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Design of Rigid Body Dynamics for Pitch Regulation Mechanism to Maximize Energy Capture by Wind Turbine

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ABSTRACT

Wind turbines are generally designed for specific wind speeds and at below or above these speeds wind turbine could not give the expected maximum power. To obtain the maximum power at different wind speeds, pitching mechanism of the blades introduced. Mostly active pitching is used on large scale but the study gives detail advantages, design and analysis of passive pitching which is free of electronics. The study suggested the design that through centrifugal masses the rotor is able to changes the pitch angles through 10 degrees which are enough for wind speed ranges from 4-20 m/s which maintain the optimum angle of attack maximizing the power output. This report includes an in- depth analysis of design process, detailed components and assembly, recommendations, and conclusions.

I. INTRODUCTION

Windappears through pressure differentialsbetweenregions in the atmosphere. Wind may be defined as the air/gasses movement in the atmosphere to stabilize the heat disproportion which is caused by the uneven air heating by the sun. The energy of air convergence is to turn many times into the history of mankind, and to experience a new process reengineering as the primary form of renewable energy on mechanical basis. Wind energy is an alternative/renewable, wildly distributed and clean source of energy which has no greenhouse gases (GHG) emissions during the operations. The world has enormous sources of wind especially at and near the coastal and hilly areas. It has been estimated that if only 10-15% of wind energy used for the electricity generation, it would be enough to meet the electricity requirements of all the world.

Wind power is converted to electricity by using wind turbines which consists of a rotor, blades, generator and electronic control unit mounted on a pole/tower several meters high from the ground. Wind turbines can be constructed as stand-alone to many in numbers in the series. The capacity of wind turbines also varies from kilowatts to MW. The main advantage of wind energy that it may be installed as stand-alone and size can also be changed according to the requirements.Pakistan has been a lot of offers in the Asian wind energy. In recent years, the government has completed many projects, to show that wind energy will be viable in this country. A 50 MW capacity wind power plant was developed at Jhimpir, Sindh province. This corridor has a capacity of almost 50000 MW at an average air speed of 7 m/s. [1]

Many designs has been made and are in working all over the world. Basically the wind turbines may be divided into two categories i.e. horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT).

A pitch controlled win turbine's EC (electronic controller) check and control the turbine's power output several times in a second. So that when the power output reaches too high, it send signals to the blade pitch mechanism which turns the rotor blade slightly out of the wind direction to normalize the speed of rotor.Contrarily, the rotor blades turned back to original position whenever the wind speed drops again to normal.

Manipulatingbladepitch as afunction of windandrotor speedcanproduce optimal anglesofattack, whichcan increase power outputover agreaterrangeofwindspeeds. SherifEl-Henaouiworkedonwindturbineandconcluded that during the periods of increased speed of wind, the pitch of the blades is controlled in order to control the turbine's poweroutput to its ostensible value.Whenwindspeedsreacha predefined threshold,typically 28m/s,theturbinestops powerproductionbyturningthebladestoa90° position. [2]

II. MATERIAL & METHOD

Up-windturbineis based on yawmechanismto turntherotoraccording tothewind directionwhereas downwindturbines lacks the yawmechanismbecausetheyareself-

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oriented.Windspeedgenerally havetwo degreeof freedomto drive themaximum power fromthe windandCanbe changedto keep the rotation rateof turbine nearly constantwhichisbeingoperatedinvarying speedof windswhenthe powergeneration efficiency ofwindturbineisoptimizedwith therotation.Boththepitchofbladesandyaw mechanismare usedtoshutdowntherotor undervarystrongwind.Themaximumspeed after witch windturbine shutdown their power production is cutoutspeed.

III. Design of Rotor

A set of design requirements was established inordertojustify thevariablepitchrotor design and comparethe performance parameters.Modificationswerelimitedtothe turbinerotor,facing turbinehousing and controller. Thedesign requirements encompassoperating requirements,practical considerations,andsafety.The following designrequirements weremadetoverify the performanceofthe newvariablepitchrotor turbine:

a) Thenewdesignmustdemonstratean increasedpoweroutputoverthewind speed rangeof 4to 7 m/s
b) Thebladesshouldbeabletopitcha total of 15°
c) The m e c h a n i s m m u s t b e a b l e t o operateintypicalweatherconditions, and bewaterproof.

