LAMPIRAN 2.Perhitungan Torsi, daya, dan efisiensi turbin Darrieus NACA 0015

2.1 Perhitungan Torsi

- **Kecepatan 2 (EXP)**

  Dik:

  U = 2 m/s ω = 29.351 rad/s C_{L1} = **0.997** SIN (2.471 x)

  A = (0.8)(0.18) = 0.144 ρ = 998.2 kg/m^3 C_{L2} = 0.875 SIN(2.321 (x)

  D = 0.6 m   R = 0.3 m C_D = 1.039 sin(0.3074 x + 1.532) + 0.9072 sin(3.926 x - 1.76)

$$\mathbf{T_{L\ rata\text{-}rata}} = \frac{\dfrac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \rho(0.5)(W)^2 A.CL.\big(Rsin(x)\big)dx + \frac{1}{\pi}\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \rho(0.5)(W)^2 A.CL.\big(Rsin(x)\big)dx}{2}$$

Perhitungan torsi *lift* pada sudu 1:

$$T_{L_1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \rho(0.5)(W)^2 A.CL.\big(Rsin(x)\big)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(U+(-\omega R))^2(H)(c)\big(0.997sin(2.471x)\big)\big(R\ sin(x)\big)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(2+((-29.351)(0.3))^2(0.8)(0.18)\big(0.997sin(2.471x)\big)\big(0.3\ sin(x)\big)dx\right)$$

$$= \frac{1}{\pi}.998.2(0.5)(2+((-29.351)(0.3))^2(0.997)(0.8)(0.18)(0.3)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} sin(x)sin(2.471x)dx$$

$$= 316.891\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} sin(x)sin(2.471x)dx$$

$$= (316.891)\,(0.75)$$

$$= 237.668 \ \text{Nm } \textit{(searah putarant urbin)}$$

$$T_{L_2} = \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \rho(0.5)(W)^2 A.\,CL.\,\big(R\sin(x)\big)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)\big(U+(-\omega R)\big)^2 (H)(c)\big(0.875\ \sin(2.321x)\big)\big(0.3\ \sin(x)\big)dx\right)$$

$$= \frac{1}{\pi}(499.1)(\,46.312)\,(0.875)(0.8)(0.18)(0.3)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx\right)$$

$$= 278.114\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx\right)$$

$$= (278.114\,)\,(-0.494)$$

$$= -137.388 \ \text{Nm } \textit{(berlawanan arah turbin)}$$

Perhitungan torsi *lift* pada sudu 2:

$$T_{L1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(2+((-29.23)(0.3))^2 (H)(c)\left(0.997\sin\left(2.471(x+\tfrac{2\pi}{3})\right)\right)\left(0.3\ \sin\left(x+\tfrac{2\pi}{3}\right)\right)dx\right)$$

$$= (316.891\,)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin\left(x+\tfrac{2\pi}{3}\right)\sin(2.471x+1.648\boldsymbol{\pi})dx$$

$$= (316.891\,)\,(-0.384)$$

$$= -121.686\,\text{Nm } \textit{(berlawanan arah turbin)}$$

$$T_{L2} = \frac{1}{\pi} \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)(2 + ((-29.23)(0.3))^2 (H)(c) \left(0.875 \sin \left(2.321 \left(x + \frac{2\pi}{3} \right) \right) \right) \left(0.3 \sin \left(x + \frac{2\pi}{3} \right) \right) dx \right)$$

$$= 278.114 \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x + 1.548\pi) \sin \left(x + \frac{2\pi}{3} \right) dx \right)$$

$$= (278.114) . (0.563)$$

$$= 156.578 \text{Nm} \text{ } \textit{(searah putaran turbin)}$$

Perhitungan torsi *lift* pada sudu 3:

$$T_{L1} = \frac{1}{\pi} \left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(2 + ((-29.23)(0.3))^2 (H)(c) \left(0.997 \sin \left(2.471 \left(x + \frac{4\pi}{3} \right) \right) \right) \left(0.3 \sin \left(x + \frac{4\pi}{3} \right) \right) dx \right)$$

$$= (316.891) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin \left(x + \frac{4\pi}{3} \right) \sin(2.471x + 3.294 \, \pi) dx$$

$$= (316.891)(0.415)$$

$$= 131.51 \, Nm \textit{(searah putaran turbin)}$$

$$T_{L2} = \frac{1}{\pi} \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)(2 + ((-29.23)(0.3))^2 (H)(c) \left(0.875 \sin \left(2.321 \left(x + \frac{4\pi}{3} \right) \right) \right) \left(0.3 \sin \left(x + \frac{4\pi}{3} \right) \right) dx \right)$$

$$= (278.114) \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x + 3.094\pi) \sin \left(\left(x + \frac{4\pi}{3} \right) \right) dx \right)$$

$$= (278.114)(-0.456)$$

$$= -126.82 \text{ Nm} \textit{(berlawan anarah turbin)}$$

Jadibesar torsi *lift* total dariturbin Darrieus dengan hydrofoil NACA 0015 padakecepatanaliran 2 m/s adalah:

$$T_{L\,\text{rata-rata}}\text{ total } = \frac{(T_{L1sudu1} + T_{L2sudu1}) + (T_{L1sudu2} + T_{L2sudu2}) + (T_{L1sudu3} + T_{L2sudu3})}{2}$$

$$= \frac{(237.668 - 137.388) + (-121.686 + 156.578) + (131.51 - 126.82)}{2}$$

$= 69.931$ Nm *(searah putaran turbin)*

$$\mathbf{T_D} = \frac{1}{2\pi}\int_0^{2\pi} \frac{1}{2}\rho(W)^2 A.\, C_D.\, (R\cos(x))\, dx$$

Perhitungan torsi *drag* pada sudu 1:

$$T_D = \frac{1}{2\pi}\int_0^{2\pi} \frac{1}{2}\rho(W)^2.\, H.\, c.\, C_D.\, (R\cos(x))\, dx$$

$$= \frac{1}{2\pi}(998.2)(0.5)(46.312)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)(\cos(x))dx$$

$$= 158.9227 \int_0^{2\pi}(1.039\sin(0.3074\,x + 1.532) + 0.9072\sin(3.926x - 1.76))(\cos(x))dx$$

$$= 158.9227 \int_0^{2\pi}\big(1.039\sin(0.3074x + 1.532)\big)\big(\cos(x)\big) + \big(0.9072\sin(3.926x - 1.76)\big)\big(\cos(x)\big)dx$$

$$= 158.9227 \int_0^{2\pi} 1.039\left(\tfrac{1}{2}\sin(1.3074x + 1.532) + \tfrac{1}{2}\sin((-0.6926)x + 1.532)\right)dx + \int_0^{2\pi} 0.9072\left(\tfrac{1}{2}\sin(4.926x - 1.76) + \tfrac{1}{2}\sin(2.926x - 1.76)\right)dx$$

$$= 158.9227\left(0.5193(0.28895 - 0.54545 - (-0.02045 + 1.44343)) + 0.4536(-0.17857 - 0.30063 - (-0.20291 - 0.3416))\right)$$

$$= 158.9227(-0.8725 + 0.0296)$$

$$= -133.9559\text{Nm }\textit{(searah putaran turbin)}$$

Perhitungan torsi *drag* pada sudu 2:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(46.312)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)(\cos\left(x+\frac{2\pi}{3}\right))dx$$

$$=158.9227\int_0^{2\pi}(1.039\sin\left(0.3074\,x+\frac{2\pi}{3}+1.532\right)+\ 0.9072\sin\left(3.926x+\frac{2\pi}{3}-1.76\right))(\cos\left(x+\frac{2\pi}{3}\right))dx$$

