Design of Ground-Gen Airborne Wind Energy System

Sayalee Maske[1], Alimoddin Patel[2], N.R.Kodle[3], Digambar Date[4]

[1]M.Tech Student Dept. of Mechanical Engg. College of Engineering Osmanabad, Maharashtra, India
[2]Associate professor Dept. Of Mechanical Engg. College of Engineering Osmanabad, Maharashtra, India
[3]Workshop Supritendent Dept. Of Mechanical Engg. College of Engineering Osmanabad, Maharashtra, India
[4]H.O.D. Dept. Of Mechanical Engg and dean of Academics. College of Engineering Osmanabad, Maharashtra, India

---***---

Abstract – *Energy is a common Man's daily commodity. Energy is a fundamental ingredient in human life. Electrical energy is important resource for any developing country. Along with the increasing population, the demand of electrical energy is also increasing. So, the generation of large amount of electrical energy is one of the most important challenge the mankind is facing today.*

A large amount of energy demand is covered by fossil fuels. But fossil fuels are non-eco friendly. They causes pollution and they are main cause of global warming and climate change due to excessive emission of carbon dioxide and other harmful wastes. Renewable energy sources used to produce energy from natural sources, are nowadays used to meet ever-increasing energy requirement worldwide replacing conventional energy sources. Among various technologies for producing energy from renewable energy sources, Airborne Wind Energy System is most promising energy system.

This thesis paper shows the overview of methods of extracting energy from high altitude wind. This thesis paper describes the constructional details of Ground-Gen Airborne Wind Energy System. This thesis paper consists of CATIA models of different parts of Ground-Gen Airborne Wind Energy System and it's assembly model. This thesis describes the quantitative approach for the design and comparison result of quantitative approach and simulation model of Ground-Gen Airborne Wind Energy System.

Key words – Renewable Energy Source, AWES, Ground-Gen AWES, Design, Simulation, CATIA V5, MATLAB SIMULINK.

1. INTRODUCTION

Electrical energy is the basic necessity for the economic development of a country. It is practically impossible to estimate the actual magnitude of the part that energy has played in the building up of present day civilization. Energy is a fundamental ingredient in human life. There is no industrial, agricultural, health, domestic or any other sort of process that does not require of degree of energy. The greater the per capita consumption of energy in a country, the higher is the standard of living of it's people. As stated in abstract, one of the important challenge that mankind is facing today is the generation of sustainable energy generation.

The fossil fuels are the main source for generation of electrical energy. But they have adverse effect on the environment such as global warming and climate change. Also they are unequally distributed. They are non-renewable raw materials. They are limited resources. Also they have been depleted to a great extent due to their continuous exploitation. Due the lots of disadvantages of fossil fuels, a lot of research is done to use renewable energy sources for generation of energy. Renewable energy sources are eco-friendly. They are available in large amount. Also they are sustainable. The various forms of renewable energy sources are solar, wind, hydroelectric, etc. one of the most promising form is the wind energy.

Wind energy is a prominent energy source. It is clean and sustainable source(1). The currently available and most used technology is conventional wind turbine(2). It is a device that uses appropriate mechanism with alternator and turbine blades to convert winds kinetic energy into electrical energy. But this technology is costly and intermittence. Also it is limited to the certain altitude due to it's heavy and bulky construction.

Generally stronger and more persistent wind is obtained at higher altitude. Airborne Wind Energy System is a system which extract the energy from high altitude wind.

2. METHOD FOR EXTRACTING HIGH ALTITUDE WIND ENERGY

AWES are devices that converts kinetic energy of high altitude wind into electrical energy(3). All types of AWES consists of mainly two components, a ground system and at least one aircraft which are connected by cables generally known as tethers.

The methods for extracting the energy from high altitude wind are mainly categorized based on the place where the kinetic energy to electrical energy conversion takes place. They are categorized as "Ground-Gen AWES" and" Fly-Gen AWES". In Ground-Gen AWES the conversion of kinetic energy into electrical energy is takes place on the ground, whereas in fly-Gen AWES such conversion takes place on the aircraft(4).

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 09 | Sep 2021 www.irjet.net p-ISSN: 2395-0072

In Ground-Gen AWES, the ground station is connected to kite or aircraft via tether. As electrical energy is generated at ground, the tether need not be conductive type .The electric generator is attached to the rotating mechanism such as winch which is connected to the tether. In this system traction force is used to generate the electrical energy. The power produced by this system is intermittent.

In Fly-Gen AWES, the propeller turbine on the flying device or the flow induced rotational motion of the complete device drives on-board generators from where the electrical energy is transmitted to the ground by a conductive tether(4). The power generated by fly-Gen system is continuous. The examples of Fly-Gen AWES are lifting balloon, generating quadcopter, multi-plane with turbines, etc.

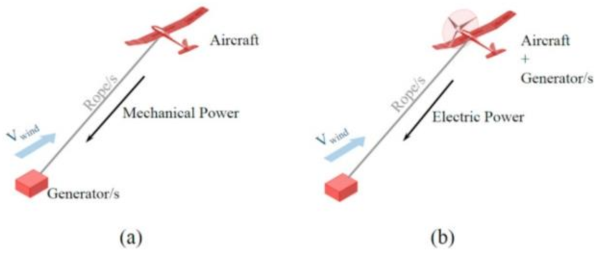


Fig 2.1. a) Ground-Gen AWES B)Fly-Gen AWES(4)

3. CONSTRUCTIONAL DETAILS OF SINGLE KITE GROUND-GEN AWES

In Ground-Gen AWES, the conversion of kinetic energy into electric energy is takes place at ground. The system consists of ground station and a single kite connected via tether.

