

Electric Energy (3rd Edition)

Chapter 6, Problem 22E

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Step 1 of 9

Write the formula for the coefficient of performance of wind turbine, C_p .

$$C_p = k_1 \left(\Lambda - k_2 \beta - k_3 \beta^3 - k_4 \right) e^{-k_5 \beta}$$
$$\Lambda = \frac{1}{TSR + k_6 \beta} \frac{k_7}{1 + \beta^3}$$

Substitute 20 for k_1 , 0.1 for k_2 , 0.002 for k_3 , 0.003 for k_4 , 15 for k_5 , 1 for k_6 , and 0.02 for k_7 .

$$C_p = 20 \left[\Lambda - 0.1\beta - 0.002\beta^3 - 0.003 \right] e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + \beta} \frac{0.02}{1 + \beta^3}$$

Comment

Step 2 of 9

(a)

The angle of attack α is,

$$\alpha = 90^\circ + \alpha_{ind} - \beta$$

Here,

β is the pitch angle

α_{ind} is the wind speed

The pitch angle β is,

$$\beta = 90^\circ + \alpha_{ind} - \alpha$$

Take wind speed as $20 \angle -80^\circ$.

$$\text{Substitute } -80^\circ \text{ for } \alpha_{ind},$$
$$\beta = 90^\circ - 80^\circ - \alpha$$
$$\beta = 10^\circ - \alpha$$

Substitute 0° for α .

$$\beta = 10^\circ - 0^\circ$$
$$\beta = 10^\circ$$

Substitute 10° for α .

$$\beta = 10^\circ - 10^\circ$$
$$\beta = 0^\circ$$

Substitute 20° for α .

$$\beta = 10^\circ - 20^\circ$$
$$\beta = -10^\circ$$

Substitute 30° for α .

$$\beta = 10^\circ - 30^\circ$$
$$\beta = -20^\circ$$

As α increases from 0° to 30° , β decreases from 10° to -20° .

Comment

Step 3 of 9

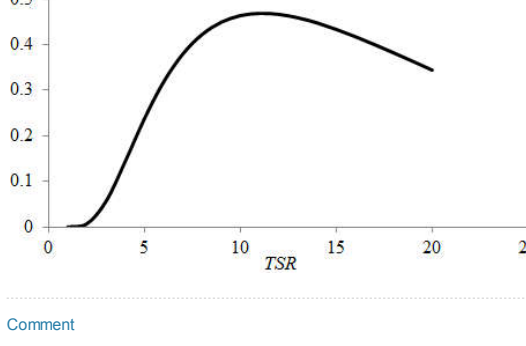
Consider the formulae.

$$C_p = 20 \left[\Lambda - 0.1\beta - 0.002\beta^3 - 0.003 \right] e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + \beta} \frac{0.02}{1 + \beta^3}$$

Substitute 10° , that is, $10 \times \left(\frac{\pi}{180} \right)$ for β .

$$C_p = 20 \left[\Lambda - 0.1 \times 10 \times \left(\frac{\pi}{180} \right) - 0.002 \times \left(10 \times \left(\frac{\pi}{180} \right) \right)^3 - 0.003 \right] e^{-15\beta}$$
$$= 20 \left[\Lambda - 0.0174 - 1.0633 \times 10^{-3} - 0.003 \right] e^{-15\beta}$$
$$= 20 \left(\Lambda - 0.02 \right) e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + 10 \times \left(\frac{\pi}{180} \right)} \frac{0.02}{1 + \left(10 \times \left(\frac{\pi}{180} \right) \right)^3}$$
$$= \frac{1}{TSR + 0.174} - 0.0199$$

Plot C_p versus TSR for α equal to 0° as TSR varies from 1 to 20.



Comment

Step 4 of 9

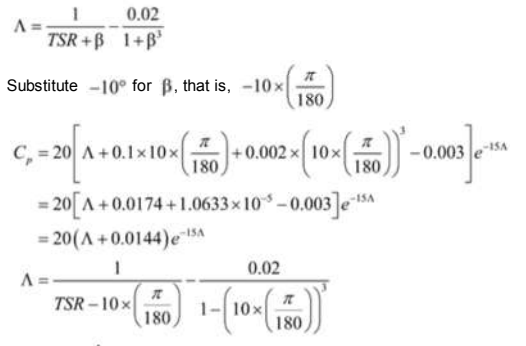
Consider the formulae.

$$C_p = 20 \left[\Lambda - 0.1\beta - 0.002\beta^3 - 0.003 \right] e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + \beta} \frac{0.02}{1 + \beta^3}$$

Substitute 0° for β .

$$C_p = 20 \left[\Lambda - 0.003 \right] e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + 10 \times (0)} \frac{0.02}{1}$$
$$= \frac{1}{TSR} - 0.02$$

Plot C_p versus TSR for α equal to 10° as TSR varies from 1 to 20.



