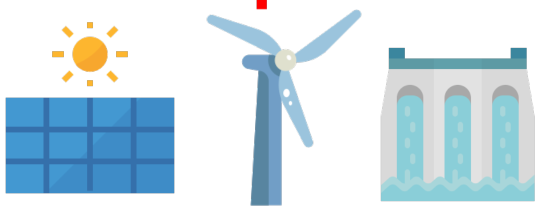

Renewable Energy

◆25 Practice Questions

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Here's a set of 25 fully solved problems on renewable energy engineering. Problems were taken from a carefully researched assortment of textbooks. All problems are solved step by step. Enjoy! ■

Problems	Subject
1 – 8	Solar power
9 – 16	Wind power
17 – 25	Tidal and hydropower

PROBLEMS

Problem 1. In approximately which day of the year does the sunlight intensity in the Northern Hemisphere reach its maximum value?

(A) March 21
(B) June 21
(C) July 21
(D) December 21

Problem 2. A silicon solar cell of band gap equal to 1.11 eV is uniformly illuminated by monochromatic light of intensity equal to 900 W/m^2 and wavelength 800 nm. The external quantum efficiency at this wavelength is 0.85. If the area of the cell is 10 cm^2, the light current obtained is most nearly:

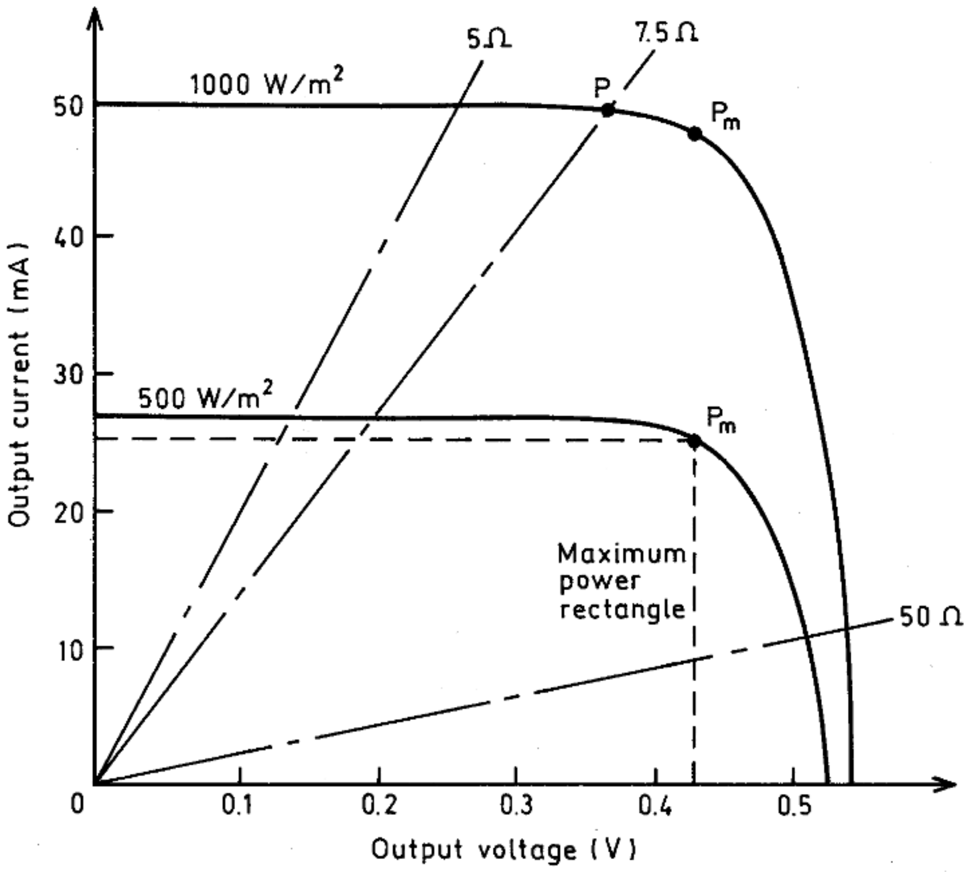
(A) 0.113 A
(B) 0.235 A
(C) 0.341 A
(D) 0.493 A

Problem 3. A certain solar cell is irradiated with sunlight at 500 W/m^2. The electrical efficiency of the cell is 15%, the fill factor is 0.61, and the aperture area is 5 cm^2. The power output associated with this cell is most nearly:

(A) 13 mW
(B) 18 mW
(C) 23 mW
(D) 28 mW

Problem 4. The *I-V* chart on the next page shows characteristic curves for a solar cell when irradiated at 500 and 1000 W/m^2. Also shown are load lines for different resistance levels. The power output obtained when 30 of these cells are connected in parallel to a 50-Ω load and irradiated at 500 W/m^2 is, most nearly:

(A) 74 mW
(B) 168 mW
(C) 336 mW
(D) 504 mW



Problem 5. For a flat-plate solar collector having the following characteristics, calculate the fin efficiency. Ignore bond resistance.