The selected variable pitchrotor designtook into account variouspitch controlling methodsandthethree mainselection parameters areoutline below.

Thestudy choosetotakeapassiveapproach topitchtheblades.Thismeansthatnomotors or actuatorscouldbe used,andthesystem wouldoperatewithoutany inputcontrol. Passive controlwasdeterminedasthe optimalmethodduetoitsrelativesimplicity, sizeconstraints,andcost.Thewiring needed foractivecontrolalsocreatedissueswithslip rings and brushes.

Withthemasshavingalinearmovementdue tocentripetalforce,an angular displacement motionmustbe achieved.Twomainoptions emergedforpitch transduction; lead screw blockandslider linkageviacentralslider. Although bothapproaches had evidentupsides,theteamchose tousealinkage system.

The centripetalslider Armisselected asthe finaldesignfor thevariablepitchrotor.The systemcanbe brokendownintosixmajor components or assemblies.

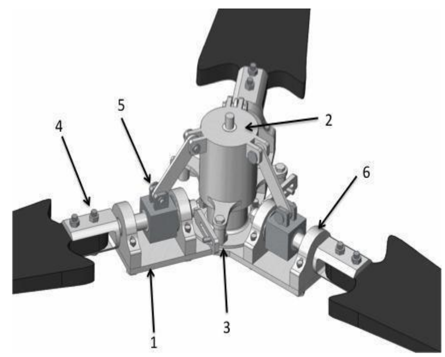

Figure 1.Blade configuration

IV. Rigid body dynamics & computational fluid dynamics

The dynamicsofthesystemisanalysisin order todevelopa theoreticalmodelof this relationship.Basedonthe resultsof this analysis,parameterssuchasspring stiffness andcentripetalmasscanbe refinedinorder tobetter matchthe designtoimplement experimentally. Whenthe rotor movesdue tothe aerodynamicforcesofthebladesoccurredby the windspeed, thecentral arm mases experience a centrifugalforce andmoves outward.

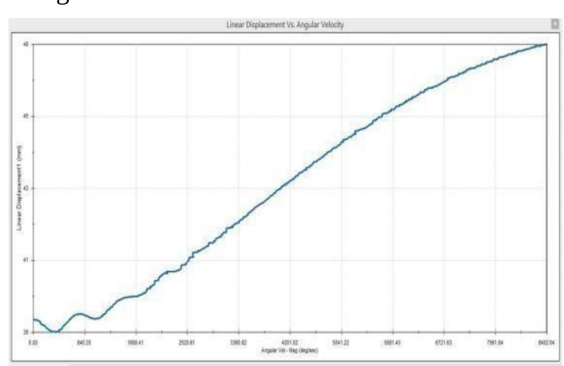

Figure 2. Graph between Angular Speed of Turbine &DisplacementCoveredByMasses.

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Whenaxialslider pusheddowndue to centrifugalforces by centralmasses,the bladesare pitchedaroundtheirownaxis through pinassemblieswhichgives the following graph.

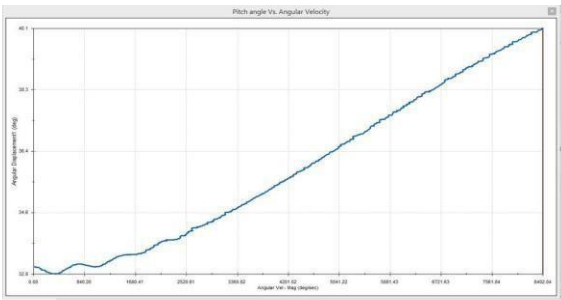

Figure 3. GraphbetweenPitchAngle ofBlade&angularspeed ofTurbine

V. COMPUTATIONAL FLUID DYNAMICS (CFD)

To analyze theeffectivenessofa HAWT,methodsof computationalfluid dynamics(CFD) wereusedtosimulate various airflows and directions.CFD on aero foilofHAWTgivesustheliftanddragforces andthroughtheseforceswe canfindliftand dragco-efficient.

