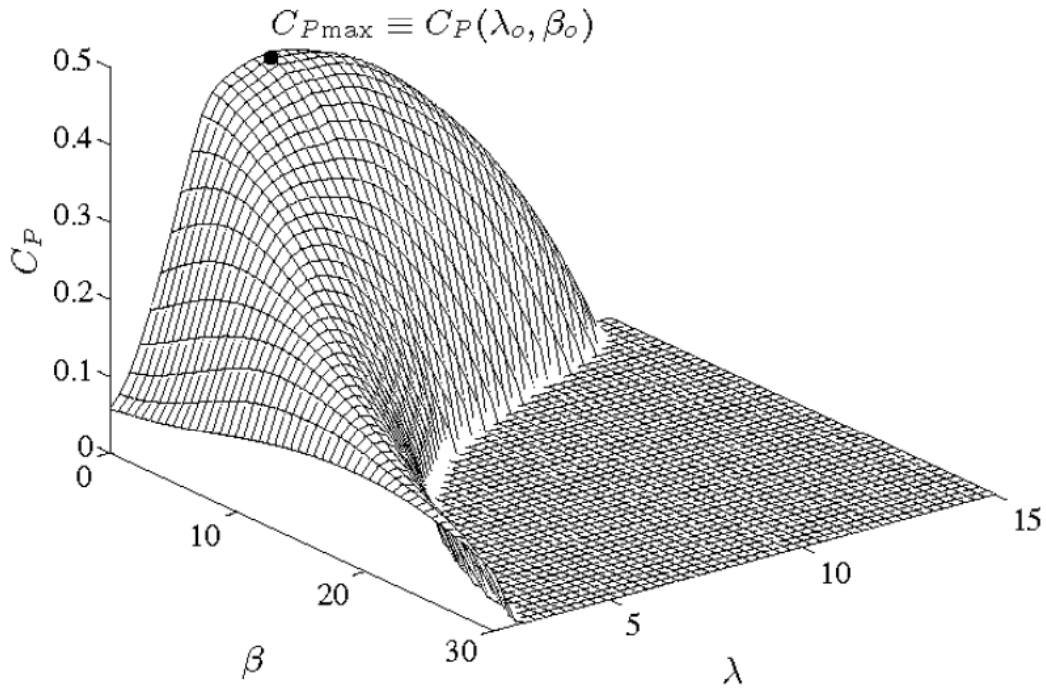
Renewable Energy

Power

$$P_r = C_P(\lambda, \beta) P_V = \frac{1}{2} \rho \pi R^2 C_P(\lambda, \beta) V^3,$$



Cp

$$c_p(\lambda,\theta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\theta - c_4\theta^{c_5} - c_6\right)\exp\left(\frac{-c_7}{\lambda_i}\right),$$

$$1/\lambda_i = \left[\left(\frac{1}{\lambda + c_8\theta}\right) - \left(\frac{c_9}{\theta^3 + 1}\right)\right]^{-1}.$$

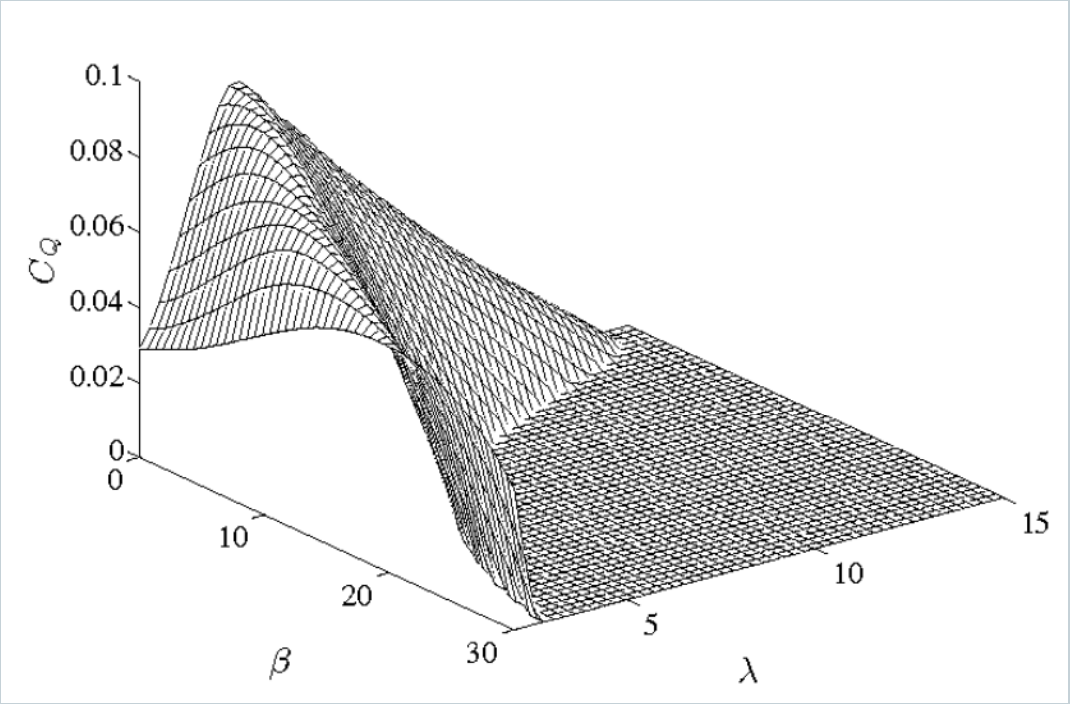
	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9
Heier (1998)	0.5	116	0.4	0	—	5	21	0.08	0.035
Constant-speed wind turbine	0.44	125	0	0	0	6.94	16.5	0	−0.002
Variable-speed wind turbine	0.73	151	0.58	0.002	2.14	13.2	18.4	−0.02	−0.003