→ Overall heat loss coefficient, U_c = 8 W/m²·°C
→ Tube spacing = 200 mm
→ Tube outside diameter = 24 mm
→ Tube inside diameter = 20 mm
→ Plate thickness = 0.5 mm
→ Plate material: copper (thermal conductivity = 390 W/m·°C)
→ Heat transfer coefficient inside the tubes = 450 W/m²·°C

(A) 0.796
(B) 0.844
(C) 0.906
(D) 0.945

Problem 6. For the collector introduced in the previous problem, compute the efficiency if the running fluid is water (specific heat c_p = 4.18 kJ/kg·K), the flow rate is 0.09 kg/s, the collector area is 6 m², the transmittance-absorptance product is $(\tau\alpha)$ = 0.83, the collector efficiency factor is F' = 0.88, the global solar radiation for one hour is 2.9 MJ/m², and the collector operates at a temperature difference of 10°C.
(A) 60.9%
(B) 69.2%
(C) 73.5%
(D) 81.1%

Problem 7. The following are steps involved in the conversion of sunlight to electricity in organic photovoltaics. Which of the following alternatives ranks the four steps in correct order?

P. Exciton diffusion to the donor-acceptor interface.
Q. Charge transport to, and collection at, the electrodes.
R. Absorption of sunlight and formation of an exciton.
S. Exciton dissociation into free charges (electrons and holes).

(A) S → P → Q → R
(B) R → P → S → Q
(C) R → S → P → Q
(D) P → S → R → Q

Problem 8. The counterelectrode of dye-sensitized solar cells is generally constituted of:
(A) Platinum.
(B) Palladium.
(C) Silver.
(D) Gold.

Problem 9. A wind turbine rated at 1.8 MW and power coefficient $C_P = 0.24$ operates in a constant freestream airspeed of 16 m/s. Taking ρ = 1.225 kg/m^3 as the air density, the radius of the rotor recommended for this turbine is most nearly:
(A) 13.6 m
(B) 19.8 m
(C) 24.5 m
(D) 30.8 m

Problem 10. A certain wind turbine is rated at 1.4 MW. The blade diameter is 45 m and the rated wind speed is 15 m/s. The gearbox and generator efficiencies are both equal to 0.95; all other efficiency metrics are equal to unity. What is the power coefficient of the turbine? Take ρ = 1.225 kg/m^3 as the density of air.
(A) 0.299
(B) 0.358
(C) 0.472
(D) 0.561

Problem 11. A wind turbine with a rotor diameter of 30 m has an axial induction factor of 0.4. The wind speed is assumed constant with altitude and equal to 8 m/s, and the density of air may be taken as 1.225 kg/m^3. What is the thrust coefficient?
(A) 0.689
(B) 0.811
(C) 0.960
(D) 1.13

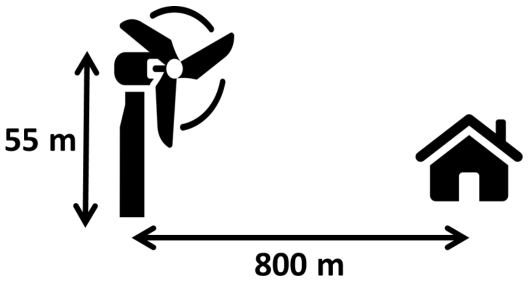
Problem 12. "The distribution of wind that passes a wind turbine blade is altered by the presence of the tower. For upwind rotors, the wind directly in front of the tower is redirected and thereby reduces the torque at each blade when in front of the tower. The torque pulsations due to this effect are most significant when a turbine has blades downwind of the tower and wind is blocked as opposed to redirected. This affects the rotation regime of the blades and may lead to pronounced oscillations in the system's power generation performance."

The phenomenon described above is:
(A) Wind shear.
(B) Tower shadow.
(C) 3p oscillation.
(D) Himmelskamp effect.

