MAJOR PROJECT-II

Optimum Performance Evaluation of Solar Enhanced Magnus Effect Wind Turbine concept

Submitted in partial fulfillment of the requirement for the award of degree of

Master of Technology

In

Renewable Energy Technology

Submitted by

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DECLARATION

I, hereby declare that the work embodied in the dissertation entitled **“Optimum Performance Evaluation of Solar Enhanced Magnus Effect Wind turbine concept ”** towards the partial fulfillment of the requirements for the award of degree of **Master of Technology** with specialization in **Renewable Energy Technology** is an authentic record of my own work carried out under the supervision of **Shri Naushad A. Ansari**, Assistant Professor, Mechanical Engineering Department, Delhi Technological University, Delhi.

The matter embodied in this dissertation record has not been submitted by me for the award of any other degree.

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CERTIFICATE

This is to certify that the work embodied in the dissertation entitled **"OPTIMUM PERFORMANCE EVALUATION OF SOLAR ENHANCED MAGNUS EFFECT WIND TURBINE CONCEPT"** by Krishan Chand (2K15/RET/06) in partial fulfillment for the award of **degree of Master of Technology in Renewable Energy Technology**, is an authentic record of student's own work carried out under my supervision.

This is also certified that the report has not been submitted to any other Institute or University for the award of any degree.

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ABSTRACT

The conventional sources of energy like thermal power plant, power generating from fossil fuels etc were the main contributors in the energy scenario earlier but due to increasing earth temperature i.e. global warming due to pollution, and declining of fossil fuels invoke us to think of more reliable and eco friendly sources of energy and makes us shift to the renewable sources of energy to extract power and satisfy our need. We are presenting here that how to optimize Solar Enhanced Magnus Effect Based Wind Turbine using GA technique with MATLAB software. In the present study, power generation from a novel wind turbine is optimized, this turbine utilizes the Magnus Effect along with solar panels on the cylinders(rotating cylinders are used in place of wings) to harness the wind energy. In this wind turbine, wings (aerodynamic) are replaced by the rotating cylinders and it is shown that aerodynamic efficiency of such a novel turbine is more than the conventional wind turbine. The body structure of cylinders(rotating cylinders that act as wings) are covered by the solar panels so that at every instant of time some area of cylinder is covered with the solar panel and some energy will be extracted from sun also. In this study, values of some parameters are assumed to determine the maximum power at a particular cylinder radius and angular rotation of cylinders.

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Nomenclature

a = Induction factor

C_l = Section lift coefficient

C_p = Power coefficient

I = Insolation

L = Lift force

M = Torque with respect to the rotor hub (Nm)

N = No. of Blades

R_c = Radius of the cylinder (m)

R_t = Radius of the rotor; span of the cylinder

R_e = Reynolds no. based on the diameter of the cylinder

V_{wind} = Ambient air speed approaching the turbine (m/s)

V_∞ = Ambient air speed approaching the section (m/s)

$\dot{W}$ = Power (W) (generated, extracted, solar)

β = Angle between V_{wind} and V_∞

θ = Angular position around the cylinder surface

$\bar{\upsilon}$ = Kinematic viscosity of air (m^2/s)

ω_c = Spin angular speed of the cylinder (rad/s)

ω_t = Rotational speed of the rotor (rad/s)

1. Introduction

Energy is one of the most important needs of every country. Energy has become the basic need and we are surrounded by the electronic gadgets. Electricity is required to lighten the street lamps, vehicles require gasoline and diesel even we require energy in the form of electricity in our houses for lighten, heating and powering our devices. We were dependent on fuels earlier, burning of which cause a lot of pollution in the environment [1].

Due to environmental concern we are now shifting from conventional sources of energy to non - conventional sources of energy (renewable energy). A number of initiatives is taken to curb the carbon emissions and can limit the average earth or say global temperature change. In fact in Paris climate Summit (or COP21) held in Paris,2015, whole world came together to curb the emission of green house gases, decided to focus more on the renewable energy sources than the conventional ones so that emission can be reduced. As the human population is increasing day by day thus puts more demands on our energy infrastructure. For sustainable development and a secure future (healthy environment) for our children and their children we have to restrict ourselves to conventional sources and shift to renewable sources for satisfying the energy needs.

Renewable Energies are generated from those sources that do not have a definite end, or that can be recycled, like solar power, wind power and water power etc.

The current scenario shows that a development must be a sustainable development i.e. we cannot think of development without taking care of environment. Energy is one of the basic needs as we have discussed above, so we have to shift to the renewable energy for sustainable development. In order to increase their efficiency, much research is under way [3]. Cost of electricity is much cheaper as compared to earlier times infact cost of electricity of solar energy is much cheaper than that of produced by coal thermal power plant, but still there is a lot more potential in solar and wind energy to harness. Actually, to harness energy from wind and solar we have to depend on their availability, if wind is not there then no wind energy and same is with the solar energy if sun is not there then no solar energy. Fortunately, these two energy sources can coexist and does not depend on each other for their existence, so if one is not there than other can be harvested. A novel wind turbine that utilizes Magnus effect to create lift and solar panels on the blades of turbine to harness solar energy is introduced in this study.