$$=158.9227\int_0^{2\pi}\left(1.039\sin\left(0.3074\,x+\frac{2\pi}{3}+1.532\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)+\left(0.9072\sin\left(3.926\,x+\frac{2\pi}{3}-1.76\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=158.9227\int_0^{2\pi}1.039\left(\frac{1}{2}\sin\left(1.3074x+1.3074\frac{2\pi}{3}+1.532\right)+\frac{1}{2}\sin\left((-0.6926)x-0.6926\frac{2\pi}{3}+1.532\right)\right)dx+\int_0^{2\pi}0.9072\left(\frac{1}{2}\sin\left(4.926x+4.926\frac{2\pi}{3}-1.76\right)+\frac{1}{2}\sin\left(2.926x+2.926\frac{2\pi}{3}-1.76\right)\right)dx$$

$$=158.927\,(0.18252-0.25075)$$

$$=-10.844\ \text{Nm \textit{(searah putaran turbin)}}$$

Perhitungan torsi *drag* pada sudu 3:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(46.312)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)(\cos\left(x+\frac{4\pi}{3}\right))dx$$

$$=158.9227\int_0^{2\pi}(1.039\sin(0.3074\,x+1.532)+\ 0.9072\sin(3.926x-1.76))(\cos\left(x+\frac{4\pi}{3}\right))dx$$

$$=158.9227\int_0^{2\pi}\left(1.039\sin\left(0.3074\,x+\frac{4\pi}{3}+1.532\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)+\left(0.9072\sin\left(3.926\,x+\frac{4\pi}{3}-1.76\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)dx$$

$$=158.9227\int_0^{2\pi}1.039\left(\frac{1}{2}\sin\left(1.3074x+1.3074\frac{4\pi}{3}+1.532\right)+\frac{1}{2}\sin\left((-0.6926)x-0.6926\frac{4\pi}{3}+1.532\right)\right)dx+\int_0^{2\pi}0.9072\left(\frac{1}{2}\sin\left(4.926x+4.926\frac{4\pi}{3}-1.76\right)+\frac{1}{2}\sin\left(2.926x+2.926\frac{4\pi}{3}-1.76\right)\right)dx$$

$$=158.927\,(1.28473-0.0036379)$$

= 203.5374 Nm *(berlawanan arah turbin)*

Jadi besar torsi *drag* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 2 m/s adalah:

$T_{D \text{ rata-rata}}$ total $= (T_{Dsudu1} + T_{Dsudu2} + T_{Dsudu3})$

$\qquad = -133.9559 - 10.844 + 203.5374$

$\qquad = 58.7379$ Nm *(berlawanan arah turbin)*

Jadi torsi rata-rata total untuk turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 2 m/s adalah:

$T_{\text{rata-rata}} = (T_{L \text{ rata-rata}}$ total $- T_{D \text{ rata-rata}}$ total$)$

$\qquad = (69.931) - (58.7379)$

$\qquad = 11.193 \; Nm \; (searah \; putaran \; turbin)$

- **Kecepatan 2.5 (EXP)**

  Dik:

  U = 2.5 m/s ω = 41.833 rad/s C_{L1} = 1.012 SIN (2.339x)

  A = (0.8)(0.18) = 0.144 ρ = 998.2 kg/m^3 C_{L2} = 0.7747 SIN(2.46 (x)

  D = 0.6 m   R = 0.3 m C_D = 1.054sin(0.1848x+1.638) + 1.016sin(4.017x -1.858)

$$T_{L\ rata\text{-}rata} = \frac{\dfrac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\rho(0.5)(W)^2 A.CL.\big(Rsin(x)\big)dx + \frac{1}{\pi}\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}\rho(0.5)(W)^2 A.CL.\big(Rsin(x)\big)dx}{2}$$

Perhitungan torsi *lift* pada sudu 1:

$$T_{L_1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\rho(0.5)(W)^2 A.CL.\big(Rsin(x)\big)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(U+(-\omega R))^2(H)(c)\big(1.012sin(2.339x)\big)\big(R\ sin(x)\big)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(2.5+((-41.833\ )(0.3))^2(0.8)(0.18)\big(1.012sin(2.339x)\big)\big(0.3\ sin(x)\big)dx\right)$$

$$= \frac{1}{\pi}.998.2(0.5)(2.5+((-41.833\ )(0.3))^2(1.012)(0.8)(0.18)(0.3)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}sin(x)sin(2.339x)dx$$

$$\frac{1}{\pi}.998.2(0.5)(101)(1.012)(0.8)(0.18)(0.3)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}sin(x)sin(2.339x)dx$$

$$= 701.493 \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin(x)\sin(2.339x)dx$$

$$= (701.493)\,(0.901)$$

$$= 632.045 \text{ Nm } \textit{(searah putarant urbin)}$$

$$T_{L_2} = \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \rho(0.5)(W)^2 A.\,CL.\,\big(R\sin(x)\big)dx \right)$$

$$= \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)\big(U + (-\omega R)\big)^2 (H)(c)\big(0.7747\sin(2.46x)\big)\big(0.3\sin(x)\big)dx \right)$$

$$= \frac{1}{\pi}\,(499.1)(\,101)\,(0.7747)(0.8)(0.18)(0.3)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.46x)\sin(x)dx \right)$$

$$= 537.003\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.46x)\sin(x)dx \right)$$

$$= (537.003\,)\,(-0.098)$$

$$= -52.626 \text{Nm } \textit{(berlawanan arah turbin)}$$

Perhitungan torsi *lift* pada sudu 2:

$$T_{L1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(2.5 + ((-41.833\,)(0.3)))^2 (H)(c)\left(1.012\sin\left(2.339(x + \tfrac{2\pi}{3})\right)\right)\left(0.3\sin\left(x + \tfrac{2\pi}{3}\right)\right)dx \right)$$

$$= (701.493\,)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin\left(x + \tfrac{2\pi}{3}\right)\sin(2.339x + 1.56\boldsymbol{\pi})dx$$

$$= (701.493)\,(-0.418)$$

$$= -293.224 \text{ Nm } \textit{(berlawanan arah turbin)}$$

$$T_{L2} = \frac{1}{\pi} \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)(2.5 + ((-41.833\,)(0.3)))^2 (H)(c) \left(0.7747 \sin\left(2.46(x + \frac{2\pi}{3})\right) \right) \left(0.3 \sin\left(x + \frac{2\pi}{3}\right) \right) dx \right)$$

$$= 537.003 \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.46x + 1.641\pi) \sin\left(x + \frac{2\pi}{3}\right) dx \right)$$

$$= (537.003).\,(0.26)$$

$$= 139.621 \text{ Nm } \textit{(searah putaran turbin)}$$

Perhitungan torsi *lift* pada sudu 3:

$$T_{L1} = \frac{1}{\pi} \left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(2.5 + ((-41.833\,)(0.3)))^2 (H)(c) \left(1.012 \sin\left(2.339(x + \frac{4\pi}{3})\right) \right) \left(0.3 \sin\left(x + \frac{4\pi}{3}\right) \right) dx \right)$$

$$= (701.493\,) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin\left(x + \frac{4\pi}{3}\right) \sin(2.339x + 3.118\,\pi) dx$$

$$= (701.493\,)(0.54)$$

$$= 378.806 \textit{ Nm (searah putaran turbin)}$$

$$T_{L2} = \frac{1}{\pi} \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)(2.5 + ((-41.833\,)(0.3)))^2 (H)(c) \left(0.7747 \sin\left(2.46(x + \frac{4\pi}{3})\right) \right) \left(0.3 \sin\left(x + \frac{4\pi}{3}\right) \right) dx \right)$$

$$= (537.003\,) \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.46x + 3.279\pi) \sin\left(\left(x + \frac{4\pi}{3}\right)\right) dx \right)$$

