based on the Betz optimization. For blades with tip speed ratios of six to nine utilizing aero foil sections with negligible drag and tip losses, Betz's momentum theory gives a good approximation. In instances of low tip speeds, high drag aero foil sections and blade sections around the hub, this method could be considered inaccurate. In such cases, wake and drag losses should be accounted for. The Betz method gives the basic shape of the modern wind turbine blade. However, in practice more advanced methods of optimization are often used.

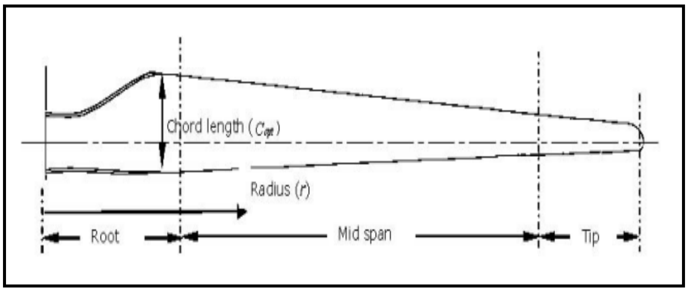

Fig.4.2. A typical blade plan and region classification.

Machine Data for Phase VI Turbine

Basic Machine Parameters

- Number of blades: 2

➢ Rotor diameter: varies with tip attachment

➢ 10.058 m with standard tip or smoke tip (all sequences except V and W)

➢ 9.886 m with tip plate (Sequence V)

➢ 11.064 m with tip extension (Sequence W)

- Hub height: 12.192 m
- Type of rotor: teetered (Sequences B, C, D, G, and 4) or rigid
- Rotational speed: 71.63 RPM synchronous speed, 90 RPM (Sequence X only) using Square D, variable-speed drive
- Cut-in wind speed: 6 m/s some tests were run at 5 m/s
- Power regulation: stall
- Rated power: 19.8 kW
- Tilt: 0°
- Cone angle: 0°, 3.4°, or 18°
- Location of rotor: upwind or downwind
- Rotational direction: counterclockwise (viewed from upwind)
- Rotor overhang: 1.401 m (yaw-axis to blade-axis); 1.469 m (yaw-axis to teeter pin)

3. RESULTS & DISCUSSION

Table.1. Values of Drag and Lift Force (N) for blade profile SG6043

Angle of Twist (Degrees)	Cl	Cd	Fl(N)	Fd(N)
0	0.0052	0.00588	0.0053	0.0052
10	0.15	0.0758	0.09236	0.04636
18	0.22	0.14	0.13	0.0852
20	0.32	0.16	0.24	0.121
22	0.525	0.199	0.3528	0.1364
24	0.61	0.3	0.381	0.162
42	0.39	0.41	0.25	0.24
52	0.449	0.441	0.27	0.275

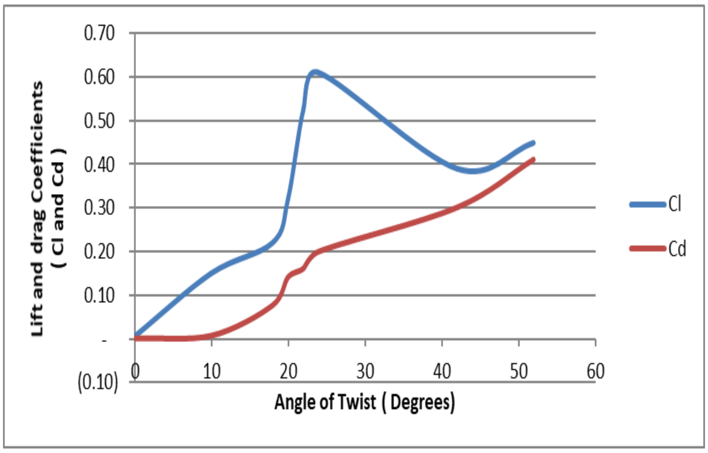

Fig.7.1. Graph of Cd and Cl with respect to blade twist angle SG6043

As the angle of twist increases for the profile the area that is exposed to the air attack increases also which will increase the resistance to the flow over the blade profile in the direction of flow. That is the reason Coefficient of drag constantly goes on increasing as the angle of twist increases from 0 to 52 degrees from 0.005 to 0.44 for profile SG6043. Drag forces are proportionally changing to drag coefficients. Lift on the other hand depends on the resistance to the flow in the direction perpendicular to the flow direction, which is almost negligible at 0 degrees twist but increases steeply up to 24 degrees twist from negligible to 0.61 it decreases as the twist is further increased as area resisting in the perpendicular direction reduces after that twist angle. Pressure plots show the zones created at 24 degrees which are sharpest.