1.1 Overview of a Wind Turbine:

First of all, let us have an overview of wind turbine. Wind turbine works on the principle of conversion of kinetic energy of wind into mechanical energy to rotate the shaft and then further into electrical energy. We cannot harness the kinetic energy of air completely as proved by Betz Limit [2], average power coefficient is 0.4. Wind turbine is composed of a number of links or elements which has their own function. The main components of a wind turbine with their function are as following:

1) Blades: These are the aerodynamic shape wings whose shape is airfoil, there is a pressure variation along the span of wing due to which lift is created. These are associated with the rotor. A wind turbine generally has 3 wings but the number of blades can vary from turbine to turbine.
2) Rotor: Rotor is a hub which connects all the wings and further connected with the rotating shaft of the turbine. The rotational force is transmitted to the shaft through this rotor from the wings.
3) Brake: Brakes are the components which are integrated with the turbine to hold the rotational shaft in case of any storm or whenever the wind velocity reaches above a certain value.
4) Low Speed Shaft: This is the link which connects rotor to the gear box through the brakes and transmit rotation to the high speed shaft.
5) Gear Box: It is a mechanical link whose function is to increase the velocity ratio i.e. the low speed into high speed. Generally the wind flowing over the wings cannot rotate them at very high velocity due to their enormous rotor size, so the low speed shaft is connected with the gear box to increase the spin of generator.
6) Generator: It is an electrical device which converts mechanical energy (rotational energy) into electrical energy and further supply the electricity to the grid. It is located in the nacelle.

7) <u>Anemometer:</u> it is a velocity measuring instrument which measures the velocity and further assist the controller to apply the brakes if velocity increases over a certain limit.
8) <u>Nacelle:</u> It is cylindrical shaped housing of wind turbine components and holds all the major components of a wind turbine like shaft, brakes, gearbox etc.
9) <u>High Speed Shaft:</u> It is a high speed rotating shaft which is connected to the generator from gear box. It makes the generator revolves at very high speed. The speed ratio of high speed shaft to low speed shaft is generally taken as 18:1.
10) <u>Tower:</u> It is long vertical cylindrical structure which carries the weight of the turbine and provides strength to the turbine in storm. It is grounded in the earth with a strong basement.
11) <u>Controller:</u> Its function is to control the brakes and other components so that the wind turbine works well.

There are many other components also whose function are very significant like pitch mechanism, yaw mechanism, basement etc. A lot of factors have to be considered for constructing a wind turbine like wind velocity, population density etc, because wind turbines cause noise pollution so it is necessary to construct it as far from the residential areas as possible.

Taking a look over wind turbine, figure 1 shows the component of a HAWT wind turbine.

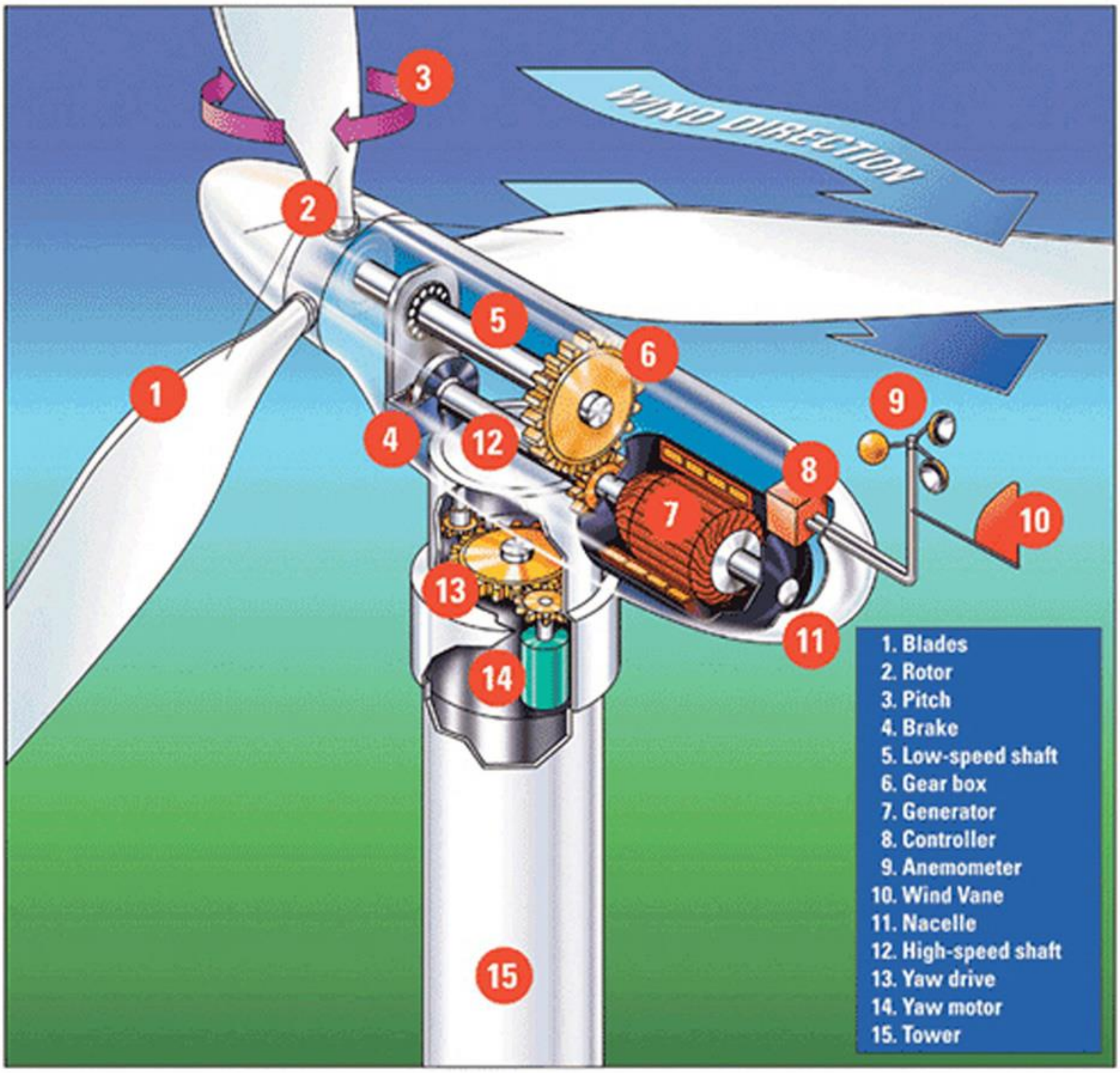

Figure 1.1 wind turbine components [28]

1.2 Classification of Wind Turbine:

On the basis of rotation of blades about their axis, Wind turbines can be classified into two categories:

1) HAWT(Horizontal Axis Wind Turbine)
2) VAWT(Vertical Axis Wind Turbine)

1) Horizontal Axis Wind Turbine:

A turbine whose axis of the rotor is parallel to wind direction and ground is termed as a horizontal-axis wind turbine (HAWT) [2].