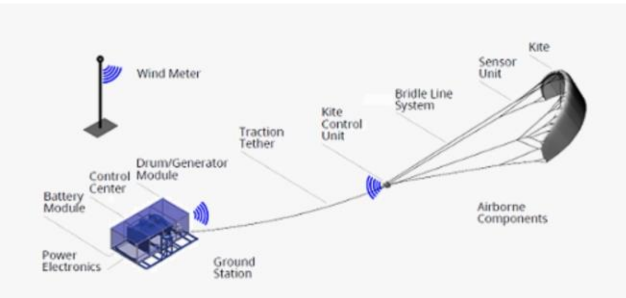


Fig 3.1. Constructional Details of Ground-Gen AWES(5)

The components of the system are:

1. Kite
2. Tether
3. Winch
4. Motor
5. Centrifugal clutch
6. Chain drive
7. Flange coupling
8. Generator
9. Shaft

The principle of operation of ground-gen AWES consists of a two phase cycle, one is energy generation cycle and second one is recovery phase. In energy generation phase, the kite is reeled-out to travel in a crosswind path generally eight-shaped path or circular. It causes traction force on the ropes which in turn rotates generator to produce electrical energy. In recovery phase, a small amount of energy is used to reel-in the kite to it's original position. Motor provides this energy during recovery phase.

Winch is a mechanical part which is drum around which a rope or cable is wound. Centrifugal clutch connects motor shaft to the chain drive which drives the winch. Generators are the induction motors generates the electrical energy. Winch is connected to generator via flange coupling. Centrifugal clutch disconnects motor from winch during traction phase and connects them during recovery phase. Chain drive is used to obtain the required speed and torque at winch as motor has different characteristics than required.

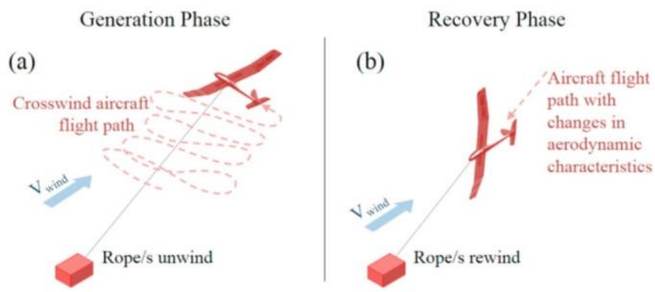


Fig 3.2. principle of Operation of Ground-Gen AWES(4)

4. DESIGN OF GROUND-GEN AWES

The Ground-Gen system is designed on the basis of kite size and it's parameters, operating altitude and tether constrains. It is important to overview the study of kite model and driveline model.

4.1.Aerodynamic performance of tethered kites:

For this thesis paper a single kite system is considered. According to Loyd(6), power generated by simple kite model is given by,

$$P = P_W A C_L F \tag{1}$$

Where, A is kite area, C_L is lift coefficient of the kite,

P_W is wind power density, F is function representing the specific model.

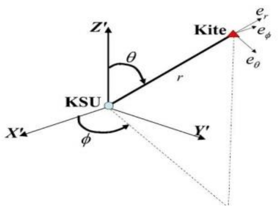


Fig 4.1. Kite in Cylindrical Coordinates(7)

The diagram shown above is adopted here. Forces acting on kite are function's of kite mass, angle of attack, it's roll angle, projected kite wing area and local effective wind speed. The different forces acting on the kite are apparent force, gravitational force and aerodynamic force(8) . Aerodynamic force has two components, lift force acting perpendicular to the kite's surface and drag force acting in the direction of effective wind . These two forces are given by,

$$F_C = \frac{1}{2}\rho A C_L |W_e|^2 \quad (2)$$

$$F_D = \frac{1}{2}\rho A C_D |W_e|^2 \quad (3)$$

The traction force acting on the tether is given by(9)

$$F^{c,trc} = \frac{1}{2}\rho A C_L E^2 (1 + \frac{1}{E^2})^{\frac{3}{2}} |W_{e,r}|^2 \quad (4)$$

Where, E is aerodynamic efficiency of the cable, $W_{e,r}$is effective wind speed along wind direction

For constant cable speed,

$$|W_{e,r}| = |W_o| \sin\theta \cos\varphi \quad (5)$$

θ is cable inclination angle, φ is cable azimuthal angle, $W_o$is nominal wind speed on horizontal plane at kite's altitude.

Considering linear wind profile(10),

$$W_o = 3.48 + 0.00573h \qquad 0m < h < 988m \quad (6)$$

$$W_o = 7.85 + 0.00146h \qquad 988m \le h \le 5000m \quad (7)$$

Aerodynamic efficiency of the kite,

$$E = \frac{C_L}{C_D} \quad (8)$$

Considering cable drag force(11),

$$E = \frac{C_L}{C_D + \frac{drC_{d,c}}{4A}} \quad (9)$$

Maximum power output is obtained by considering the following conditions,

$$\theta = \frac{\pi}{2}, \varphi = 0, r = \frac{W_o}{3}$$

The maximum power output of the kite model is given by,

$$P = \frac{2}{27}\rho A C_L E^2 \left(1 + \frac{1}{E^2}\right)^{\frac{3}{2}} |W_o|^3 \quad (10)$$

4.2. Driveline model

The rotor dynamics is represented by the equation(12),

$$F^{c,trc}R - T_g - Dw = J\dot{w} \quad (11)$$

Where, R is winch radius, T_g is generator load torque, J is equivalent moment of inertia of rotating system, D is equivalent viscous damping coefficient, w is rotor speed.