= (537.003)(0.061)

= 32.757 Nm *(berlawan anarah turbin)*

Jadibesar torsi *lift* total dariturbin Darrieus dengan hydrofoil NACA 0015 padakecepatanaliran 2.5 m/s adalah:

$$T_{L\,rata\text{-}rata}\,total = \frac{(T_{L1sudu1} + T_{L2sudu1}) + (T_{L1sudu2} + T_{L2sudu2}) + (T_{L1sudu3} + T_{L2sudu3})}{2}$$

$$= \frac{(632.045 - 52.626) + (-293.224 + 139.621) + (378.806 + 32.757)}{2}$$

$$= 418.69\ Nm\ \textit{(searah putaran turbin)}$$

$$T_D = \frac{1}{2\pi} \int_0^{2\pi} \frac{1}{2}\rho(W)^2 A.\,C_D.\,(R\cos(x))\,dx$$

Perhitungan torsi *drag* pada sudu 1:

$$T_D = \frac{1}{2\pi} \int_0^{2\pi} \frac{1}{2}\rho(W)^2.\,H.\,c.\,C_D.\,(R\cos(x))\,dx$$

$$= \frac{1}{2\pi}(998.2)(0.5)(101)(0.8)(0.18)(0.3) \int_0^{2\pi}(C_D)(\cos(x))dx$$

$$= 346.587 \int_0^{2\pi}(1.054\sin(0.1848x + 1.638) + 1.016\sin(4.017\,x - 1.858\,))(\cos(x))dx$$

$$= 346.587 \int_0^{2\pi}\big(1.054\sin(0.1848x+1.638)\big)\big(\cos(x)\big) + \big(1.016\sin(4.017\,x-1.858\,)\big)\big(\cos(x)\big)dx$$

$$= 346.587 \int_0^{2\pi} 0.527\left(\left(-\frac{1}{1.1848}\right)\cos(1.1848x+1.638)+\frac{1}{0.8152}\cos\big((-0.8152)x+1.638\big)\right)dx + \int_0^{2\pi} 0.508\left(\left(-\frac{1}{5.017}\right)\cos(5.017x+1.858)+\frac{1}{3.017}\cos\big((3.107)x+1.858\big)\right)dx$$

$$= 346.587\,(-0.12658 + 0.00060452)$$

$$= -43.6617 Nm\ \textit{(searah putaran turbin)}$$

Perhitungan torsi *drag* pada sudu 2:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(101)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=346.587\int_0^{2\pi}\left(1.054\sin\left(0.1848\left(x+\frac{2\pi}{3}\right)+1.638\right)+1.016\sin\left(4.017x+\left(x+\frac{2\pi}{3}\right)-1.858\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=346.587\int_0^{2\pi}\left(1.054\sin\left(0.1848\left(x+\frac{2\pi}{3}\right)+1.638\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)+\left(1.016\sin\left(4.017\left(x+\frac{2\pi}{3}\right)-1.858\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=346.587\int_0^{2\pi}0.527\left(\left(-\frac{1}{1.1848}\right)\cos\left(1.1848x+1.1848\frac{2\pi}{3}+1.638\right)+\frac{1}{0.8152}\cos\left(-0.8152x-0.8152\frac{2\pi}{3}+1.638\right)\right)dx+\int_0^{2\pi}0.508\left(\left(-\frac{1}{5.017}\right)\cos\left(5.017x+5.017\frac{2\pi}{3}+1.858\right)+\frac{1}{3.017}\cos\left(3.107x+3.107\frac{2\pi}{3}+1.858\right)\right)dx$$

$$= 346.587\,(1.36574-0.008636)$$

$$= 470.3575 \text{ Nm } \textit{(berlawanan arah turbin)}$$

Perhitungan torsi *drag* pada sudu 3:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(101)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=346.587\int_0^{2\pi}\left(1.054\sin\left(0.1848\left(x+\frac{4\pi}{3}\right)+1.638\right)+1.016\sin\left(4.017x+\left(x+\frac{4\pi}{3}\right)-1.858\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)dx$$

$$=346.587\int_0^{2\pi}\left(1.054\sin\left(0.1848\left(x+\frac{4\pi}{3}\right)+1.638\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)+\left(1.016\sin\left(4.017\left(x+\frac{4\pi}{3}\right)-1.858\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)dx$$

$$=346.587\int_0^{2\pi}0.527\left(\left(-\frac{1}{1.1848}\right)\cos\left(1.1848x+1.1848\frac{4\pi}{3}+1.638\right)+\frac{1}{0.8152}\cos\left(-0.8152x-0.8152\frac{4\pi}{3}+1.638\right)\right)dx+\int_0^{2\pi}0.508\left(\left(-\frac{1}{5.017}\right)\cos\left(5.017x+5.017\frac{4\pi}{3}+1.858\right)+\frac{1}{3.017}\cos\left(3.107x+3.107\frac{4\pi}{3}+1.858\right)\right)dx$$

$$= 346.587\,(-0.08464+0.01048)$$

$$= -25.7017 \text{ Nm } \textit{(searah putaran turbin)}$$

Jadi besar torsi *drag* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 2.5 m/s adalah:

$$T_{D\ \text{rata-rata}}\ \text{total} = (T_{Dsudu1} + T_{Dsudu2} + T_{Dsudu3})$$

$$= -43.6617 + 470.3575 - 25.7017$$

$$= 400.994\ \text{Nm}\ (berlawanan\ arah\ turbin)$$

Jadi torsi rata-rata total untuk turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 2.5 m/s adalah:

$$T_{\text{Rata-rata}} = (\ T_{L\ \text{rata-rata}}\ \text{total} - T_{D\ \text{rata-rata}}\ \text{total})$$

$$= (418.69) - (400.994)$$

$$= 17.696\ Nm\ (searah\ putaran\ turbin)$$

- **Kecepatan 3 (EXP)**

  Dik:

  U = 3 m/s   ω = 56.897 rad/s $C_{L1} = 0.997$ SIN (2.471 x)

  A = (0.8)(0.18) = 0.144   ρ = 998.2 kg/m³ $C_{L2} = 0.875$ SIN(2.321 (x)

  D = 0.6 m   R = 0.3 m $C_D = 1.039 \sin(0.3074\,x + 1.532) + 0.9072 \sin(3.926\,x - 1.76)$

$$T_{L\ \text{rata-rata}} = \dfrac{\dfrac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\rho(0.5)(W)^2 A.\,CL.\left(Rsin(x)\right)dx + \dfrac{1}{\pi}\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}\rho(0.5)(W)^2 A.\,CL.\left(Rsin(x)\right)dx}{2}$$