Table.2. Values of Drag and Lift Force (N) for blade profile A 18

Angle of Twist (Degrees)	Cl	Cd	Fl(N)	Fd(N)
10	0.12	0.10	0.10	0.09
18	0.32	0.16	0.19	0.10
20	0.36	0.18	0.22	0.12
22	0.44	0.23	0.26	0.14
24	0.57	0.28	0.35	0.16
42	0.50	0.36	0.30	0.22
52	0.52	0.45	0.32	0.28

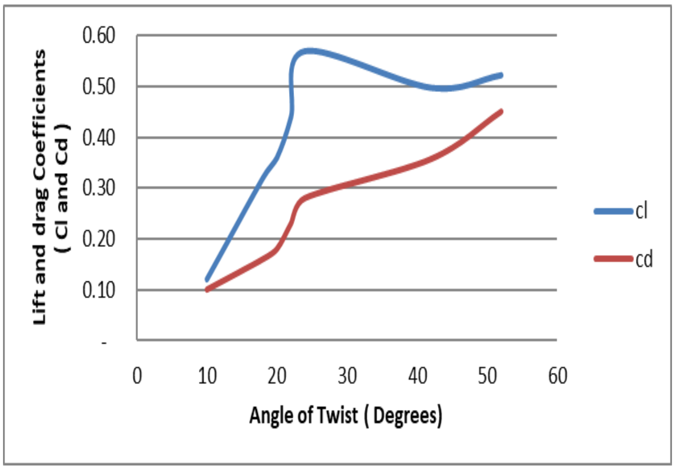

Fig.7.2: Graph of Cd and Cl with respect to blade twist angle A18 profile

As the angle of twist increases for the profile the area that is exposed to the air attack increases also which will increase the resistance to the flow over the blade profile in the direction of flow. That is the reason Coefficient of drag constantly goes on increasing as the angle of twist increases from 10 to 52 degrees from 0.1 to 0.45 for profile A18. Drag forces are proportionally changing to drag coefficients. Lift on the other hand depends on the resistance to the flow in the direction perpendicular to the flow direction, which is 0.12 at 10 degrees twist but increases steeply up to 24 degrees twist from negligible to 0.57 it decreases as the twist is further increased as area resisting in the perpendicular direction reduces after that twist angle. Pressure plots show the zones created at 24 degrees which are sharpest.

Table 3.Values of Drag and Lift Force (N) for blade profile BW3

Angle of Twist (Degrees)	Cl	Cd	Fl(N)	Fd(N)
10	0.10	0.07	0.08	0.04
18	0.11	0.10	0.10	0.09
20	0.27	0.12	0.15	0.10
22	0.35	0.19	0.12	0.21
24	0.54	0.24	0.36	0.25
42	0.44	0.33	0.27	0.20
52	0.48	0.42	0.31	0.26