All the commercial wind turbines, grid connected, are horizontal axis wind turbine. Generally, two or three blades are employed in horizontal axis wind turbine. The rotor is employed to convert the kinetic energy of wind (linear motion of wind) into mechanical rotational energy that further rotates the shaft of generator to generate electricity. The lift is created over the blades of horizontal axis wind turbines due to pressure difference that is caused because of the shape of the blades i.e. airfoils. The wind speed is more over the longer side of the blade and thus from Bernoulli's equation ($\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$) , if velocity is more than pressure will get reduce and hence a pressure difference is created between top and bottom surfaces of blades which creates lift and rotates the blades as shown in fig. 2.

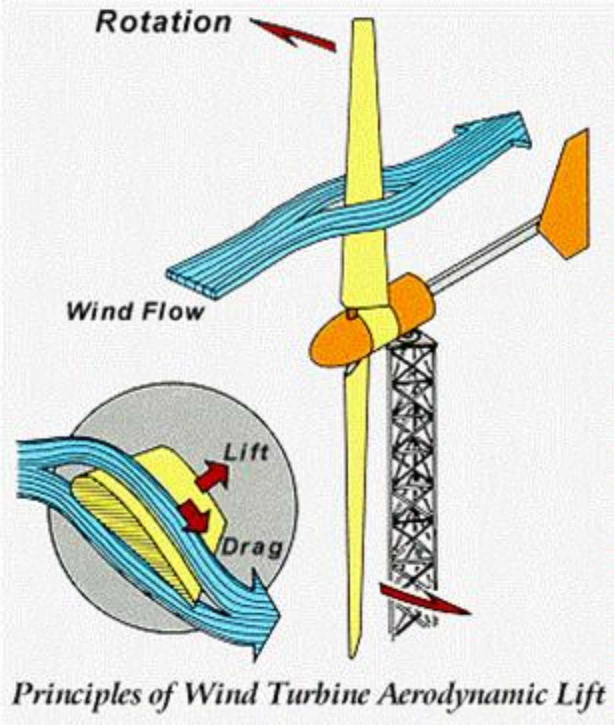

Figure 2 lift produced by wind turbine [29]

2). Vertical Axis Wind Turbine:

A vertical-axis wind turbine (VAWT) is turbine whose axis of rotation is perpendicular to the both wind stream and the ground. Vertical Axis Wind Turbine does not require to pointed in the direction of wind and that's why these are used on sites where wind direction is highly variable or has turbulent winds. There are two types of VAWT:

1. **Darrieus Wind Turbine**: Darrieus wind turbines are commonly called "Eggbeater" turbines, because they look like a giant eggbeater [2]. They have good efficiency, but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Darrieus wind turbine is shown in fig.3.

Figure 3 series of Darrieus wind turbine [30]

2. **Savonius wind turbine** : A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers [2]. Because they are a drag type turbine they are less efficient than the common HAWT. Savonius are excellent in areas of turbulent wind and self starting. Savonius wind turbine is shown in fig. 4

Figure 4 Savonius wind turbine [31]

1.3 Magnus Effect

The force acting on a spinning object (cylinder or sphere) moving through air in a direction at an angle to the axis of spin is called Magnus Force and this effect is known as Magnus Effect. German physicist Gustav Magnus in 1852 discovered the Magnus Effect [3].

When a spinning ball moves through the air, the boundary layer of air around the ball also spins along with the ball. On one side, the direction of velocity of air and boundary layer of air cling around the ball are same and no collision of particles occur which lead the air to move faster where as on other side it is in opposite direction and particles of air collide with the boundary layer and decelerate the flow around the ball. The region of deceleration creates a high pressure area and region of acceleration creates a low pressure area [3]. The pressure difference on the two sides of a ball creates lift force (Magnus force) and this press difference cause the ball to move in the direction of low pressure area.

The wind is flowing over a rotating basketball (bb) as shown in the fig. 5. At point A, magnitude of velocity is high because of the additional velocity component of a rotating basketball. Due to this high velocity pressure at this point becomes low where as at point B, magnitude of velocity is less resulting in high pressure. This pressure difference will create a lift force in upward direction as shown in the given fig 5.