Perhitungan torsi *lift* pada sudu 1:

$$T_{L_1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\rho(0.5)(W)^2 A.\,CL.\left(Rsin(x)\right)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(U + (-\omega R))^2 (H)(c)\left(0.997\sin(2.471x)\right)\left(R\sin(x)\right)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(3 + ((-56.897)(0.3))^2(0.8)(0.18)\left(0.997\sin(2.471x)\right)\left(0.3\sin(x)\right)dx\right)$$

$$= \frac{1}{\pi}.998.2(0.5)(3 + ((-56.897)(0.3))^2(0.997)(0.8)(0.18)(0.3)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin(x)\sin(2.471x)dx$$

$$= \frac{1}{\pi}(499.1)(197.94)(0.997)(0.8)(0.18)(0.3)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin(x)\sin(2.471x)dx$$

$$= 1354.41\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin(x)\sin(2.471x)dx$$

$$= (1354.41)\,(0.715)$$

$$= 968.403 \text{ Nm } \textit{(searah putarant urbin)}$$

$$T_{L_2} = \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \rho(0.5)(W)^2 A.\,CL.\left(R\sin(x)\right)dx \right)$$

$$= \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)\left(U + (-\omega R)\right)^2 (H)(c)\left(0.875\,\sin(2.321x)\right)\left(0.3\,\sin(x)\right)dx \right)$$

$$= \frac{1}{\pi}(499.1)(\,197.94)\,(0.875)(0.8)(0.18)(0.3)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx \right)$$

$$= 1188.675\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx \right)$$

$$= (1188.675\,)\,(-0.494)$$

$$= -587.205 \text{ Nm } \textit{(berlawanan arah turbin)}$$

Perhitungan torsi *lift* pada sudu 2:

$$T_{L1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(3 + ((-56.897)(0.3))^2 (H)(c)\left(0.997\sin\left(2.471(x + \tfrac{2\pi}{3})\right)\right)\left(0.3\,\sin\left(x + \tfrac{2\pi}{3}\right)\right)dx \right)$$

$$= (1354.41\,)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin\left(x + \tfrac{2\pi}{3}\right)\sin(2.471x + 1.648\,\pi)dx$$

$$= (1354.41\,)\,(-0.384)$$

$$= -520.093 \text{ Nm } \textit{(berlawanan arah turbin)}$$

$$T_{L2} = \frac{1}{\pi} \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)(3 + ((-56.897)(0.3))^2 (H)(c) \left(0.875 \sin\left(2.321\left(x + \frac{2\pi}{3}\right)\right)\right) \left(0.3 \sin\left(x + \frac{2\pi}{3}\right)\right) dx \right)$$

$$= 1188.675 \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x + 1.548\pi) \sin\left(x + \frac{2\pi}{3}\right) dx \right)$$

$$= (1188.675)(0.563)$$

$$= 669.224 \text{Nm } \textit{(searah putaran turbin)}$$

Perhitungan torsi *lift* padasudu 3:

$$T_{L1} = \frac{1}{\pi} \left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(3 + ((-56.897)(0.3))^2 (H)(c) \left(0.997 \sin\left(2.471\left(x + \frac{4\pi}{3}\right)\right)\right) \left(0.3 \sin\left(x + \frac{4\pi}{3}\right)\right) dx \right)$$

$$= (1354.41) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin\left(x + \frac{4\pi}{3}\right) \sin(2.471x + 3.294\pi) dx$$

$$= (1354.41)(0.415)$$

$$= 562.08 \text{ } Nm \textit{(searah putaran turbin)}$$

$$T_{L2} = \frac{1}{\pi} \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)(3 + ((-56.897)(0.3))^2 (H)(c) \left(0.875 \sin\left(2.321\left(x + \frac{4\pi}{3}\right)\right)\right) \left(0.3 \sin\left(x + \frac{4\pi}{3}\right)\right) dx \right)$$

$$= (1188.675) \left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x + 3.094\pi) \sin\left(\left(x + \frac{4\pi}{3}\right)\right) dx \right)$$

$$= (1188.675)(-0.456)$$

$$= -542.036 \text{ Nm } \textit{(berlawanan arah turbin)}$$

Jadi besar torsi *lift* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatana liran 3 m/s adalah:

$$T_{L\ \text{rata-rata}}\ \text{total} = \frac{(T_{L1sudu1} + T_{L2sudu1}) + (T_{L1sudu2} + T_{L2sudu2}) + (T_{L1sudu3} + T_{L2sudu3})}{2}$$

$$= \frac{(968.403 - 587.205) + (-520.093 + 669.224) + (562.08 - 542.036)}{2}$$

$$= 275.187 \text{ Nm } \textit{(searah putaran turbin)}$$

$$T_D = \frac{1}{2\pi} \int_0^{2\pi} \frac{1}{2}\rho(W)^2 A.\,C_D.\,(R\cos(x))\,dx$$

Perhitungan torsi *drag* pada sudu 1:

$$T_D = \frac{1}{2\pi} \int_0^{2\pi} \frac{1}{2}\rho(W)^2.\,H.\,c.\,C_D.\,(R\cos(x))\,dx$$

$$= \frac{1}{2\pi}(998.2)(0.5)(197.94)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)(\cos(x))dx$$

$$= 679.243\ \int_0^{2\pi}(1.039\sin(0.3074\,x + 1.532) + 0.9072\sin(3.926x - 1.76))(\cos(x))dx$$

$$= 679.243 \int_0^{2\pi}\big(1.039\sin(0.3074x + 1.532)\big)\big(\cos(x)\big) + \big(0.9072\sin(3.926x - 1.76)\big)\big(\cos(x)\big)dx$$

$$= 679.243 \int_0^{2\pi} 1.039\left(\tfrac{1}{2}\sin(1.3074x + 1.532) + \tfrac{1}{2}\sin((-0.6926)x + 1.532)\right)dx + \int_0^{2\pi} 0.9072\left(\tfrac{1}{2}\sin(4.926x - 1.76) + \tfrac{1}{2}\sin(2.926x - 1.76)\right)dx$$

$$= 679.243\left(0.5193\big(0.28895 - 0.54545 - (-0.02045 + 1.44343)\big) + 0.4536\big(-0.17857 - 0.30063 - (-0.20291 - 0.3416)\big)\right)$$

$$= 679.243(-0.8725 + 0.0296)$$

$$= -572.5325 \text{Nm } \textit{(searah putaran turbin)}$$

Perhitungan torsi *drag* pada sudu 2:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(197.94)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)(\cos\left(x+\frac{2\pi}{3}\right))dx$$

$$= 679.243\int_0^{2\pi}(1.039\sin\left(0.3074\,x+\frac{2\pi}{3}+1.532\right)+\ 0.9072\sin\left(3.926x+\frac{2\pi}{3}-1.76\right))(\cos\left(x+\frac{2\pi}{3}\right))dx$$

$$= 679.243\int_0^{2\pi}\left(1.039\sin\left(0.3074\,x+\frac{2\pi}{3}+1.532\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)+\left(0.9072\sin\left(3.926\,x+\frac{2\pi}{3}-1.76\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$= 679.243\int_0^{2\pi}1.039\left(\frac{1}{2}\sin\left(1.3074x+1.3074\frac{2\pi}{3}+1.532\right)+\frac{1}{2}\sin\left((-0.6926)x-0.6926\frac{2\pi}{3}+1.532\right)\right)dx+\int_0^{2\pi}0.9072\left(\frac{1}{2}\sin\left(4.926x+4.926\frac{2\pi}{3}-1.76\right)+\frac{1}{2}\sin\left(2.926x+2.926\frac{2\pi}{3}-1.76\right)\right)dx$$

$$= 679.243\,(0.18252-0.25075)$$

$$= -46.344\ \text{Nm}\ \textit{(searah putaran turbin)}$$

Perhitungan torsi *drag* pada sudu 3:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(197.94)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)(\cos\left(x+\frac{4\pi}{3}\right))dx$$

$$= 679.243\int_0^{2\pi}(1.039\sin(0.3074\,x+1.532)+\ 0.9072\sin(3.926x-1.76))(\cos\left(x+\frac{4\pi}{3}\right))dx$$

$$= 679.243\int_0^{2\pi}\left(1.039\sin\left(0.3074\,x+\frac{4\pi}{3}+1.532\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)+\left(0.9072\sin\left(3.926\,x+\frac{4\pi}{3}-1.76\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)dx$$

$$= 679.243\int_0^{2\pi}1.039\left(\frac{1}{2}\sin\left(1.3074x+1.3074\frac{4\pi}{3}+1.532\right)+\frac{1}{2}\sin\left((-0.6926)x-0.6926\frac{4\pi}{3}+1.532\right)\right)dx+\int_0^{2\pi}0.9072\left(\frac{1}{2}\sin\left(4.926x+4.926\frac{4\pi}{3}-1.76\right)+\frac{1}{2}\sin\left(2.926x+2.926\frac{4\pi}{3}-1.76\right)\right)dx$$

$$= 679.243\,(1.28473-0.0036379)$$

$= 870.1707$ Nm *(berlawanan arah turbin)*

Jadi besar torsi *drag* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 3 m/s adalah:

$T_{D \text{ rata-rata}}$ total $= (T_{Dsudu1} + T_{Dsudu2} + T_{Dsudu3})$

$\qquad = -572.5325 - 46.3446 + 870.1707$

$\qquad = 251.2936$ Nm *(berlawanan arah turbin)*

Jadi torsi rata-rata total untuk turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 3 m/s adalah:

$T_{\text{Rata-rata}} = (T_{L \text{ rata-rata}}$ total $- T_{D \text{ rata-rata}}$ total$)$

$\qquad = (275.187) - (251.2936)$

$\qquad = 23.893$ *Nm (searah putaran turbin)*

- **Kecepatan 3.5 (EXP)**

  Dik:

  U = 3.5 m/s   ω = 74.651 rad/s $C_{L1} = 0.997$ SIN (2.471 x)

  A= (0.8)(0.18) = 0.144   ρ = 998.2 kg/m^3 $C_{L2} = 0.875$ SIN(2.321 (x))

  D= 0.6 m   R = 0.3 m $C_D = 1.039 \sin(0.3074 x + 1.532) + 0.9072 \sin(3.926 x - 1.76)$

$$T_{\text{L rata-rata}} = \dfrac{\dfrac{1}{\pi} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \rho(0.5)(W)^2 A.\, CL.\left(R sin(x)\right) dx + \dfrac{1}{\pi} \int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \rho(0.5)(W)^2 A.\, CL.\left(R sin(x)\right) dx}{2}$$

Perhitungan torsi *lift* pada sudu 1:

$$T_{L_1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \rho(0.5)(W)^2 A.\, CL.\left(R sin(x)\right) dx \right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(U + (-\omega R))^2 (H)(c)\left(0.997\sin(2.471x)\right)\left(R \sin(x)\right) dx \right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(3.5 + ((-74.651)(0.3))^2 (0.8)(0.18)\left(0.997\sin(2.471x)\right)\left(0.3 \sin(x)\right) dx \right)$$

$$= \frac{1}{\pi}.\,998.2(0.5)(3.5 + ((-74.651)(0.3))^2 (0.997)(0.8)(0.18)(0.3) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin(x)\sin(2.471x)\,dx$$

$$= \frac{1}{\pi}(499.1)(357.032)(0.997)(0.8)(0.18)(0.3) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin(x)\sin(2.471x)\,dx$$

$$= 2443.002 \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin(x)\sin(2.471x)dx$$

$$= (2443.002)(0.71)$$

$$= 1734.531 \text{ Nm } \textit{(searah putaran turbin)}$$

$$T_{L_2} = \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \rho(0.5)(W)^2 A.\, CL.\left(R\sin(x)\right)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)\left(U+(-\omega R)\right)^2 (H)(c)\left(0.875\,\sin(2.321x)\right)\left(0.3\,\sin(x)\right)dx\right)$$

$$= \frac{1}{\pi}(499.1)(357.032)(0.875)(0.8)(0.18)(0.3)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx\right)$$

$$= 2144.059\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx\right)$$

$$= (2144.059)(-0.494)$$

$$= -1059.165 \text{ Nm } \textit{(berlawanan arah turbin)}$$

Perhitungan torsi *lift* pada sudu 2:

$$T_{L1}=\frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(3.5+((-56.897)(0.3))^2(H)(c)\left(0.997\sin\left(2.471(x+\frac{2\pi}{3})\right)\right)\left(0.3\sin\left(x+\frac{2\pi}{3}\right)\right)dx\right)$$

$$=(2443.002)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin\left(x+\frac{2\pi}{3}\right)\sin(2.471x+1.648\,\pi)dx$$

$$=(2443.002)(-0.384)$$

$$=-938.113\,\text{Nm }\textit{(berlawanan arah turbin)}$$

$$T_{L2}=\frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}998.2(0.5)(3.5+((-56.897)(0.3))^2(H)(c)\left(0.875\sin\left(2.321(x+\frac{2\pi}{3})\right)\right)\left(0.3\sin\left(x+\frac{2\pi}{3}\right)\right)dx\right)$$

$$=2144.059\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}\sin(2.321x+1.548\pi)\sin\left(x+\frac{2\pi}{3}\right)dx\right)$$

$$=(2144.059)(0.56)$$

$$=1207.105\,\text{Nm }\textit{(searah putaran turbin)}$$

Perhitungan torsi *lift* pada sudu 3:

$$T_{L1}=\frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(3.5+((-56.897)(0.3))^2(H)(c)\left(0.997\sin\left(2.471(x+\frac{4\pi}{3})\right)\right)\left(0.3\sin\left(x+\frac{4\pi}{3}\right)\right)dx\right)$$

$$=(2443.002)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin\left(x+\frac{4\pi}{3}\right)\sin(2.471x+3.294\pi)dx$$

$$= (2443.002\ )(0.41)$$

$$= 1001.631\ Nm\,(searah\ putaran\ turbin)$$

$$T_{L2}=\frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)(3.5 + ((-56.897)(0.3))^2(H)(c)\left(0.875\sin\left(2.321(x + \tfrac{4\pi}{3})\right)\right)\left(0.3\ \sin\left(x + \tfrac{4\pi}{3}\right)\right)dx\right)$$

$$=(2144.059)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x + 3.094\pi)\sin\left(\left(x+\tfrac{4\pi}{3}\right)\right)dx\right)$$

$$= (2144.059\ \ )(-0.456)$$

$$= -977.691\ Nm\ (berlawan\ anarah\ turbin)$$

Jadibesar torsi *lift* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 3.5 m/s adalah:

$$T_{L\ rata\text{-}rata}\ total\ = \frac{(T_{L1sudu1} + T_{L2sudu1}) + (T_{L1sudu2} + T_{L2sudu2}) + (T_{L1sudu3} + T_{L2sudu3})}{2}$$

$$= \frac{(1734.531 - 1059.165) + (-938.113 + 1207.105) + (1001.631 - 977.691)}{2}$$

$$= 484.149\ Nm\ (searah\ putaran\ turbin)$$

$$\mathbf{T_D} = \frac{\mathbf{1}}{\mathbf{2\pi}} \int_{\mathbf{0}}^{\mathbf{2\pi}} \frac{\mathbf{1}}{\mathbf{2}} \boldsymbol{\rho}(\boldsymbol{W})^{\mathbf{2}} \boldsymbol{A}. \boldsymbol{C_D}. (\boldsymbol{R}\cos(\boldsymbol{x})) \, d\boldsymbol{x}$$

Perhitungan torsi *drag* pada sudu 1:

$T_D = \frac{1}{2\pi} \int_{0}^{2\pi} \frac{1}{2}\rho(W)^2 . H.c. C_D. (R\cos(x)) \, dx$