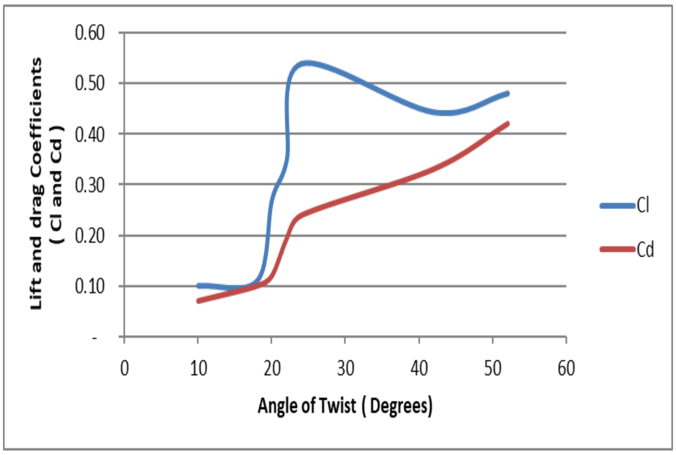

Fig.7.3: Graph of Cd and Cl with respect to blade twist angle BW3 profile

Cd and Cl are plotted with changes in the twist angle of the blade. Below is the graph of coefficient of lift and coefficient of drag Vs Angle of twist. From the graph it is observed that the coefficient of lift increases up-to 24 degree angle of twist then goes decreasing till 45 degree and again rises as angle twists on. Coefficient of drag goes on increasing as the angle of twist increases.

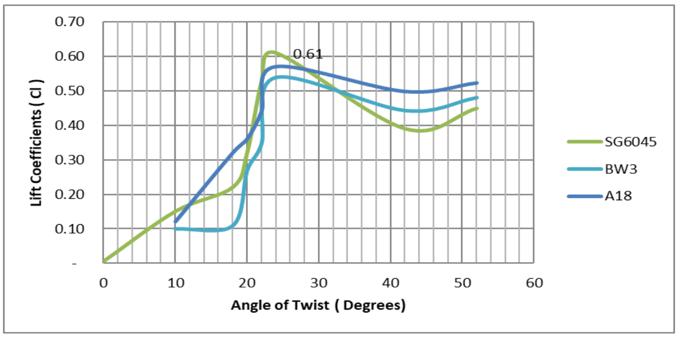

Fig.7.4: Graph of Lift coefficient vs. Angle of twist for all studied blade designs

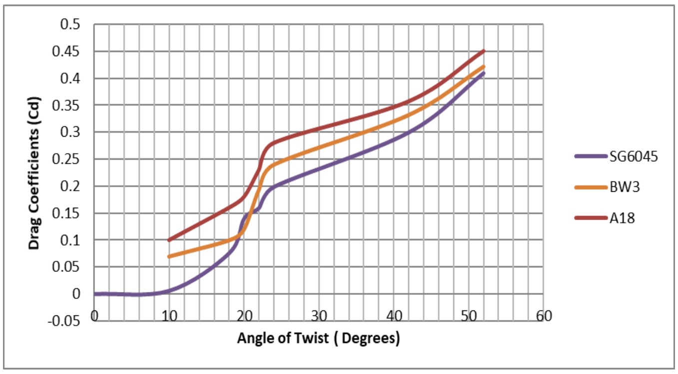

Fig 7.5: Graph of Drag coefficient vs. Angle of twist for all studied blade designs

The graphs above clearly show that the lift coefficients are higher and drag coefficients are lower at given angle of twist for SG6045 profile blade design for angles between 22 to 25 degrees twist, 24 which is found to be the best performing angle of twist for this application falls in the range of performance of SG6045. So it is clear reason for the selection of profile SG6045 blade with 24 degrees angle of twist for the application.

4. CONCLUSION

As HAWT operated by the lift force it is important to have high lift force for the blade designed while drag force cannot be very high as it may cause design weight addition. In this study we carried out the CFD analysis of SG6043 blade for the twist angle of 0°,22°,42° and 52°.It is found that the up to 25 ° angle of twist the coefficient of lift goes increasing and then goes decreasing till 45° angle of twist ,while coefficient of drag increase in liner manner till 42°. It can be clearly seen from the results that for the similar sizes of the turbine blade the angle of twist is independent of the profile and pattern in the Cl and Cd variation can be generalized for all small wind power turbines. The best performing profile at 5 m/s seconds is SG 6043 at 24 degree twist angle. So optimum angle of twist for the blade profile SG 6043 is selected as 24 degrees from the study above as it gives us highest value of the lift force for average value of the drag on the turbine blade. That is 0.38 N lift forces while drag of 0.16 N. A18 and BW 3 also follow the similar pattern of relation between angle of twist and the lift and drag coefficients according to CFD results.

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