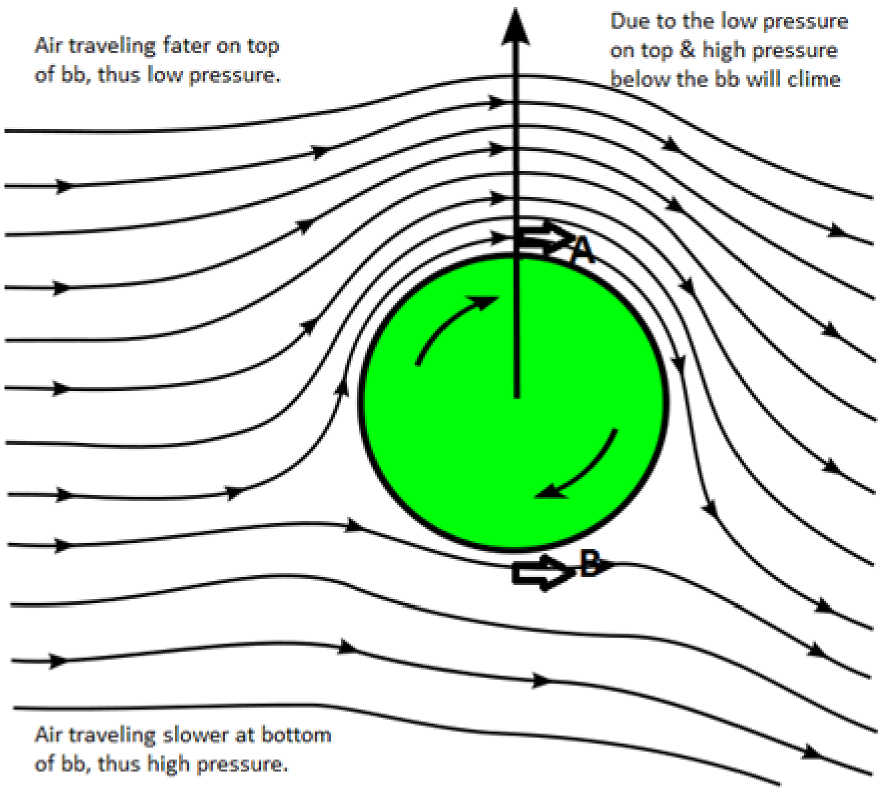

Figure 5 Lift generated by Magnus Effect [32]

1.4 Objective of Novel Wind Turbine

The main idea of Solar Enhanced Magnus Effect Wind Turbine is to obtain higher C_l values so that net lift force can be increased and hence power generation can be increased as well. In this novel turbine rotating cylinders are used instead of blades which cause Magnus effect and due to this Magnus effect higher C_l values are obtained as compared to the conventional wind turbine. The outer body of cylinder is employed with the solar cells [4]. Thus by making such a hybrid turbine, it can harness both wind energy as well as solar energy at the same time. Even if wind speed is very low or absent, the turbine can harness the energy from sun and if solar radiation are not appropriate, the turbine can harness energy from wind but it should be considered that aerodynamic performance of such a novel wind turbine cannot get affected by the implementation of solar cells. Power is supplied to rotate the cylinders to generate the Magnus effect. At very low wind speed, alignment of turbine according to the direction of sun radiations leads to generate electricity more efficiently.

Optimization of power generation of such turbine needs torque and drag calculation [4]. The gyroscopic force comes into action as the cylinder starts rotating about its axis but in this study, these effects are neglected.

There are a number of optimizing techniques which can be used to get an optimized solution to this problem but because of advantage of GA-Genetic Algorithm Technique we preferred GA technique over the other techniques. So based on such analyses, we will optimize the net power generation as a function to obtain:

1) The radius of cylinder

2) Radius of rotor

3) Maximum power generated

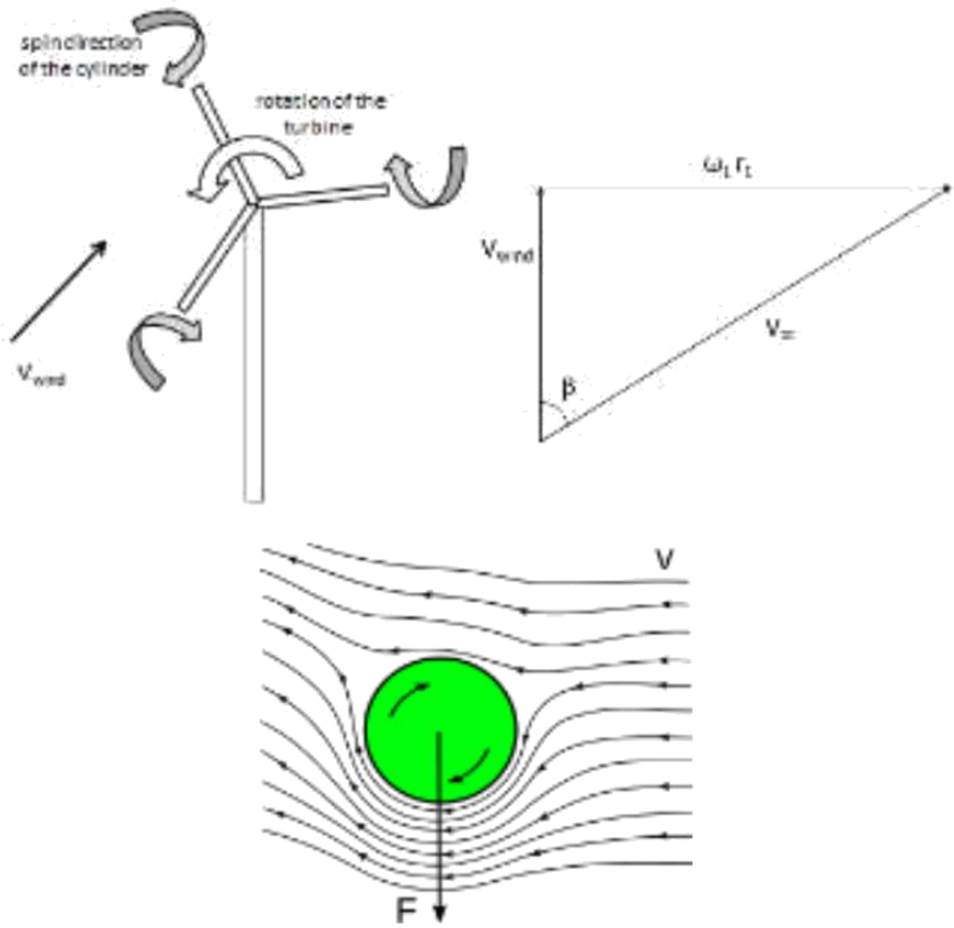

Figure 6 velocity triangle of a magnus effect wind turbine [33]

2. Literature review

1. Luka Perkovic et al.,[2013] put up a theoretically feasible concept of harvesting the wind energy based on Magnus effect at higher altitude in his journal “Harvesting high altitude wind energy for power production: The concept based on Magnus’ effect”.