$\quad = \frac{1}{2\pi}(998.2)(0.5)(357.032)(0.8)(0.18)(0.3) \int_{0}^{2\pi} (C_D)(\cos(x)) dx$

$\quad = 1225.176 \int_{0}^{2\pi} (1.039\sin(0.3074\,x + 1.532) + 0.9072\sin(3.926x - 1.76))(\cos(x)) dx$

$\quad = 1225.176 \int_{0}^{2\pi} \left(1.039\sin(0.3074x+1.532)\right)\left(\cos(x)\right) + \left(0.9072\sin(3.926x-1.76)\right)\left(\cos(x)\right) dx$

$\quad = 1225.176 \int_{0}^{2\pi} 1.039\left(\frac{1}{2}\sin(1.3074x+1.532) + \frac{1}{2}\sin\left((-0.6926)x+1.532\right)\right) dx + \int_{0}^{2\pi} 0.9072\left(\frac{1}{2}\sin(4.926x-1.76) + \frac{1}{2}\sin(2.926x-1.76)\right) dx$

$\quad = 1225.176\left(0.5193(0.28895 - 0.54545 - (-0.02045 + 1.44343)) + 0.4536(-0.17857 - 0.30063 - (-0.20291 - 0.3416))\right)$

$\quad = 1225.176(-0.8725 + 0.0296)$

$\quad = -1032.7022$ Nm *(searah putaran turbin)*

Perhitungan torsi *drag* pada sudu 2:

$T_D = \frac{1}{2\pi}(998.2)(0.5)(357.032)(0.8)(0.18)(0.3) \int_{0}^{2\pi} (C_D)(\cos\left(x + \frac{2\pi}{3}\right)) dx$

$\quad = 1225.176 \int_{0}^{2\pi} (1.039\sin\left(0.3074\,x + \frac{2\pi}{3} + 1.532\right) + 0.9072\sin\left(3.926x + \frac{2\pi}{3} - 1.76\right))(\cos\left(x + \frac{2\pi}{3}\right)) dx$

$$= 1225.176 \int_0^{2\pi} \left(1.039\sin\left(0.3074\,x + \tfrac{2\pi}{3} + 1.532\right)\right)\left(\cos\left(x + \tfrac{2\pi}{3}\right)\right) + \left(0.9072\sin\left(3.926\,x + \tfrac{2\pi}{3} - 1.76\right)\right)\left(\cos\left(x + \tfrac{2\pi}{3}\right)\right) dx$$

$$= 1225.176 \int_0^{2\pi} 1.039\left(\tfrac{1}{2}\sin\left(1.3074x + 1.3074\tfrac{2\pi}{3} + 1.532\right) + \tfrac{1}{2}\sin\left((-0.6926)x - 0.6926\tfrac{2\pi}{3} + 1.532\right)\right) dx + \int_0^{2\pi} 0.9072\left(\tfrac{1}{2}\sin\left(4.926x + 4.926\tfrac{2\pi}{3} - 1.76\right) + \tfrac{1}{2}\sin\left(2.926x + 2.926\tfrac{2\pi}{3} - 1.76\right)\right) dx$$

$$= 1225.176\,(0.18252 - 0.25075)$$

$$= -83.5939 \text{ Nm } \textit{(searah putaran turbin)}$$

Perhitungan torsi *drag* pada sudu 3:

$$T_D = \tfrac{1}{2\pi}(998.2)(0.5)(357.032)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)\left(\cos\left(x + \tfrac{4\pi}{3}\right)\right) dx$$

$$= 1225.176 \int_0^{2\pi} (1.039\sin(0.3074\,x + 1.532) + 0.9072\sin(3.926x - 1.76))\left(\cos\left(x + \tfrac{4\pi}{3}\right)\right) dx$$

$$= 1225.176 \int_0^{2\pi} \left(1.039\sin\left(0.3074\,x + \tfrac{4\pi}{3} + 1.532\right)\right)\left(\cos\left(x + \tfrac{4\pi}{3}\right)\right) + \left(0.9072\sin\left(3.926\,x + \tfrac{4\pi}{3} - 1.76\right)\right)\left(\cos\left(x + \tfrac{4\pi}{3}\right)\right) dx$$

$$= 1225.176 \int_0^{2\pi} 1.039\left(\tfrac{1}{2}\sin\left(1.3074x + 1.3074\tfrac{4\pi}{3} + 1.532\right) + \tfrac{1}{2}\sin\left((-0.6926)x - 0.6926\tfrac{4\pi}{3} + 1.532\right)\right) dx + \int_0^{2\pi} 0.9072\left(\tfrac{1}{2}\sin\left(4.926x + 4.926\tfrac{4\pi}{3} - 1.76\right) + \tfrac{1}{2}\sin\left(2.926x + 2.926\tfrac{4\pi}{3} - 1.76\right)\right) dx$$

$$= 1225.176\,(1.28473 - 0.0036379)$$

$$= 1569.5653 \text{ Nm } \textit{(berlawanan arah turbin)}$$

Jadi besar torsi *drag* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 3.5 m/s adalah:

$T_{D \text{ rata-rata}}$ total $= (T_{Dsudu1} + T_{Dsudu2} + T_{Dsudu3})$

$\qquad = -1032.7022 - 83.5939 + 1569.5653$

$\qquad = 453.2692$ Nm *(berlawanan arah turbin)*

Jadi torsi rata-rata total untuk turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 3.5 m/s adalah:

$T_{\text{Rata-rata}} = (T_{L \text{ rata-rata}}$ total $- T_{D \text{ rata-rata}}$ total$)$

$\qquad = (484.149) - (453.269)$

$\qquad = 30.88$ Nm *(searah putaran turbin)*

- **Kecepatan 4 (EXP)**

  Dik:

  U = 4 m/s ω = 95.203 rad/s C_{L1} = **0.997** SIN (**2.471** x)

  A = (0.8)(0.18) = 0.144 ρ = 998.2 kg/m^3 C_{L2} = 0.875 SIN(2.321 (x)

  D = 0.6 m   R = 0.3 m C_D = 1.039 sin(0.3074 x + 1.532) + 0.9072 sin(3.926 x - 1.76)

$$T_{L\ \text{rata-rata}} = \dfrac{\dfrac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\rho(0.5)(W)^2 A.\,CL.\left(Rsin(x)\right)dx + \dfrac{1}{\pi}\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}\rho(0.5)(W)^2 A.\,CL.\left(Rsin(x)\right)dx}{2}$$