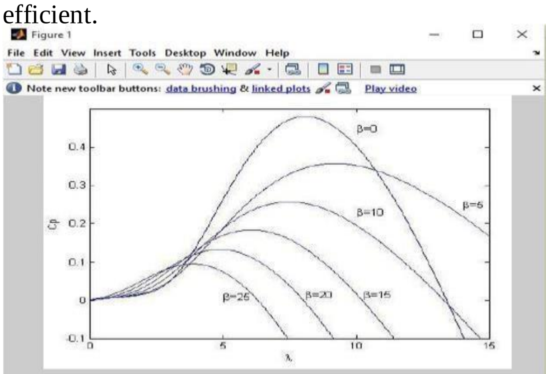

Figure 4. CFD ofanaerofoilblade

Theresultsare drag andliftforceswhose values come after CFD simulations are0.0148 and1.148respectively.IfF *A*xialisthe increment ofaxial force,and*F* power that of tangentialforce(which producesrotor acceleration and power),then [3]

$$F_{axial} = F_L \cos\emptyset + F_D \sin\emptyset$$

$$F_{power} = F_L \sin\emptyset + F_D \cos\emptyset$$

VI. MATLAB SIMULATION

Power coefficient in terms of pitch angle and tip speed ratio is [4]

$$C_p = 0.5176\left(\frac{116}{\lambda i} + 0.4\beta - 5\right)e^{\frac{-21}{\lambda i}} + 0.0068\lambda$$

And

$$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta 3 - 1}$$

From the above two equations it is possible to evaluate the value of C_p response at different tip speed ratio. By mat lab simulation we can observe the exact behavior of $C_p$with respect to tip speed ratio as under.

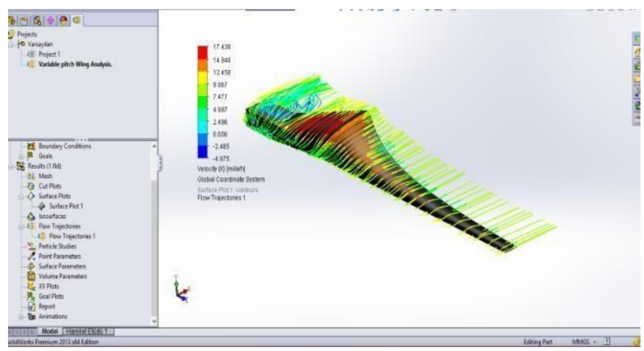

Figure 5. MATLABSimulation

Foroneparticularpitch angle,thereexistsan optimal tip speed ratiothat maximizes the powercoefficientCp. From Figure 5 it is clear that the maximum value of C_p can be obtained for a particular TSR value. By using this idea, the following MATLAB code (algorithm) was developed which compute the value of pitch angle to get the maximum value of CP for a given TSR. Thatiswhypitching ofthebladesaredonetoimprove the efficiencyof thewind turbine.

VII. MATLAB CODE

```
%mesh grid (tsr, pitch)

Cp = 0;
```

C1 = 0.5176;

C2 = 116;

C3 = 0.4;

C4 = 5;

C5 = 21;

C6 = 0.0068;

n=size(tsr);

fori=1:6

forj=1:n(2)

$$tsr_i = \frac{1}{tsr(j) + 0.08 \times pitch(i)} - \frac{0.035}{(pitch\,(i^3) + 1)^{-1}}$$

$$C_p(j) = c1 \times \frac{c2}{tsr_i - c3 \times pitch(i) - c4} \times \exp\left(\frac{-c5}{tsr - i}\right) + c6 \times tsr(j)$$

end

plot(tsr,Cp);

hold on;

end

VIII. Results & discussions

Powergeneratedbythewindturbinedepends onthesweptarea,airvelocityandco-efficient ofperformance.Thehigherthecoefficientof performancethemaximumpoweroutputwill begenerated.

$$P_{avail} = \frac{1}{2}\rho A v^3\, C_p$$

Where coefficient of performance is afunctionof pitchangleof the windturbine andtipspeedratio.Asthe coefficientof performanceisincreasedthe mechanical power output increased.

Mechanicalpower outputof turbine isalso increasedbypitchingtheangleofturbine.As thepitchangles of wind turbine vary it providesthemaximum airtostrikewith blade andgives higher output.

IX. Conclusion

The above experiment proves that the power outputofpassive pitchcontrol turbineis higherthanthat ofactive wind turbine. Asactivecontrol wind turbinegives the maxoutputatitsoptimalvalue of angle butpassivecontrolwindturbinegivestheoutputofevery valueofspeedofairby varyingthepitch angle.

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