Traction force in tether generates power,

$$P_T = F^{c,trc}V_L \quad (12)$$

Where, V_L is tether's radial velocity

$$V_L = Rw \quad (13)$$

Power consumed during recovery phase,

$$P_R = V_m I_m \quad (14)$$

V_m is voltage of motor,I_m is motor current.

Net power produced,

$$P = P_T - P_R \quad (15)$$

4.3. Power generated by the system

In this thesis paper, we considered the kite and tether parameters to design the proposed system by analytical method. The kite parameters and tether constraints are shown in table

Kite Area A	$22m^2$
Lift Coefficient of KiteC_L	1
Drag Coefficient of KiteC_D	0.2

Drag Coefficient of Tether $C_{D,C}$	1.2
Operating Altitude h	700m
Maximum Line Velocity V_w	4m/s
Length of Tether r	800m
Air Density ρ	1.225kg/m^3
Angle of Inclination	36deg
Tether Diameter d	40mm

Table 4.1. Kite Parameters and Tether Constrains

Using the eq. (9),(6),(4), (10) and (11) respectively,

The Aerodynamic efficiency of the kite, E=4.3

Wind speed at the selected altitude, W_o=7.491m/s

The traction force acting on the tether, $F^{c,trc}$=4784.94N

The maximum power generated by the selected power system, P=19.139kW, the radius of winch ,R=0.0662m.

4.4. Driveline Component Design

The driveline of Ground-Gen AWES system consists of winch, motor, centrifugal clutch, chain drive and generator. The functions of these components are stated above. The table shows the values of design parameters of driveline components which are obtained by mathematically solving the appropriate formulae. The formulae used for mathematical calculations are adopted from various research papers and studies appropriately to design driveline components.

Component	Formulae	Output
Winch	T=$\frac{\pi\tau}{16}[(d_o)^3(1-K^4)]$ K=$\frac{d_i}{d_o}$ T=$F^{c,trc}R$	T=317Nm
Motor	P=$T_m w$ T_w=Jα $T_d = F_D R$ $T_m = T_w + T_d$	P=3.383kW T_w=40Nm T_d=3.08Nm T_m=43.08Nm
Chain drive	$i = \frac{T_m}{T_R}$ $P_D = PK_s$ $K_s = K_1 + K_2 + K_3$ $V = \frac{\pi d_1 N_1}{60}$ $W = \frac{P}{V}$ $F.O.S. = \frac{W_B}{W}$	i=1.95 P_D=7.61kW K_s=2.25 V=4.183m/s W=0.788kW F.O.S=22.58

Table 4.2. Design Parameters

4.5. Selection of components

1. Winch : Winch with inside diameter 125mm and outside diameter 130mm is selected.

2. Motor: From the pre selection chart(13),the power rating leads to the selection of model MS 1122 (13), the available size of motor with 3.5kW power rating is selected for the application with following properties:

Rated torque=22Nm

Rated speed= 1520rpm

Supply voltage=260V

3. Chain Drive: The power ratings for simple roller chains depends on the speed of the smaller sprocket. The power transmitted for chain no.08B is 6.81kW corresponding to pinion speed 1400rpm and 8.10kW corresponding to 1800rpm. The rated speed of the selected motor is 1520rpm. So the design power of 7.61kW at 1520rpm speed of the smaller sprocket, leads to the selection of chain no. 08B with one strand.

4. Centrifugal clutch: Centrifugal clutch of model no. LD4S-4L is selected with sprocket teeth 14 for chain no.08B according to the design criteria.

5. Shaft: Shaft with diameter 35mm is selected

6. Generator: The induction machine of model no. LSES 180 LR with 22kW power rating is selected for the application.

5. CATIA MODELS

5.1 CAD Models of Components

The CAD models of components and assembly of these components of Ground-Gen AWES are drawn with the help of " CATIA V5" software.