2. J. Seifert,[2012] analyzed the applications of Magnus effect in various field and reviews the application of Magnus effect devices and concepts in aeronautics that have been investigated by various researchers and concludes with discussions on future challenges in their application.

3. Maro Jinbo et al.,[2014] dealt with the HCC algorithm (Hill Climbing Control) to optimize the performance of Magnus wind turbines reducing the response time to reach the maximum power point (MPPT Maximum Power Point Tracking) as well as to reduce fluctuations around that point.

4. L. C. Corrêa et al.,[2013] proposes a method to reach the maximum power point of a Magnus wind turbine. Firstly showing that this turbine is a special case of horizontal axis wind generator, whereas using rotating cylinders instead of fixed blades. Secondly an explanation was given so that how some maximum power point trackers (MPPT) can be used with wind energy conversion system and, specially, the divided step hill climbing search method (HCS). The MPPT method proposed for the Magnus turbine that is based on the control of cylinder rotation speed to change the tip speed ratio.

5. Brian Kieffer Mara et al.,[2014] analyzed the development and validation of a CFD model using ANSYS CFX for aerodynamics simulation of Magnus wind rotor blades and concluded that the first aspect ratio as the inflation layer meshing strategy and eddy viscosity transport equation turbulence model were the settings of the most favorable and well-validated working model.

6. Li, D.H.W. and Lam, T.N.T,[2007] presents a numerical approach to calculate the solar radiation on sloped planes by integrating the measured sky radiance distributions. The annual total solar yield at different sloped surfaces facing various orientations and monthly solar radiations at the optimal tilt surface and three vertical planes facing east, south, and west were determined. The energy outputs and efficiencies were simulated using a computer package. The environmental benefits in terms of greenhouse gases reductions and cost implications were also considered. The findings provide technical information for engineers to design and evaluate photovoltaic (PV) systems which could contribute to the environmental, energy, and economic aspects.

7. Ahmed Sedaghat,[2014] studied the Magnus effect wind turbine and carried out the result which deals with the designing of such a turbine because research took place on the designing of Magnus effect wind turbine is not appropriate and a lot more efforts are required to design such turbine. He considered the potential flow and developed the BEM (blade element theory). He found out the cubic function of angular induction factor from the BEM theory and this function depends upon the drag to lift ratio. He also observed that the relative wind incidence angle and the local power coefficient of the Magnus cylinder do not depend on the spin ratio.

8. Miguel Talavera and Fangjun Shu [2017] studied the issue of unmatched Reynolds number for down-scaled wind turbine test and performed an experimental study of a single model wind turbine and an array with two turbines was performed under laminar and turbulent inflow condition. Active grid system was used to create turbulent inflow and found that power coefficient was dependent on the inflow turbine intensity strongly and this result was confirmed by PIV results taken under laminar and turbulent inflow condition. For the wind turbine array case, the efficiency of turbine was dependent on the turbulent intensity in the inflow and inflow turbulence intensity influenced the wake recovery.

9. Ilmas Bayati et al.,[2017] illustrates the methodology and the experimental verification of the design of a 1/75 aero-elastic scaled rotor of the DTU 10 MW

reference wind turbine for wind tunnel tests. From the Selig low- Reynolds airfoil database, the SD7032 was chosen and corresponding constant section wing was tested at DTU red wind tunnel providing force and distributed pressure coefficients for the design , in the Reynolds range $30\text{-}250*10^3$ and for different attack angles.

10. Theo Gentils et al.,[2017] optimized the integrated structure of offshore wind turbine support structure based on finite element analysis and genetic algorithm and provide an efficient way to reduce the currently high cost of offshore wind energy. They developed a structural optimization model for OWT support structures based on a coupled parametric FEA(Finite Elemental Analysis) and GA (Genetic Algorithm) minimizing the mass of the support structure under multi- criteria constraints and this results in a reduction of 19.8% in the global mass of the support structure. This result was also satisfying all the design constraints.

11. J. Seifert, [2012] reviews the application of Magnus effect devices and concept in aeronautics. The first application of Magnus effect was rotor ship Buckau invented by Anton Flettner: a boat extracts propulsive force from the air around the two large rotating cylinders. He also gave the future challenges in the application of Magnus effect devices.

12. Qing'n Li et al., [2016] studied the effect of turbulent inflows on the airfoil of Horizontal Axis Wind Turbine at low Reynolds Number. They designed UMY02T0126 airfoil and measured the surface pressure by the multiport pressure devices and carried out with the results for 13° of angle of attack that when direction of angle of attack is increased then the lift coefficients of dynamic state showed larger values increase than those in the static state.

13. Rupender Kumar Pachauri and Yogesh K. Chauhan, [2012] explored the potential of wind energy in India and assessment on wind technology was explored for Indian context. They discussed the state wise status, challenges, development of wind power and market for small wind turbine systems in detail.