Torque

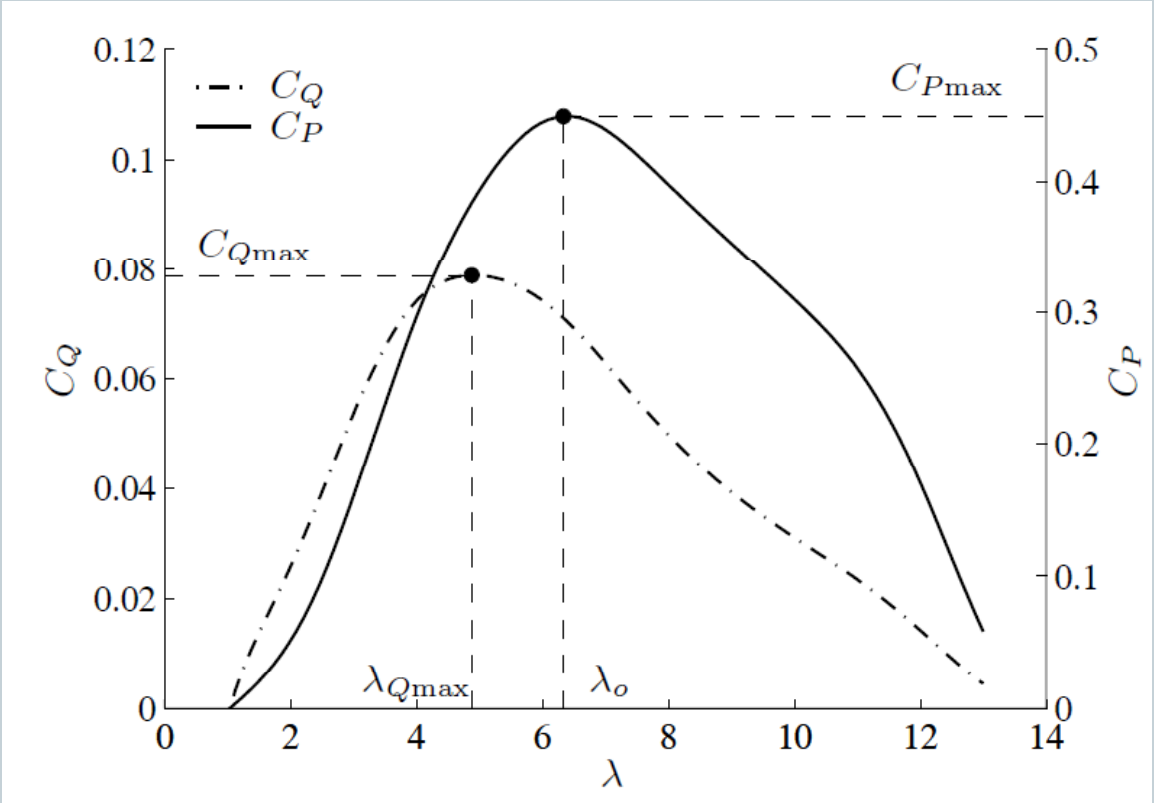
$$P_r = C_P(\lambda, \beta)P_V = \frac{1}{2}\rho\pi R^2 C_P(\lambda, \beta)V^3,$$