1. Winch

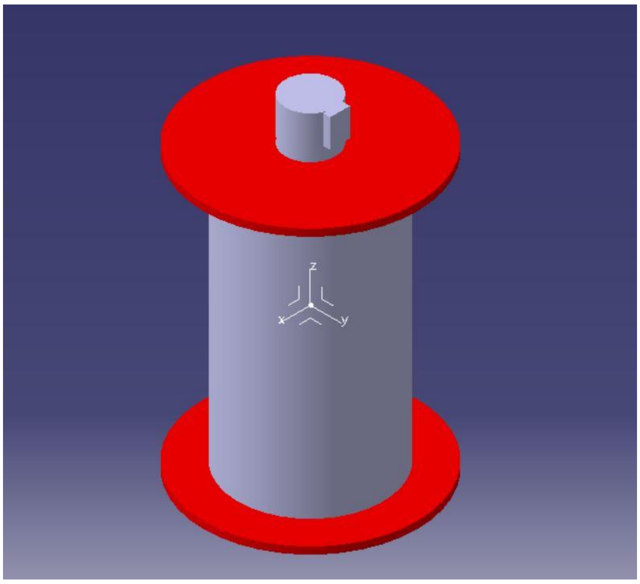


Fig 5.1.1. Winch CAD Model

2. Flange Coupling

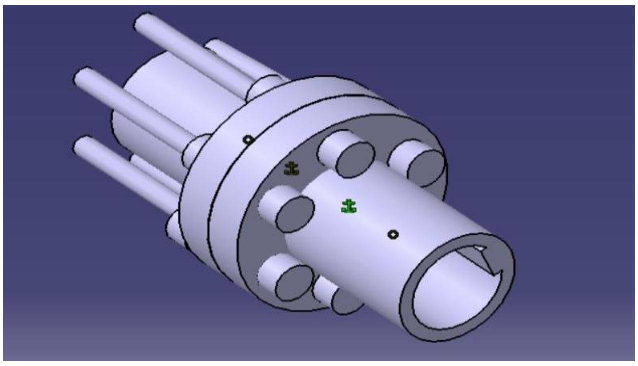


Fig 5.1.2. Flange Coupling CAD model

3. Chain Drive

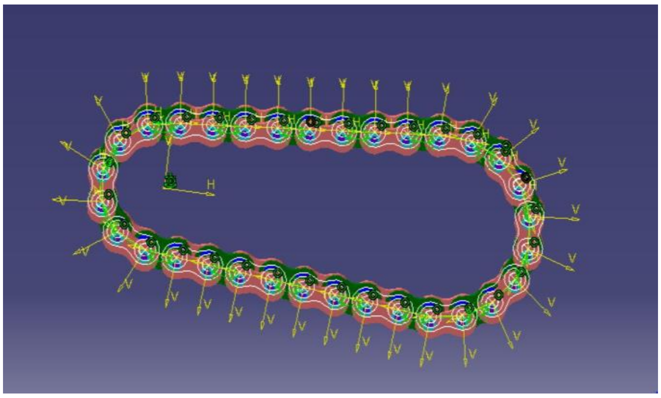


Fig 5.1.3. Chain Drive CAD Model

4. Big Sprocket

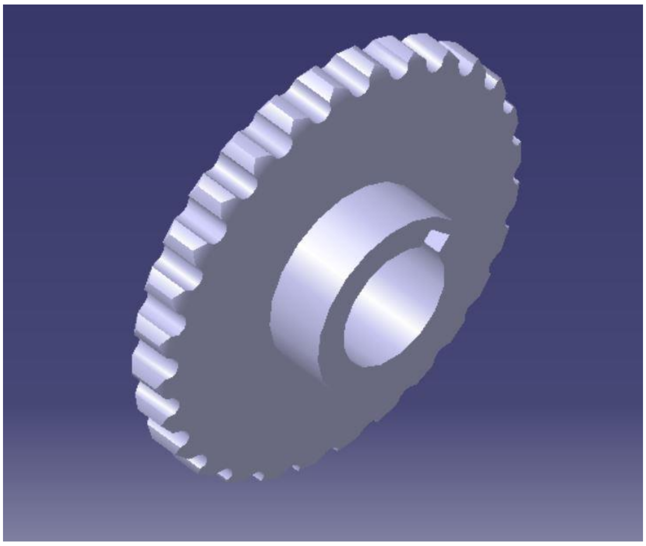


Fig 5.1.4. Big Sprocket CAD Model

5. Small Sprocket

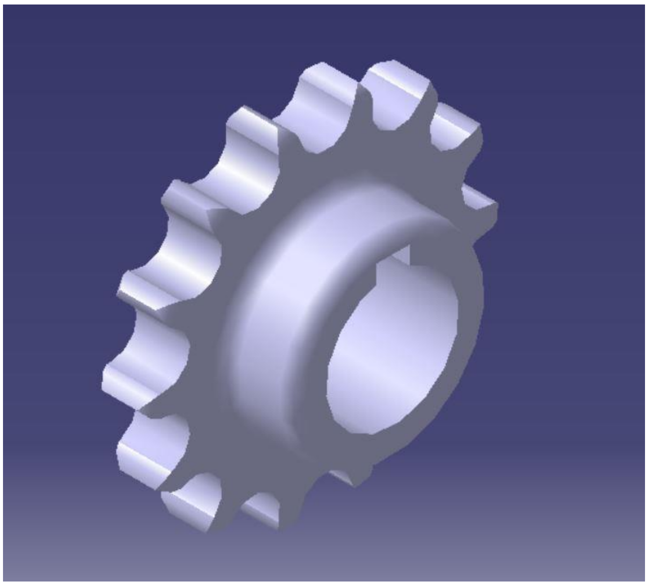


Fig 5.1.5. Small Sprocket Cad Model

6. Generator

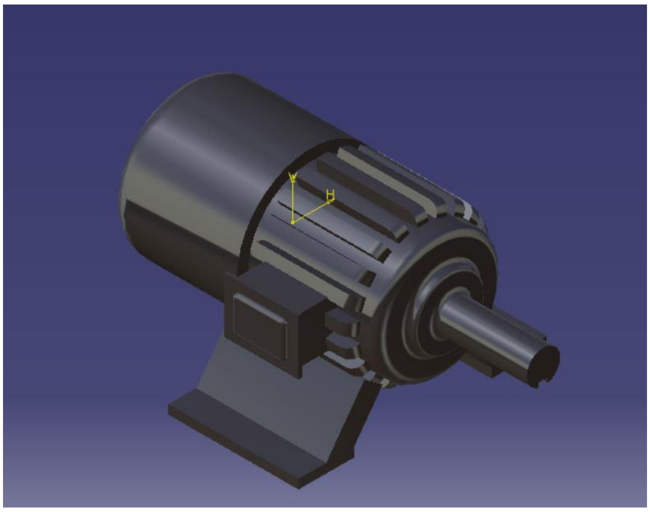


Fig 5.1.6. generator CAD Model

7. Motor

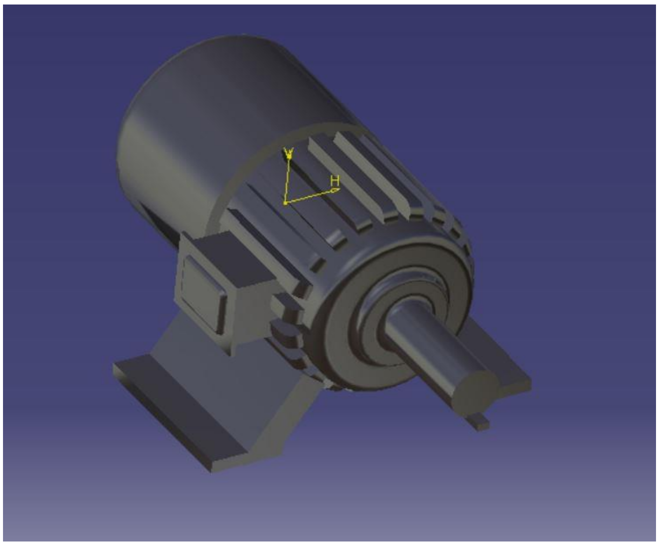


Fig 5.1.8. Motor CAD Model

8. Chain Drive Shaft

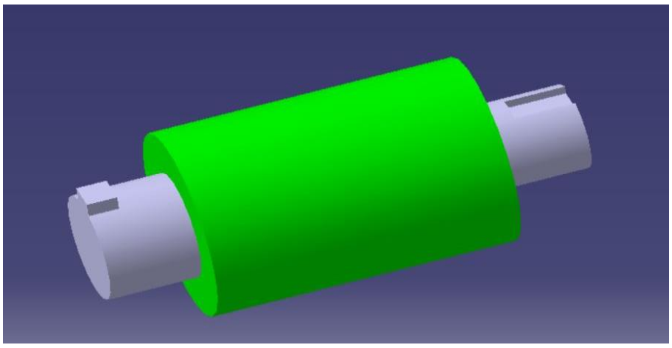


Fig 5.1.8. Chain Drive shaft CAD Model

9. Coupling Shaft