14. Seyed Ali Kazemi et al.,[2016] studied the aerodynamic performance of a circulating airfoil section for Magnus systems and the airfoil NACA0021 was modified to a treadmill like circulating shape to get the better lift to drag ratio, performance(power efficiency) of a wind turbine strongly depends on the lift to drag ratio. They investigated the aerodynamic performance computationally and experimentally: computational method is based on the finite volume discretization of RANS(Reynolds Average Navier-Stokes) equations and the shear stress transport (k-ωSST(shear stress transportational)) turbulence modeling. They carried out with the result that the lift to drag ratio was 130 with the modified airfoil NACA0021 where as with the latter one it was seldom 45.

15. Ahmad Sedaghat et al., [2015] studied a novel circulating airfoils for use in Magnus wind turbine blades, the airfoil considered was NACA0015. The data for wind turbine showed that the lift to drag ratio was increased only up to 200 by the researchers but they used infinite volume TVD scheme and resulted in the higher value of lift to drag ratio i.e. 278.

16. Ricardo Luiz Utsch de Freitas Pinto and Bruna Patricia Furtado Goncalves, [2017] gave a revised theoretical analysis of aerodynamic optimization of Horizontal Axis Wind Turbines based on the BEM theory. They showed that a Horizontal Axis Wind Turbine can never reach Betz limit, irrespective of considering the drag effects. They formulated the problem into non linear programming problem with equality and inequality constraints and carried out with the results that optimal tip speed ratio and power coefficient are function of maximum airfoil lift to drag ratio.

17. Egemen Ol Ogretim et al.,[2016] evaluated the power generated from Solar Enhanced Magnus Effect Wind Turbine analytically and derived the formulae for power generation from lift caused by magnus effect, solar energy and power required to rotate the cylinders. The two factors were power generating and one was power consuming. They calculated power generation from such a novel wind turbine and then compared with that of conventional Horizontal Axis Wind Turbine of following parameters:

1. Radius of rotor = 10 m
2. Number of Blades = 3
3. Wind speed = 15 m/s
4. Time period of Rotor = 3.33 s

By taking these values, the power generation due to lift caused by Magnus effect came out 385kW, and showed that there is an increase of 24-35% of net power generation. But they calculated the power generation in a discrete manner i.e. for a particular set of parameters net power generation was calculated.

3. GA technique Optimization

3.1 Introduction

Optimization, in general, means making most out of it, including the best use by optimizing the resources [5].

A genetic algorithm (GA) solves complex optimization problems and it is based on the natural evolution process. In this approach, population changes continuously through cross breeding, mutation and natural selection. An explicit mathematical formulation is not required in implementation and, the parameter values, such as; population size, crossover rate, mutation rate, etc. are appropriately chosen to maintain the desired accuracy in the solution. The main steps of GA approach are:

- Chromosome representation
- Generation of initial population
- Evaluation of fitness function
- Selection process
- Genetic operations (crossover, mutation)
- Selection of best chromosomes according to the fitness values
- Termination criteria

In this work, the GA approach is applied to find the optimal values of various parameters shown in chapter 6 (Methodology). The objective function

Objective Function = - [(711*W*R^2*V) + (9000*R) - (2436.57*W*R^2)]

is also represented by equation 4 with the constraints and this objective function is to be optimized. In this study, the objective function is net power generated by the novel wind turbine.

Genetic algorithms are search algorithms that follow the law of mechanics of natural selection and natural genetics. They combine survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human search. In every generation, a new set of artificial creatures (strings) is created using bits and pieces of the fittest of the old; an occasional new part is tried for good measure. Being a random search technique, genetic algorithm is not a simple random walk. Genetic Algorithms exploit historical information efficiently to figure out new search points with the expectations of improved performance.

John Holland, his colleagues and his students developed the Genetic Algorithm at the University of Michigan.

The main steps of genetic algorithm are in a brief as following:

Initial population begins with randomly generated states. These states are satisfactory to the problem and represented by a bit string.

Fitness function produces the next generation of states. More a fitness function is good, better the states will be provided by it. Actually, a score is given to each state by fitness function and this score is the deciding factor for a structure to get selected for the reproduction. One having higher fitness score have the higher probability of getting selected for cross over and the one having lower score might not get selected.

In selection process for reproduction, randomly any two pairs are selected. This selection is based on the fitness function score that is given to every individual string and one may be selected more than once while one may not be selected at all.

In crossover; a point is chosen within the bit string, termed as crossover point, randomly. The parents are exchanged at crossover point to produce the offspring. Initially the population is diverse in this process which leads to large crossover in the beginning though in future generations, it will get settle down.

Each location in the bit string can be subjected to a mutation with a small random probability.

