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ME451 Laboratory

PI CONTROL DESIGN PROJECT
WEEK 1

Bring the course textbook to the Lab
'C.L.Philips and R.D.Harbor, Feedback Control Systems'

NOTE: It maybe helpful to look at the following in the course textbook before coming to the lab:

Chapter 7:
- **Sections 7.1 to 7.5**
- **Section 7.10**

Figure 1: The *WindDrive* Residential Wind Powered Electric Generator Prototype

Introduction:

As stated in the Whirlwind memorandum of January 18, the Residential Wind Power Development Group is dedicated to the development of the new *WindDrive* wind powered electric generator for residential use. In the previous months we have investigated various techniques related to control systems analysis and design because we feel that the ability to accurately control a process is vital to high technology product performance. We have verified the mathematical model that governs the response of the DC servomotor, and are now ready to apply these tools to design a speed control system. We will test the control design process on the servomotor in lab because it is a good physical model to serve in place of the *WindDrive* electric generator. After you finalize your design, your design will be tested by Whirlwind technicians to see if it meets performance specifications.

The WindDrive Electric Generator

The *WindDrive* electric generator (Fig. 1) has an electrical voltage output $e_g(t)$ that is determined by a combination of wind speed $v_w(t)$ and propeller angle of attack $\alpha_g(t)$.

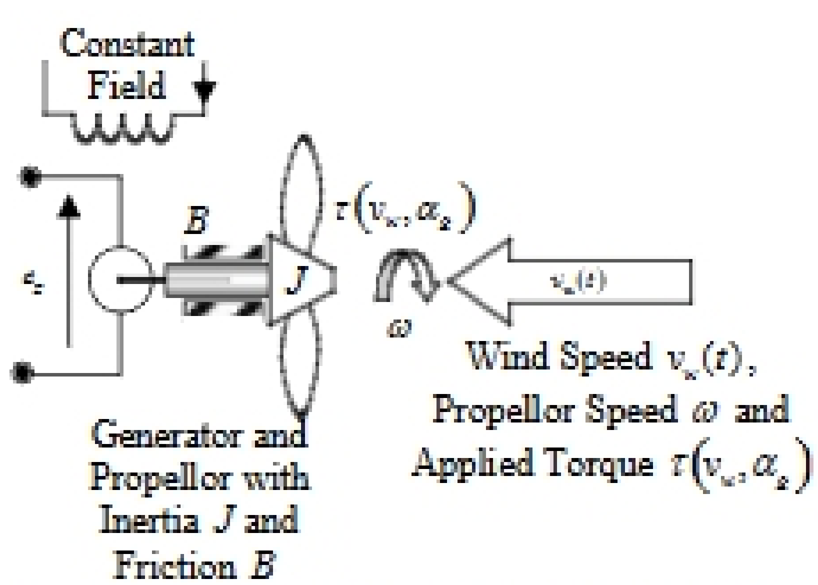

Figure 2. The WindDrive Wind Turbine

Lift Force L produces Torque
$T = rL = k_{lift} v_w \alpha_{rel} = r k_{lift} v_w (\alpha_g - r\omega)$

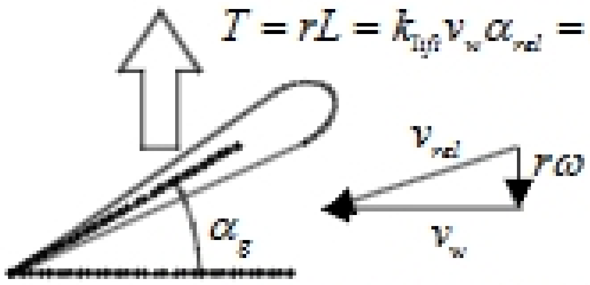

Figure 3. Angle of Attack

The turbine propeller blade airfoil rotates at speed $\omega = \dot{\theta}$ with angle of attack $\alpha_g(t)$ (Fig. 3). The propeller's effective angle of attack is reduced by the propeller's rotation speed ω and determines the Lift force L and torque T on the generator. This torque generated is proportional to the product of this angle and the wind velocity.

As the wind speed varies, we can use feedback control (Fig. 2) of propeller angle of attack $\alpha_g(t)$ to control the system's electrical voltage output $e_g(t)$.

Instead of the voltage being regulated to control motor speed, the wind turbine angle of attack α will be regulated to control the generator speed and resulting voltage. The torque applied to the generator,

$$T = rL = k_{lift} v_w \alpha_{rel} = K_{wind} (\alpha_g - r\omega) \tag{1}$$

where $K_{wind} = k_{lift} v_w$ is a wind speed dependent coefficient for the airfoil and r is the radius of the center of lift on the propeller blades. Following the derivations in the text [Phillips and Harbor section 2.72], the wind generator rotation speed ω produces the electrical potential

$$e_g = K_g \omega \tag{2}$$

through the generator's emf constant K_g. The generator's speed is modeled by

$$J\dot{\omega} + B\omega = T \tag{3}$$

Taking the Laplace Transform of (1)&(3) and substituting (1) into (3) yields the system model,

$$(Js + B + rK_{wind})\Omega(s) = K_{wind}\alpha_g(s) \tag{4}$$

Now using this result in the Laplace transform of (2) yields the system model

$$E_g(s) = \left[\frac{K_g K_{wind}}{(Js + B + rK_{wind})}\right]\alpha_g(s) \tag{5}$$

This model has the transfer function