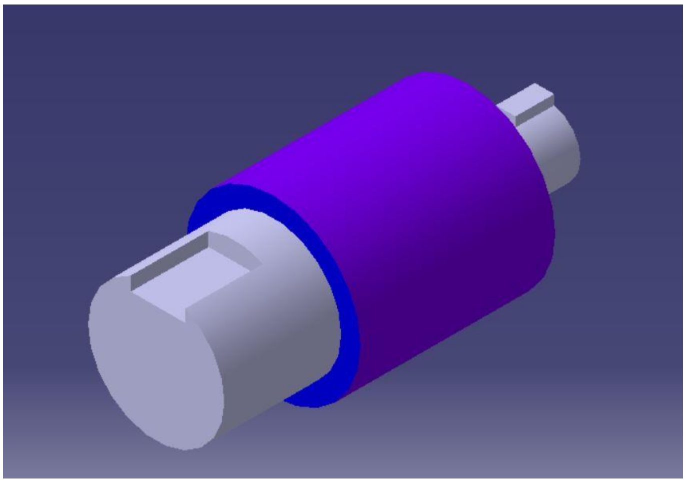


Fig 5.1.9. Coupling Shaft CAD Model

5.2. Assembly Models

1. Chain drive Assembly

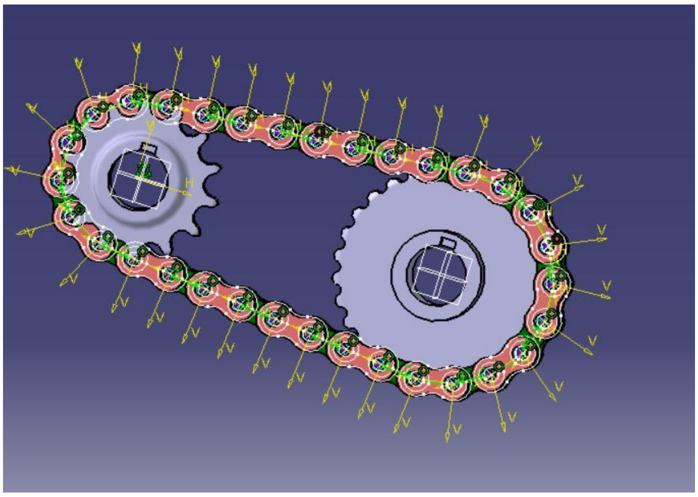


Fig 5.2.1. Chain Drive Assembly Model

2. chain Drive with Motor Assembly

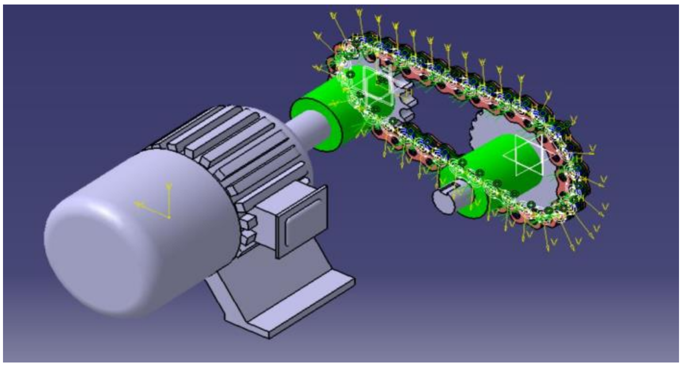
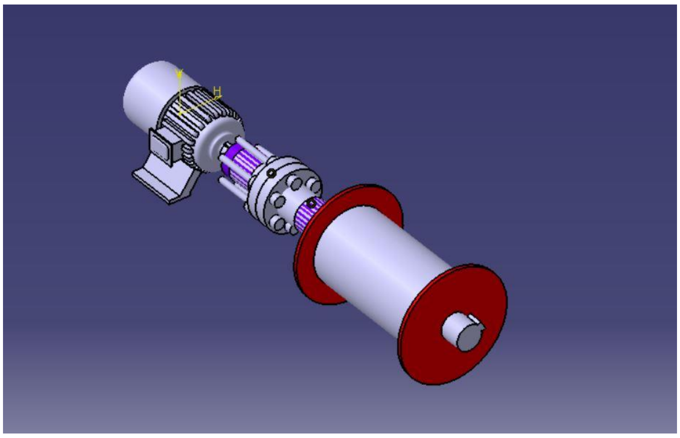


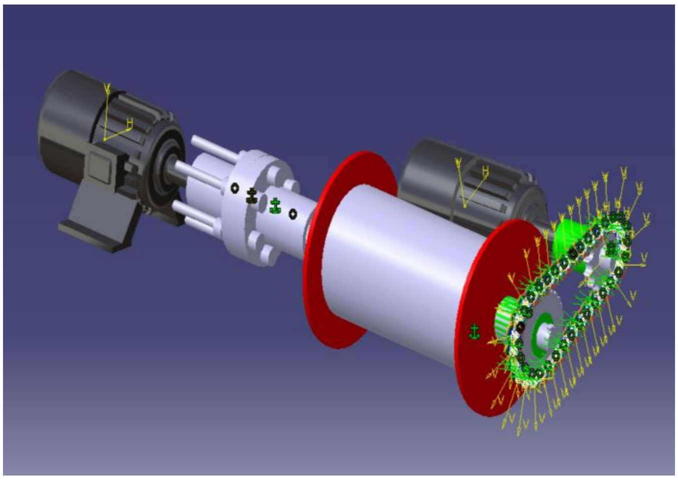
Fig 5.2.2. Chain Drive with Motor Assembly Model

3. Winch-Generator Assembly



5.2.3. Winch-Generator Assembly Model

4. Full Assembly



5.2.4 Full Assembly Model

6. Simulation Model

A simple simulation model is generated which is as follows:

The drive line consists of DC motor, centrifugal clutch, chain drive, winch and a generator.