3.2 Flow chart of Genetic Algorithm:

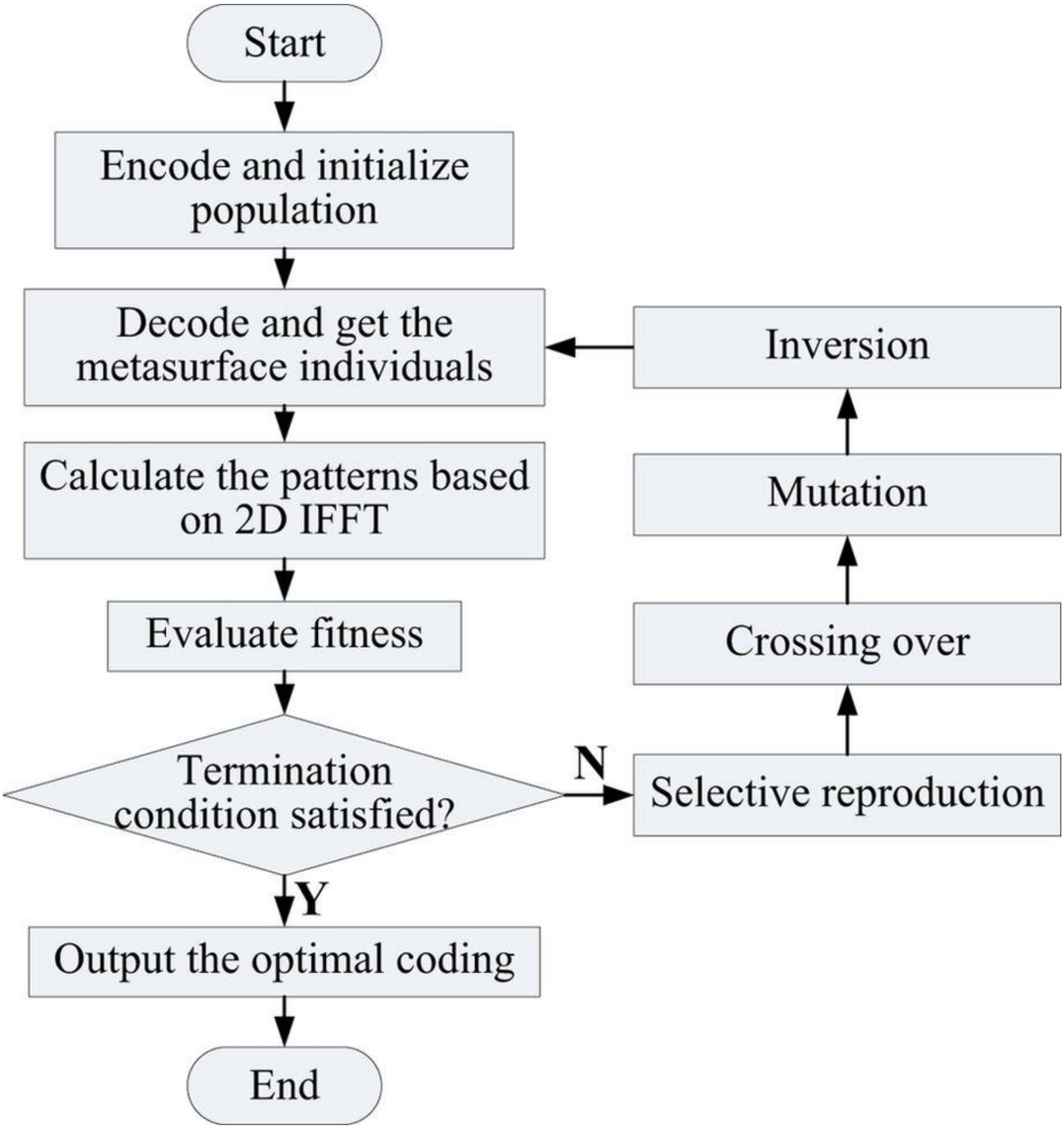

Figure 7 GA flow chart [34]

4. Methodology

For the basic aerodynamic analysis of this solar enhanced Magnus effect wind turbine, we consider a flow model which is:

- inviscid
- incompressible flow

4.1 Power Generation due to Lift:

The novel turbine employed here consist of three cylinders that rotates around one of its ends, when a cylinder rotates about its axis along with the rotation of blades or cylinders about the hub axis then a lift force is generated due to Magnus Effect. This lift force is normal to the resultant velocity direction (governing flow direction). Now using the velocity triangle, lift force along the governing flow direction can be found out [4] as shown in the fig. 6. A small cross-section is considered on the cylinder and lift force is calculated on this section, after that this lift force is integrated along the span of the cylinder. Now the turbine does not see the actual wind speed but less than the actual wind speed because the stream tube is expanded, hence instead of using velocity V_{wind} one must use (1-a)V_{wind}. and the governing equation of power generation from lift force due to Magnus Effect is as following:

$$W_{gen} = N\,(\omega_c R_c^2)(\omega_t R_t^2)\pi\, V_{wind} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where N is no. of blades, ω_c is rotational speed of the cylinder (rad/s), R_c is Radius of the cylinder (m), ω_t is rotational speed of the rotor (rad/s), R_t is the radius of rotor, V_{wind} is the ambient wind speed approaching the turbine and the value of π is 3.14.

4.2 Power Generation due to Solar Energy:

Apart from the power generation from wind energy, power is also generated from solar energy. The topology used for the cylindrical blades when expanded gives the shape of rectangle. The area of this rectangle is $2R_cR_{t.,}$but this area is only for one cylinder and in my study , I have taken 3 cylinders or blades so area will get multiplied by 3 as well [4]. While these cylinders are revolving continuously therefore incidence angle of sun rays will also varies and at any instant some cross section of these cylinders will surely receive sun rays and will contribute in power production [4]. Due to continuously spinning of cylindrical blades, it is difficult to calculate the area of such turbine hence an average value is considered for the performance of such a novel wind turbine.

The cylinder over which solar cells are attached is considered of dodecagon shape, fig (2). The power generated by the solar is written below [4]:

$$W_{solar} = 2R_cR_tI \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (2)$$

Where R_c , R_t and I are radius of cylinder, rotor and insolation respectively.

Therefore by considering a dodecagon area can be simply calculated and hence work produced by solar can be calculated.

4.3 Power Required to Rotate the Cylinders:

The cylinders we have considered here will require energy to rotate and cause Magnus Effect. The required energy is supplied by attaching the rotating cylinders with the external power sources. The peripheral speed, ratio of velocity of cylinder and free stream velocity at a point, is taken as λ = 3 and Reynolds number is considered maximum up to 1000 [7]. So we are required to supply electrical energy to these cylinders in order to generate the desired effect. The equation is [4]:

$$T = 2R_c^2C_t\omega_cN(V_{wind}^2R_t + \omega_t^2R_t^3/3) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Where T is the power required for rotating the cylinder, R_c is the radius of the cylinder (m), C_t is torque coefficient, ω_c is rotation of the cylinder (rad/s), N is no. of blades, ω_t is rotational speed of the rotor (rad/s), R_t is the radius of rotor (m), V_{wind} is the ambient wind speed approaching the turbine (m/s).