Perhitungan torsi *lift* pada sudu 1:

$$T_{L_1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\rho(0.5)(W)^2 A.\,CL.\left(Rsin(x)\right)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(U + (-\omega R))^2(H)(c)\left(0.997sin(2.471x)\right)\left(R\,sin(x)\right)dx\right)$$

$$= \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(4 + ((-95.203)(0.3))^2(0.8)(0.18)\left(0.997sin(2.471x)\right)\left(0.3\,sin(x)\right)dx\right)$$

$$= \frac{1}{\pi}.998.2(0.5)(4 + ((-95.203)(0.3))^2(0.997)(0.8)(0.18)(0.3)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}sin(x)sin(2.471x)dx$$

$$= \frac{1}{\pi}(499.1)(603.238)(0.997)(0.8)(0.18)(0.3)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}sin(x)sin(2.471x)dx$$

$$= 4127.673\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}sin(x)sin(2.471x)dx$$

$$= (4127.673)\,(0.7)$$

$$= 2889.371 \text{ Nm } \textit{(searah putaran turbin)}$$

$$T_{L_2} = \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \rho(0.5)(W)^2 A.\,CL.\left(R\sin(x)\right)dx \right)$$

$$= \frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} 998.2(0.5)\left(U + (-\omega R)\right)^2 (H)(c)\left(0.875\,\sin(2.321x)\right)\left(0.3\,\sin(x)\right)dx \right)$$

$$= \frac{1}{\pi}(499.1)(\,603.238)\,(0.875)(0.8)(0.18)(0.3)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx \right)$$

$$= 3622.582\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \sin(2.321x)\sin(x)dx \right)$$

$$= (3622.582\,)\,(-0.494)$$

$$= -1789.556 \text{ Nm } \textit{(berlawan anarah turbin)}$$

Perhitungan torsi *lift* pada sudu 2:

$$T_{L1} = \frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 998.2(0.5)(4 + ((-56.897)(0.3))^2 (H)(c)\left(0.997\sin\left(2.471(x + \frac{2\pi}{3})\right)\right)\left(0.3\,\sin\left(x + \frac{2\pi}{3}\right)\right)dx \right)$$

$$= (4127.673)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin\left(x + \frac{2\pi}{3}\right)\sin(2.471x + 1.648\pi)dx$$

$$= (4127.673)\,(-0.4)$$

$$= -1568.516 \text{ Nm } \textit{(berlawan anarah turbin)}$$

$$T_{L2}=\frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}998.2(0.5)(4+((-56.897)(0.3))^2(H)(c)\left(0.875\sin\left(2.321(x+\frac{2\pi}{3})\right)\right)\left(0.3\sin\left(x+\frac{2\pi}{3}\right)\right)dx\right)$$

$$=(3622.582)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}\sin(2.321x+1.548\pi)\sin\left(x+\frac{2\pi}{3}\right)dx\right)$$

$$=(3622.582\ )(0.564)$$

$$=2043.136\ \text{Nm }\textit{(searah putaran turbin)}$$

Perhitungan torsi *lift* pada sudu 3:

$$T_{L1}=\frac{1}{\pi}\left(\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}998.2(0.5)(4+((-56.897)(0.3))^2(H)(c)\left(0.997\sin\left(2.471(x+\frac{4\pi}{3})\right)\right)\left(0.3\sin\left(x+\frac{4\pi}{3}\right)\right)dx\right)$$

$$=(4127.673)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin\left(x+\frac{4\pi}{3}\right)\sin(2.471x+3.294\pi)dx$$

$$=(4127.673\ )(0.41)$$

$$=1692.346\ \textit{Nm(searah putaran turbin)}$$

$$T_{L2}=\frac{1}{\pi}\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}998.2(0.5)(4+((-56.897)(0.3))^2(H)(c)\left(0.875\sin\left(2.321(x+\frac{4\pi}{3})\right)\right)\left(0.3\sin\left(x+\frac{4\pi}{3}\right)\right)dx\right)$$

$$=(3622.582)\left(\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}\sin(2.321x+3.094\pi)\sin\left(\left(x+\frac{4\pi}{3}\right)\right)dx\right)$$

$$=(3622.582\ )(-0.456)$$

$$=-1651.897\ \text{Nm }\textit{(berlawanan arah turbin)}$$

Jadibesar torsi *lift* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 4 m/s adalah:

$T_{L\ \text{rata-rata}}$ total $= \underline{(T_{L1sudu1} + T_{L2sudu1}) + (T_{L1sudu2} + T_{L2sudu2}) + (T_{L1sudu3} + T_{L2sudu3})}$

$$2$$

$$= \frac{(2889.371 - 1789.556) + (-1568.516 + 2043.136) + (1692.346 - 1651.897)}{2}$$

$$= 807.442 \text{ Nm } \textit{(searah putaran turbin)}$$

$$\mathbf{T_D = \frac{1}{2\pi} \int_0^{2\pi} \frac{1}{2} \rho(W)^2 A. C_D. (R \cos(x))\ dx}$$

Perhitungan torsi *drag* pada sudu 1:

$T_D = \frac{1}{2\pi} \int_0^{2\pi} \frac{1}{2} \rho(W)^2. H. c. C_D. (R \cos(x))\ dx$

$= \frac{1}{2\pi} (998.2)(0.5)(603.238)(0.8)(0.18)(0.3) \int_0^{2\pi} (C_D)(\cos(x)) dx$

$= 2070.047 \int_0^{2\pi} (1.039 \sin(0.3074\ x + 1.532) + 0.9072 \sin(3.926x - 1.76))(\cos(x)) dx$

$= 2070.047 \int_0^{2\pi} \left(1.039 \sin(0.3074x + 1.532)\right)\left(\cos(x)\right) + \left(0.9072 \sin(3.926x - 1.76)\right)\left(\cos(x)\right) dx$

$= 2070.047 \int_0^{2\pi} 1.039 \left(\frac{1}{2}\sin(1.3074x + 1.532) + \frac{1}{2}\sin\left((-0.6926)x + 1.532\right)\right) dx + \int_0^{2\pi} 0.9072 \left(\frac{1}{2}\sin(4.926x - 1.76) + \frac{1}{2}\sin(2.926x - 1.76)\right) dx$

$= 2070.047 \left(0.5193\left(0.28895 - 0.54545 - (-0.02045 + 1.44343)\right) + 0.4536\left(-0.17857 - 0.30063 - (-0.20291 - 0.3416)\right)\right)$

$= 2070.047(-0.8725 + 0.0296)$

$= -1744.8418 \text{ Nm } \textit{(searah putaran turbin)}$

Perhitungan torsi *drag* pada sudu 2:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(603.238)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=2070.047\int_0^{2\pi}\left(1.039\sin\left(0.3074\,x+\frac{2\pi}{3}+1.532\right)+0.9072\sin\left(3.926x+\frac{2\pi}{3}-1.76\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=2070.047\int_0^{2\pi}\left(1.039\sin\left(0.3074\,x+\frac{2\pi}{3}+1.532\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)+\left(0.9072\sin\left(3.926\,x+\frac{2\pi}{3}-1.76\right)\right)\left(\cos\left(x+\frac{2\pi}{3}\right)\right)dx$$

$$=2070.047\int_0^{2\pi}1.039\left(\frac{1}{2}\sin\left(1.3074x+1.3074\frac{2\pi}{3}+1.532\right)+\frac{1}{2}\sin\left((-0.6926)x-0.6926\frac{2\pi}{3}+1.532\right)\right)dx+\int_0^{2\pi}0.9072\left(\frac{1}{2}\sin\left(4.926x+4.926\frac{2\pi}{3}-1.76\right)+\frac{1}{2}\sin\left(2.926x+2.926\frac{2\pi}{3}-1.76\right)\right)dx$$

$$=2070.047\,(0.18252-0.25075)$$

$$=-141.2392\text{ Nm }\textit{(searah putaran turbin)}$$

Perhitungan torsi *drag* pada sudu 3:

$$T_D = \frac{1}{2\pi}(998.2)(0.5)(603.238)(0.8)(0.18)(0.3)\int_0^{2\pi}(C_D)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)dx$$

$$=2070.047\int_0^{2\pi}(1.039\sin(0.3074\,x+1.532)+0.9072\sin(3.926x-1.76))\left(\cos\left(x+\frac{4\pi}{3}\right)\right)dx$$

$$=2070.047\int_0^{2\pi}\left(1.039\sin\left(0.3074\,x+\frac{4\pi}{3}+1.532\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)+\left(0.9072\sin\left(3.926\,x+\frac{4\pi}{3}-1.76\right)\right)\left(\cos\left(x+\frac{4\pi}{3}\right)\right)dx$$