In the simulation model, one side of the winch is connected to the DC motor with the chain drive and a centrifugal clutch. The input for centrifugal clutch is given by controller. During traction phase, clutch disconnects the motor from chain drive and during recovery phase, clutch connects the motor to chain drive as controller sends signal to centrifugal clutch. During traction phase, winch drives the shaft connected to generator via flange coupling, hence generates energy. During recovery phase, a small amount of energy produced is used by motor to reel-in the kite.

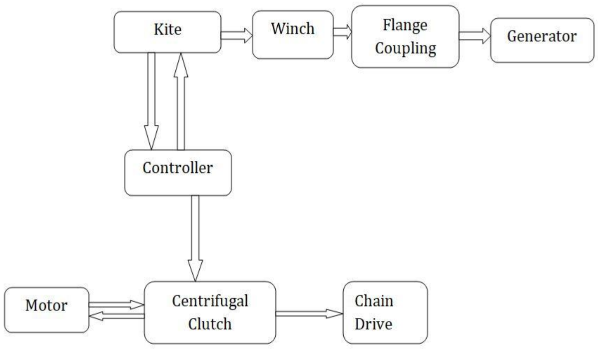


Fig 6.1. Simulation Model

The characteristics of DC motor and generator are simulated with the help of" MATLAB SIMULINK" software. The simulation model used to obtain torque-speed characteristics of DC motor is shown below(14).