4.4 Values of Constant parameters:

We have obtained the required equations and now considering some variables constant for a while we will modify these equations in simpler form [4].

The parameters considered as constants are shown in the table no. 1 as following:

Table 1: List of parameters and their values

S. No.	Parameters	Values	Reference
1	A	1/3	[4]
2	N	3	[4]
3	I	150	[4]
4	C_l	0.1182	[7]
5	C_p	0.38	[4]
6	R_t	10	[4]
7	ω_t	1.865	[4]

4.5 Transformed Governing Equations and Bounds:

The equations after putting values of the above parameters become simple and are as follows

$\dot{W}_{gen} = 711*W*R^2*V$

$\dot{W}_{solar} = 9000*R$

$T = 2436.57*W*R^2$

Where W, R, V are given in the below table 2.

The defined variables in the GA technique with their lower and upper bounds are as following :

Table 2: symbols used for variables and their bounds

S.no.	Variables	Symbol used in MATLAB	Lower bound	Upper bound
1	R_c	R	0.3	0.8
2	ω_c	W	0	56.25
3	V_{wind}	V	3.5	15

We are getting power from two sources i.e. W_{gen} (watt) and W_{solar} (watt) and supplying the T to the cylinders so we will subtract the T from the sum of W_{gen} and W_{solar} . So the objective function becomes

Objective Function = $-[(711*W*R^2*V\ )+(9000*R)-(2436.57*W*R^2\ )]$………(4)

Bounds are as following:

$$0.3 \leq R \leq 0.8$$
$$0 \leq W \leq 56.25$$
$$3.5 \leq V \leq 15$$

R is taken from 0.3 to 0.8 [4],

W is taken from 0 to 56.25 [7],

V is wind velocity that is taken from 3.5 to 15 [4].

After keeping these function and bounds in the MATLAB with the help of GA technique we get the optimized output.

5. Results

We are bounded by the Betz limit to harness the wind energy, (16/27) percent of maximum wind energy. Wind flowing over the aerodynamic wings creates a lift force on the wings but here wings are replaced by the rotating cylinders and more lift is created by the cylinders, hence the net output is increased. This work is done by considering a wind turbine of specific diameter of 20m and rotor period of rotation as 3.33s [4].

The results given by Mat Lab using Genetic Algorithm technique are shown in the table 3, and further results are discussed below:

Table 3: Optimized values of variables and power generation

S. No.	Variables	Optimized values
1	R	0.8
2	W	56.25
3	V	14.99
4	Power generation	303.423

The optimized values of parameters: radius of cylinder, rotation of cylinder and wind speed are as follows:

1) The cylinder radius comes out to be 0.8 meters.

2) The angular velocity of cylinder comes out to be 56.25 rad/s, or this result can be manipulated as time period of cylinder rotation in seconds as shown by equation 4.

The formula for time period is as follows:

$$T = \frac{2\pi}{\omega} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5)$$

Therefore, time period of cylinder comes out to be 0.1117 seconds.

3) The wind velocity at which wind power will be harnessed maximum comes out to be 14.99 or 15 seconds approx.

4) The net power generation comes out to be 303.423kW.

When the system was conventional wind turbine the net output was 242kW [3] but as the system is changed and lift occurs due to Magnus effect, the net power comes out to be 303.423kW. so there is an increase of approximately 61kW power output. These all outputs come out for a fixed rotor period, fixed radius of wings/cylinders. As we change these parameters obviously we will get different result corresponding to the new parameters. So we can say that by using GA technique in Solar Enhanced Magnus Effect approx. 25 % of power is increased which is a significant figure.

Validation of the Result:

The study performed by Egemen Ol Ogretim et al., was discrete i.e. the power generation was calculated by fixing the values of radius of cylinder and rotation of cylinder. But I took here parameters in a wide range and found out the optimized values at which this power generation is maximum as shown in table no. 2.

The study done by Egemen Ol Ogretim, estimated that the net power generation can be increased from 24 to 35 %, depending on the number of blades used, when such a novel turbine is used instead of conventional wind turbine. The result given by computerized GA optimization technique using MATLAB software for 3 blades (N=3), showed that the net power generation is increased by 25% as shown in the table no. 3. Which is in the given range estimated by the Egemen Ol Ogretim. Hence, the results are validated by computerized GA optimization technique using MATLAB software.

6. Conclusions

We are bounded by the betz limit to harness the wind energy i.e. up to max. 59.3%, so to increase the net power output such a beautiful concept, Magnus effect, is very useful. Power generation from a conventional wind turbine can be given by equation 5 [4].

$$\text{Power Gen} = \frac{1}{2}\rho * k * (\pi R_t^2) V_{wind}^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where ρ is the air density (and generally taken as 1.2kg/m^3), k is conversion constant from W to kW (k=0.001), R_t is the radius of rotor (R_t = 10 m), V_{wind} is wind velocity (V_{wind} = 15 m/s). This power comes from the rate of decrease in kinetic energy of wind. By implementing this concept of Magnus effect and using GA technique to optimize, we are getting an increase in 25% of power output as compared to the conventional wind turbine which gives 242kW with an average power factor of 0.38.

The study focused only on such a turbine whose radius of wings as 10 m, rotor period as 4 seconds. Different results can be obtained if the parameters are varied. This type of turbine needs more research in designing and to realize them.

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