Final Report
Wind Turbine Blade Design

Research Project

Adviser: Prof. Fei-Bin Hsiao

Reporter :

Ms. Nattirat Promwang

Outline

- Theories
- Calculation processes
- MATLAB Output
- Soildworks
- Discussion
- Conclusion

Objectives

- To gain the theoretical knowledge of Blade Element Momentum Theory (BEM)
- To apply BEM to design wind turbine blade shape and performance

Design Plan

- Horizontal Axis Wind Turbine (HAWT)
- Small wind turbine with 3 blades
- 1250 W power input
- 5 degree of initial angle of attack
- Tip speed ratio (λ) of 6
- RPM from 0 to 900
- Wind speed from 3 to 12 m/s

Calculation Processes

1. Calculate Efficient Radius (R) from 1D-Momentum Theory

$$R = \sqrt{\frac{P}{\frac{1}{2}\rho U^3 \pi \, Cp}}$$

2. Locate the radius at blade root and tip
3. Subdivide the blade into 10 sections

$$r_i = r_{i-1} + \frac{r_{tip} - r_{root}}{\text{the number of section}}$$

Calculation Processes

4. Determine "Local tip speed ratio"

$$\lambda_{r_i} = \left(\frac{r_i}{r_{tip}}\right) * \lambda$$

5. Find the value of angle of relative wind

$$\varphi_i = tan^{-1}\left(\frac{2}{3\,\lambda_{r_i}}\right)$$

6. Find the value of blade pitch angle

$$\theta_{p_i} = \varphi_i - \alpha$$

Calculation Processes

7. Calculate the chord length

$$c_i = \frac{(8\pi sin\varphi_i)}{3BC_l \ \lambda_{r_i}}$$

8. Determine "Local Solidity"

$$\sigma_i' = \frac{Bc_i}{2\pi r}$$

9. Determine relative velocity

$$U_{rel_i} = \frac{2V_s}{3sin\varphi_i}$$

Calculation Processes

10. Redesign pitch angle

$$\varphi_{new_i} = tan^{-1}(\frac{2V_s}{3\ r\omega})$$

11. Recalculate angle of attack

$$\propto_{new_i} = \varphi_{new_i} - \theta_p$$

Calculation Processes

12. Determine axial and angular induction factors

$$a_i = 1/\ [1+sin^2\varphi_i/\ (\sigma' C_l cos\varphi_i)]$$

$$a_i' = 1/\ [(4\cos\varphi_i/\ (\sigma' C_l)) - 1]$$

13. Recalculate tip speed ratio

$$\lambda_{\mathrm{r,new_i}} = (a_i/a_i')\ \mathrm{tan}\varphi_i$$

Calculation Processes

13. Calculate torque

From Momentum Theory

$$dQ = 4a'(1-a)\rho U \pi r^3 \Omega \, dr$$

From Blade Element Theory

$$dQ = B\frac{1}{2}\rho U_{rel}^{\;2}\left(C_l \sin\varphi - C_d \cos\varphi\right) c r dr$$

14. Calculate power coefficient

$$C_P = \left(8/\lambda^2\right)\int_{\lambda_h}^{\lambda} \lambda_r^{\;3} a'(1-a)\left[1-(C_d/C_l)\cot\varphi\right] d\lambda_r$$

Calculation Processes

- Problem due to "Tip Loss"

$$F = (2/\pi)\cos^{-1}\left[\exp\left(-\left\{\frac{(B/2)[1-(r/R)]}{(r/R)\sin\varphi}\right\}\right)\right]$$

$$a = 1/\left[1 + 4F\sin^2\varphi/(\sigma' C_l\cos\varphi)\right]$$

$$a' = 1/[(4F\cos\varphi/(\sigma' C_l))-1]$$

$$U_{rel} = \frac{U(1-a)}{\sin\varphi} = \frac{U}{(\sigma' C_l/4F)\cot\varphi + \sin\varphi}$$

Calculation Processes

- Problem due to “Tip Loss”

$$dQ = 4Fa'(1-a)\rho U\pi r^{3}\,\Omega\,\mathrm{dr}$$

$$C_p = 8/\lambda^2 \int_{\lambda_h}^{\lambda} \mathrm{F}\lambda_r^3\, a_i'\,(1-\ a_i)\,[1-(C_d/C_l)\cot\theta_{p_i}]\,\mathrm{d}\lambda_r$$