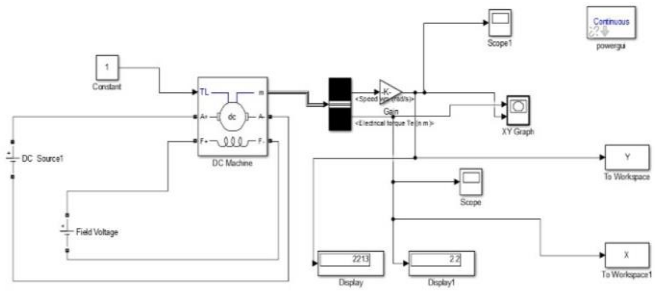


Fig 6.2. Simulation Model of Torque-Speed Characteristics of DC motor

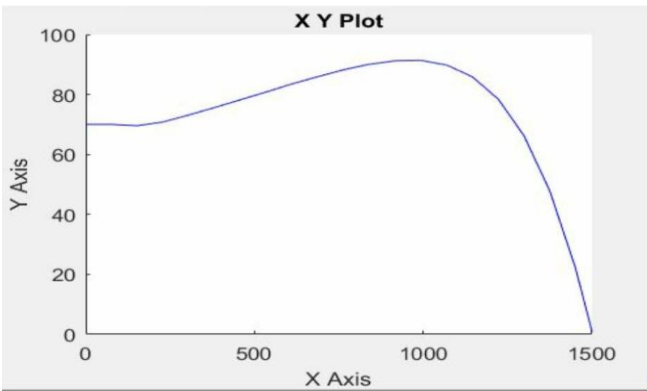


Fig 6.3. Torque-Speed Characteristics of DC Motor

The graph shows that torque increases as speed increases until it reach the maximum torque value, after reaching maximum torque value, torque decreases with increasing speed.

The model is simulated for the proposed DC motor with rated power 3.5kW, rated torque 22Nm, rated speed 1520rpm and rated voltage of 260V, the simulation gives the maximum speed of 1575rpmand torque 22Nm. The model is simulated for another motor with rated power4kW, rated speed1750, and rated voltage240, the simulation gives the maximum speed of 2230rpm and torque 22 Nm.

The simulation model used to obtain torque-speed characteristic of induction motor is shown below(15).

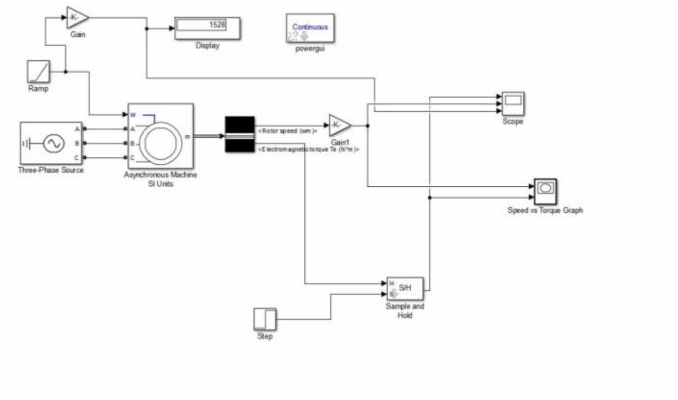


Fig 6.4. Simulation Model of Torque-speed Characteristics of Generator.

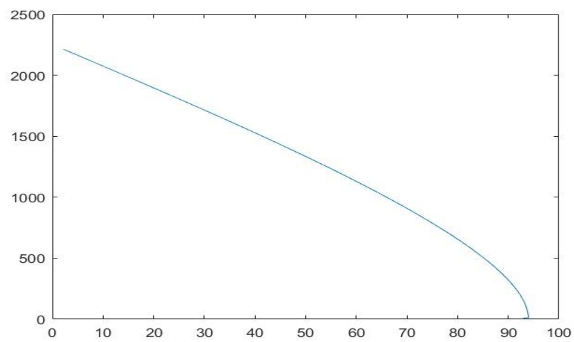


Fig 6.5. Speed- Torque Characteristics of Generator

The graph shows that, for generator which is basically three phase induction motor, speed decreases with increasing torque.

The model is simulated for generator with rated power 22kw, rated speed 1458rpm and rated voltage 400V, the maximum speed obtained is1528rpm . The same model is simulated for another generator with rated power4kW, rated speed1430rpm and rated voltage400V. The maximum speed is 1528rpm.

The model 1528rpm.

The simulation model of kite is shown below(12)

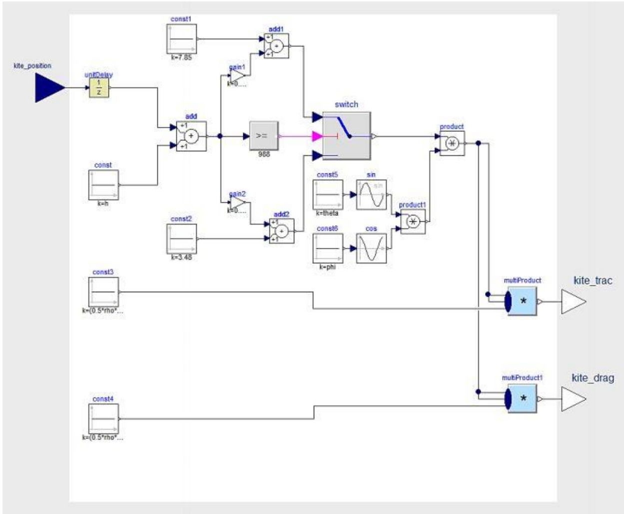


Fig 6.6. Simulation Model of Kite

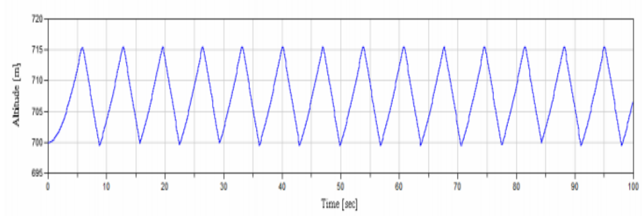


Fig 6.7. Output of Kite(12)

The graph shows that, during traction phase, kite travels the distance of 15m that is line length and during recovery phase , kite travels back to it's original position.