Comment

Step 5 of 9

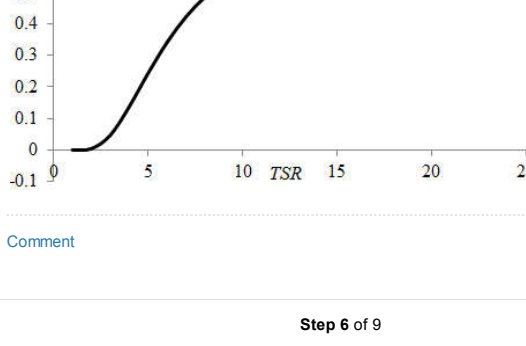
Consider the formulae.

$$C_p = 20 \left[\Lambda - 0.1\beta - 0.002\beta^3 - 0.003 \right] e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + \beta} \frac{0.02}{1 + \beta^3}$$

Substitute -10° for β , that is, $-10 \times \left(\frac{\pi}{180} \right)$.

$$C_p = 20 \left[\Lambda + 0.1 \times 10 \times \left(\frac{\pi}{180} \right) + 0.002 \times \left(10 \times \left(\frac{\pi}{180} \right) \right)^3 - 0.003 \right] e^{-15\beta}$$
$$= 20 \left[\Lambda + 0.0174 + 1.0633 \times 10^{-3} - 0.003 \right] e^{-15\beta}$$
$$= 20 \left(\Lambda + 0.0144 \right) e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR - 10 \times \left(\frac{\pi}{180} \right)} \frac{0.02}{1 - \left(10 \times \left(\frac{\pi}{180} \right) \right)^3}$$
$$= \frac{1}{TSR - 0.174} - 0.02$$

Plot C_p versus TSR for α equal to 20° as TSR varies from 1 to 20.



Comment

Step 6 of 9

Consider the formulae.

$$C_p = 20 \left[\Lambda - 0.1\beta - 0.002\beta^3 - 0.003 \right] e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + \beta} \frac{0.02}{1 + \beta^3}$$

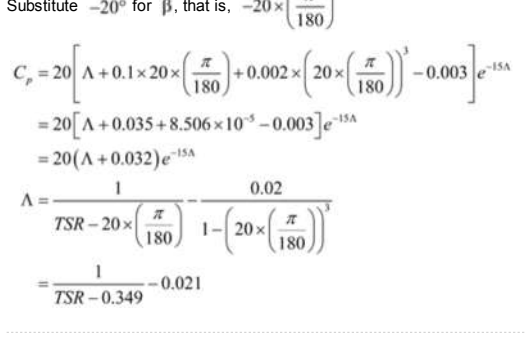
Substitute -20° for β , that is, $-20 \times \left(\frac{\pi}{180} \right)$.

$$C_p = 20 \left[\Lambda + 0.1 \times 20 \times \left(\frac{\pi}{180} \right) + 0.002 \times \left(20 \times \left(\frac{\pi}{180} \right) \right)^3 - 0.003 \right] e^{-15\beta}$$
$$= 20 \left[\Lambda + 0.035 + 8.506 \times 10^{-3} - 0.003 \right] e^{-15\beta}$$
$$= 20 \left(\Lambda + 0.032 \right) e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR - 20 \times \left(\frac{\pi}{180} \right)} \frac{0.02}{1 - \left(20 \times \left(\frac{\pi}{180} \right) \right)^3}$$
$$= \frac{1}{TSR - 0.349} - 0.021$$

Comment

Step 7 of 9

Plot C_p versus TSR for α equal to 30° as TSR varies from 1 to 20.



Comment

Step 8 of 9

(b)

Consider the formulae.

$$C_p = 20 \left[\Lambda - 0.1\beta - 0.002\beta^3 - 0.003 \right] e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + \beta} \frac{0.02}{1 + \beta^3}$$

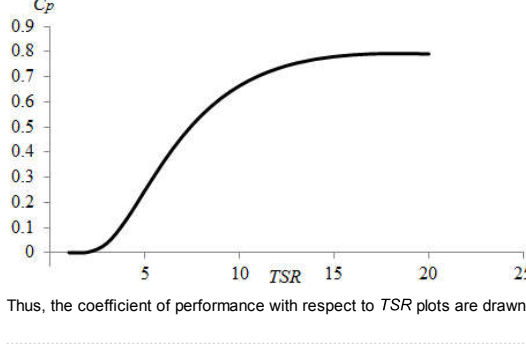
Substitute 30° , that is, $30 \times \left(\frac{\pi}{180} \right)$ for β .

$$C_p = 20 \left[\Lambda - 0.1 \times 30 \times \left(\frac{\pi}{180} \right) - 0.002 \times \left(30 \times \left(\frac{\pi}{180} \right) \right)^3 - 0.003 \right] e^{-15\beta}$$
$$= 20 \left[\Lambda - 0.0523 - 2.87 \times 10^{-3} - 0.003 \right] e^{-15\beta}$$
$$= 20 \left(\Lambda - 0.0556 \right) e^{-15\beta}$$
$$\Lambda = \frac{1}{TSR + 30 \times \left(\frac{\pi}{180} \right)} \frac{0.02}{1 + \left(30 \times \left(\frac{\pi}{180} \right) \right)^3}$$
$$= \frac{1}{TSR + 0.5236} - 0.0175$$

Comment

Step 9 of 9

Plot C_p versus TSR for β equal to 30° as TSR varies from 1 to 12.



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