$$T_r = \frac{1}{2}\rho\pi R^3 C_Q(\lambda, \beta)V^2,$$

$$C_Q = C_P/\lambda.$$



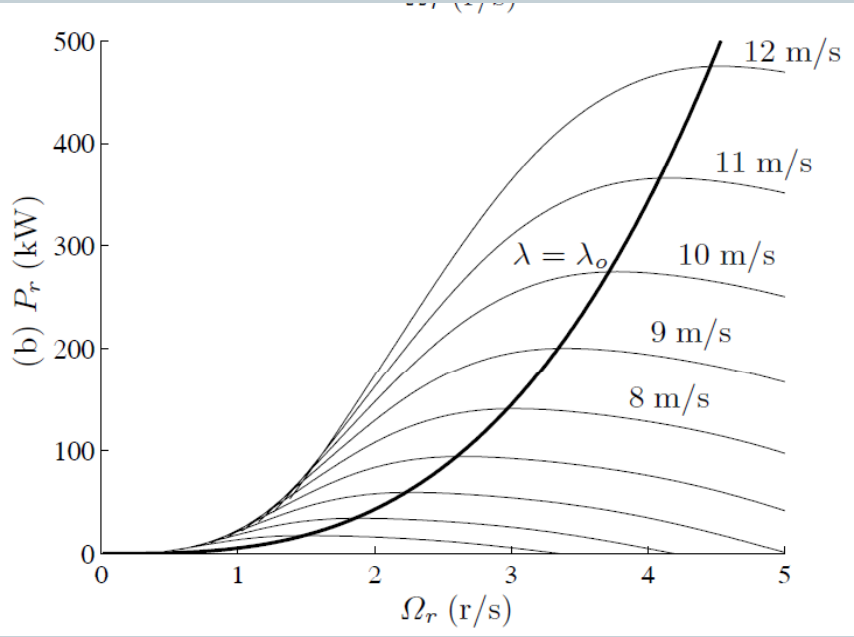
Typical variations of CQ and Cp for a fixed-pitch wind turbine

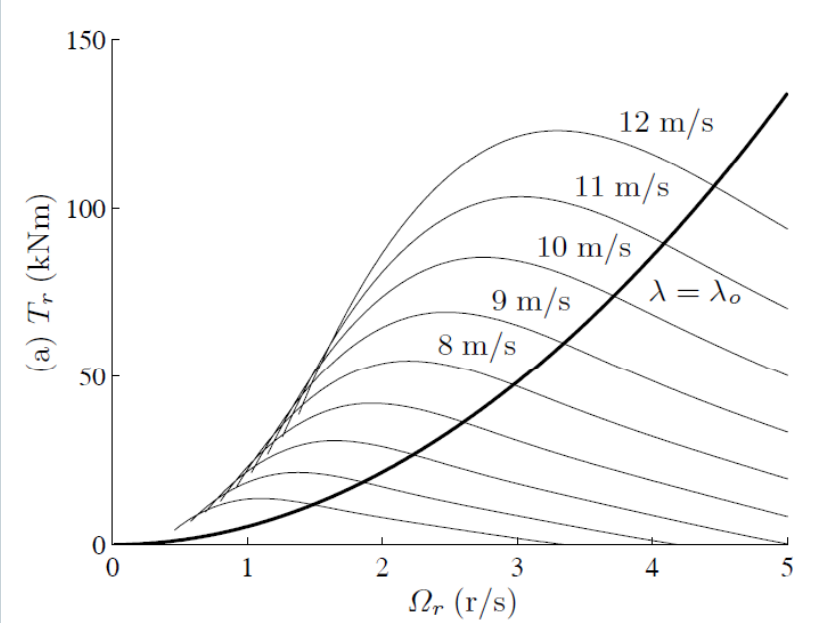


In the case of fixed-pitch wind turbines, CQ and CP vary only with λ, since β = 0 naturally