$$=2070.047\int_0^{2\pi}1.039\left(\frac{1}{2}\sin\left(1.3074x+1.3074\frac{4\pi}{3}+1.532\right)+\frac{1}{2}\sin\left((-0.6926)x-0.6926\frac{4\pi}{3}+1.532\right)\right)dx+\int_0^{2\pi}0.9072\left(\frac{1}{2}\sin\left(4.926x+4.926\frac{4\pi}{3}-1.76\right)+\frac{1}{2}\sin\left(2.926x+2.926\frac{4\pi}{3}-1.76\right)\right)dx$$

$$= 2070.047\ (1.28473 - 0.0036379)$$

$$= 2651.9196\ \text{Nm}\ \textit{(berlawanan arah turbin)}$$

Jadi besar torsi *drag* total dari turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 4 m/s adalah:

$$T_{D\ \text{rata-rata}}\ \text{total} = (T_{Dsudu1} + T_{Dsudu2} + T_{Dsudu3})$$

$$= -1744.8418 - 141.2392 + 2651.9196$$

$$= 765.8386\ \text{Nm}\ \textit{(berlawanan arah turbin)}$$

Jadi torsi rata-rata total untuk turbin Darrieus dengan hydrofoil NACA 0015 pada kecepatan aliran 4 m/s adalah:

$$T_{\text{Rata-rata}} = (\ T_{L\ \text{rata-rata}}\ \text{total} - T_{D\ \text{rata-rata}}\ \text{total})$$

$$= (807.442) - (765.8386)$$

$$= 41.603\ \text{Nm}\ \textit{(searah putaran turbin)}$$

2.2 Perhitungan Daya Turbin P_T (Power Turbin)

Rumus: $P_t = T. \omega$

$U = 2\ m/s \quad \omega = 29.351\ \text{Rad/sec} \quad T = 11.193\ Nm$

$P_t = T. \omega$

$P_t = = 11.193\ Nm . 29.351$

$P_t = 328.526\ \text{Watt}$

$U = 2.5\ m/s \quad \omega = 41.833\ \text{Rad/sec} \quad T = 17.696 Nm$

$P_t = T. \omega$

$P_t = 17.696\ Nm. 41.833$

$P_t = 740.277\ \text{Watt}$

$U = 3\ m/s \quad \omega = 56.897\ \text{Rad/sec} \quad T = 23.893\ Nm$

$P_t = T. \omega$

$P_t = 23.893\ Nm . 56.897$

$P_t = 1359.44\ \text{Watt}$

$U = 3.5\ m/s \quad \omega = 74.651\ \text{Rad/sec} \quad T = 30.88\ Nm$

$P_t = T. \omega$

$P_t = 30.88\ Nm. 74.651$

$P_t = 2305.223\ Watt$

$U = 4\ m/s \quad \omega = 95.203\ \text{Rad/sec} \quad T = 41.603\ Nm$

$P_t = T. \omega$

$P_t = 41.603 . 95.203$

$P_t = 3960.73\ \text{Watt}$

2.3 Perhitungan Daya Hidrolis P_h (Power Hidrolis)

Rumus : $P_h = \rho\, g\, Q\, H$

$$= \rho\, g\, (A\, U)\left(\frac{U^2}{2.g}\right)$$

$$= \rho\, (A)\left(\frac{U^3}{2}\right)$$

$$= \rho\, (H)(D)\left(\frac{U^3}{2}\right)$$

U = 2 m/s   H = 0.8 m D= 0.6 $\rho = 998.2$ kg/m^3

P_h $= \rho\, (H)(D)\left(\frac{U^3}{2}\right)$

P_h $= (998.2)\ (0.8)(\ 0.6)\left(\frac{2^3}{2}\right)$

P_h $= 1916.544$ Watt

U = 2.5 m/s H = 0.8 m D= 0.6 $\rho = 998.2$ kg/m^3

P_h $= \rho\, (H)(D)\left(\frac{U^3}{2}\right)$

P_h $= (998.2)\ (0.8)(\ 0.6)\left(\frac{2.5^3}{2}\right)$

P_h $= 3743.25$ Watt

U = 3 m/s   H = 0.8 m   D= 0.6 $\rho = 998.2$ kg/m^3

P_h $= \rho\, (H)(D)\left(\frac{U^3}{2}\right)$

P_h $= (998.2)\ (0.8)(\ 0.6)\left(\frac{3^3}{2.}\right)$

P_h $= 6468.336$ Watt

U = 3.5 m/s   H = 0.8 m   D= 0.6 $\rho = 998.2$ kg/m^3

P_h $= \rho\, (H)(D)\left(\frac{U^3}{2}\right)$

P_h $= (998.2)\ (0.8)(\ 0.6)\left(\frac{3.5^3}{2.}\right)$

P_h $= 10271.478$ Watt

U = 4 m/s   H = 0.8 m   D= 0.6 $\rho = 998.2$ kg/m^3

P_h $= \rho\, (H)(D)\left(\frac{U^3}{2}\right)$

P_h $= (998.2)\ (0.8)(\ 0.6)\left(\frac{4^3}{2}\right)$

P_h $= 15332.352$ Watt

2.4 Perhitungan Efisiensi Turbin (ηT)

Rumus $: \eta T = \dfrac{P_t}{P_h} \times 100\%$

1. Kecepatanaliran 2 m/s

   $P_T = 328.526$ Watt $\qquad$ $P_H = 1916.544$ Watt

   $\eta T = \dfrac{P_t}{P_h} \times 100\%$

   $\eta T = \dfrac{328.526 \text{ Watt}}{1916.544 \text{ Watt}} \times 100\%$

   $\eta T = 17.14$ %

2. Kecepatanaliran 2.5 m/s

   $P_T = 740.277$ Watt $\qquad$ $P_H = 3743.25$ Watt

   $\eta T = \dfrac{P_t}{P_h} \times 100\%$

   $\eta T = \dfrac{740.277 \text{ Watt}}{3743.25 \text{ Watt}} \times 100\%$

   $\eta T = 19.776$ %

3. Kecepatanaliran 3 m/s

P_T = 1359.44 Watt P_H= 6468.336   Watt

$$\eta T = \frac{P_t}{P_h} \times 100\%$$

$$\eta T = \frac{1359.44 \text{ Watt}}{6468.336 \text{ Watt}} \times 100\%$$

ηT = 21.02 %

4. Kecepatanaliran 3.5 m/s

P_T = 2305.223 $Watt$ P_H= 10271.478   Watt

$$\eta T = \frac{P_t}{P_h} \times 100\%$$

$$\eta T = \frac{2305.223 \text{ Watt}}{10271.478 \text{ Watt}} \times 100\%$$

ηT = 22.44 %

5. Kecepatanaliran 4 m/s

P_T = 3960.73 Watt P_H= 15332.352 Watt

$$\eta T = \frac{P_t}{P_h} \times 100\%$$

$$\eta T = \frac{3960.73 \text{ Watt}}{15332.352 \text{ Watt}} \times 100\%$$

ηT = 25.833 %

Kecepatanaliran (U)	Torsi Nm	P_t Watt	P_h Watt	η_t
2 m/s (Exp)	11.193	328.526	1916.544	17.14 %
2.5 m/s	17.696	740.277	3743.25	19.776 %
3 m/s (Exp)	23.893	1359.44	6468.336	21.02 %
3.5 m/s (Exp)	30.88	2305.223	10271.478	22.44 %
4 m/s (Exp)	41.603	3960.73	15332.352	25.833 %

Grafik Hubungan Kecepatan aliran - Efisiensi Turbin