The simulation model of controller(12)

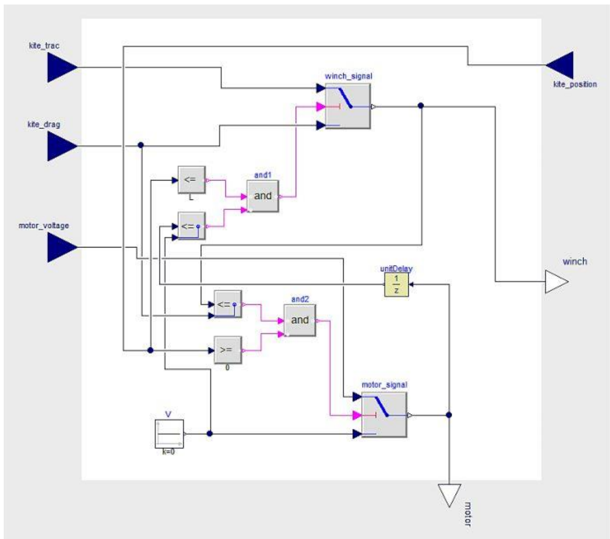


Fig 6.8. Simulation Model of Controller(12)

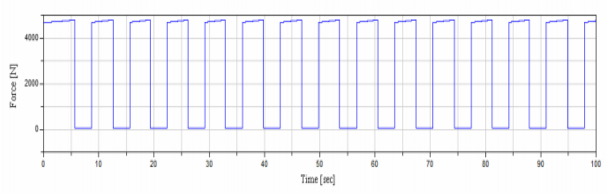


Fig 6.9. Output of Controller(12)

The graph shows that, the maximum traction force obtained in traction phase is 4800N. during recovery phase, the value of traction force is zero.

7. RESULT

The result shows that the design data obtained by quantitative approach and the simulative approach is approximately same. Hence, the design proposed in this thesis is safe.

8. Future Scope

The power output of the proposed system is intermittent, hence the future scope in obtaining the continuous power output is possible. Lot of research is going on to obtain the maximum efficiency of this system. By decreasing aerodynamic drag coefficient, the efficiency increases. Hence research is going on to use materials and aerofoil shapes to get minimum drag coefficient.

9. Conclusion

The thesis paper shows the detailed study of design of Ground-Gen Airborne Wind Energy System.

The design is done by using various methodologies. The first one is by the mathematical calculations method. The design data obtained is simulated with the help of "MATLAB SIMULINK" software. The detailed drawings of proposed design model are drawn with the help of "CATIA V5" software. Along with the design of different parts, the assembly of different parts is also done.

ACKNOWLEDGEMENT

This project would have been a distant if not for the help and encouragement from various people. We take immense in thanking Dr. Mane V.V. Principal of College of Engineering Osmanabad, for having permitted us to carry out this project work.

I would like to express my heartfelt gratitude to. Patel A.Z. (Project Guide & coordinator) for supporting me and guiding me to prepare this detailed project work.

I am also thankful to the entire friends and family members who directly and indirectly inspired and helped us for completion of this project.

References

1. https://www.conserve-energy-future.com > ... web results Various Disadvantages of Wind Energy- Conserve Energy Future.
2. https://en.m.wikipedia.org > wiki.
3. https://www.researchgate.net > 2823...(PDF) Airborne Wind Energy System: A review of the technologies.
4. https://www.sciencedirect.com > pii Web Results Airborne wind Energy System: A review of the technologies.
5. https://onlinelibrary.wiley.com >full web result Improving reliability and safety of airborne wind energy systems.
6. Miles L. Loyd "Crosswind Kite Power". J. Energy, vol4.no.3,pp 106-111,1980.
7. Lorenzo Fagiano. "High-altitude Wind Power Generation". IEEE Transactions on Energy Conversion, Vol. 25, No. 1, March 2010
8. M. Ahmed, A. Hably, S. Bacha. "Power Maximization of a Closed-orbit Kite Generator System". 50 th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC) Orlando, FL, USA, December 12-15, 2011.
9. Lorenzo Fagiano. "Control of Tethered airfoils for High–Altitude Wind Energy Generation". PhD dissertation, Politecnico di Torino, Italy, February 2009.
10. B. Lansdorp, W J. Ockels. "Design of a 100 MW laddermill for wind energy generation from 5 km altitude". 7 th World Congress on Recovery, Recycling and Re-Integration, Peking, China, 25-29 September 2005.
11. Lansdorp, R. Ruiterkamp, P. Williams, .J. Ockels. "Long-Term Laddermill Modeling for Site Selection". AIAA-2008-6690, AIAA Modeling and Simulation Technologies Conference and Exhibit, Honolulu, Hawaii, 18-21 August 2008.
12. https://www.diva-portal.org >...PDF Web Results Design of High Altitude Wind Power Generation System-DiVA
13. Silinki-pradu-stalego-MS1-MS2-katalog,pdf
14. https://youtu.be/CnLWhu4BPdg
15. https://youtu.be/aicNiN4VzF4