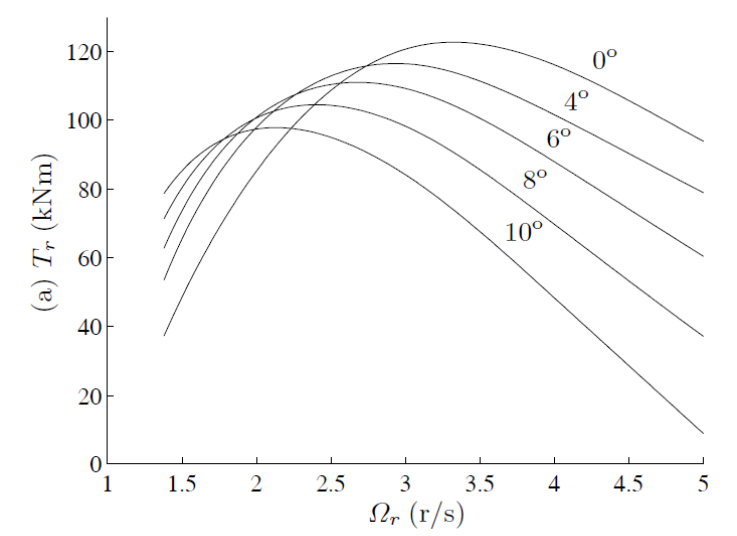
Torque and power vs. rotor speed

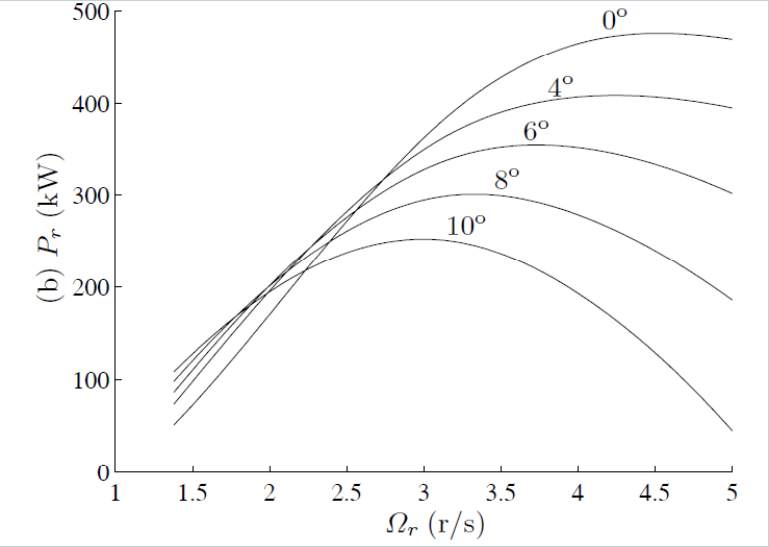
- fixed-speed turbines will operate with maximum efficiency just for a unique wind speed,
- whereas variable-speed turbines can potentially work with maximum efficiency over a wide wind speed range at least up to rated power

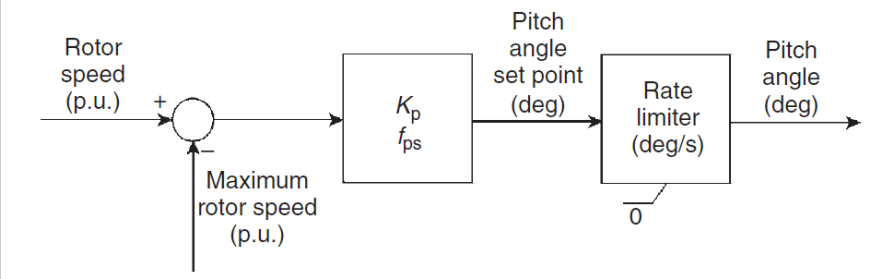




Torque and power vs. rotor speed with pitch angle as parameter and V = 12 m/s







The maximum rate of change of the pitch angle is in the order of 3–10 degrees per second, depending on the size of the wind turbine. As the blade pitch angle can change only slowly, the pitch angle controller works with a sample frequency fps, which is in the order of 1–3 Hz.

PSCAD Model

This component models a pitch angle regulator of a wind turbine. The inputs to the model are the mechanical speed of the machine Wm and the power output of the machine Pg. The output is the pitch angle of the turbine.

Input: Wm: Mechanical speed of the machine [rad/s], Pg: Power output of the machine based on the machine rating [pu]

Output: Beta: Pitch angle [°]

w_m	=	Mechanical speed of the machine [rad/s]
w_{ref}	=	Reference speed [rad/s]
P_{ref}	=	Power Demand [MW]
P_g	=	Power output of the machine based on the machine rating [pu]
K_s	=	Gain [°/pu]
K_p	=	Proportional gain [°/pu]
K_I	=	Integral gain [°/pu]
G_m	=	Gain multiplier [°/pu]
K_4	=	Blade actuator integral gain [s]