Problem 13. A horizontal-axis wind turbine system consists of a two-blade propeller driving a generator via a gearbox. The generator is required to deliver a rated capacity of 2 MW with the wind turbine rotating at 20 rpm. The overall efficiency of the turbine is 40%. What is the shaft diameter if the maximum permitted shear stress in the shaft is 50 MPa?
(A) 48.8 cm
(B) 62.4 cm
(C) 77.8 cm
(D) 90.0 cm

Problem 14. A wind turbine with a cut-in velocity of 6 m/s and a cut-out velocity of 18 m/s is installed in a site where winds are Weibull-distributed with shape parameter $k = 2.34$ and scale parameter $c = 9.7$ m/s. For how many hours in a 24-hour period will the wind turbine generate power?
(A) 11 h
(B) 13 h
(C) 17 h
(D) 21 h

Problem 15. Consider a single 55 m tall wind turbine that generates a noise level of 106 dB(A) at hub height. Assuming that sound radiates in a spherical pattern, and that the atmospheric sound absorption coefficient is 0.005 dB/m, what is the sound level received at a house located 800 m away from the base of the turbine?



(A) 35.9 dB
(B) 47.8 dB
(C) 55.5 dB
(D) 61.7 dB

Problem 16. Regarding vertical-axis wind turbines (VAWTs), which of the following statements is **false**?
(A) Darrieus-type VAWTs are omnidirectional.
(B) Darrieus-type VAWTs cannot self-start.
(C) The performance of Darrieus- and Savonius-type VAWTs in turbulent wind fields is superior to that of horizontal turbines.
(D) Maintenance of Darrieus- and Savonius-type VAWTs is made easier by the fact that machinery is located at ground level.

Problem 17. The following paragraph describes a mechanism that may lead to the failure of hydroelectric plant dams.

"__________ is the process by which finer soil particles are moved through constrictions between larger soil particles by seepage forces. Soils susceptible to __________ are usually described as internally unstable. Internally unstable soils are usually broadly graded soils with particles from silt or clay to gravel size, whose particle size distribution curves are concave upward, or gap-graded soils."

What is the term that correctly completes the blank spaces above?
(A) Piping.
(B) Suffusion.
(C) Blowout.
(D) Differential settlement.

Problem 18. Which of the following is **not** a defensive design measure used to protect dams from earthquake effects?
(A) Making the impervious zone more plastic.
(B) Increasing the freeboard.
(C) Flattening the embankment slopes.
(D) Narrowing the dam crest.

Problem 19. A small stream has a slope of 0.04 and a constant discharge of 120 m^3/s. The water is laden with sediments and has an average density of 1100 kg/m^3. The stream power per unit of stream length is, most nearly:
(A) 39.8 kW/m
(B) 44.6 kW/m
(C) 51.8 kW/m
(D) 65.5 kW/m

Problem 20. A Pelton turbine with effective radius 0.85 m is installed in a hydropower scheme with head equal to 710 m. The jet diameter observed is 60 mm. What is the rotational speed of the turbine?
(A) 51.0 rad/s
(B) 69.6 rad/s
(C) 83.3 rad/s
(D) 102 rad/s

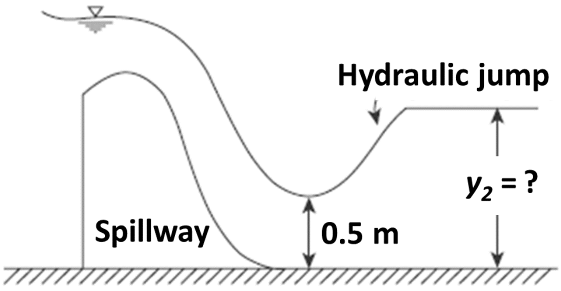
Problem 21. The following data apply to a Francis turbine:

→ Water flow rate = 25 m^3/s
→ Rotor height = 0.50 m
→ Radius at inlet = 0.75 m
→ Runner speed = 40 rad/s
→ Stator blade angle with radius = 65°

What is the power output of the turbine under these conditions?
(A) 17 MW
(B) 25.5 MW
(C) 34 MW
(D) 42.5 MW

Problem 22. A hydropower penstock model with diameter equal to 20 cm and negligible wall thickness is carrying water when the outlet is suddenly closed. The discharge is 32 liters/sec. Assuming water has density and modulus of elasticity equal to 1000 kg/m^3 and 2.2 GPa, respectively, the water hammer pressure rise developed is most nearly:
(A) 1.06 MPa
(B) 1.51 MPa
(C) 1.90 MPa
(D) 2.23 MPa

Problem 23. Water emerges from an ogee spillway with velocity equal to 12 m/s and depth equal to 0.5 m at its toe. The tailwater depth required to form a hydraulic jump at the toe is, most nearly:



(A) 3.6 m
(B) 4.8 m
(C) 6.0 m
(D) 7.2 m

Problem 24. A deep water wave has wavelength equal to 50 m and amplitude of 2 m. Find the period T and the energy E per unit length of the wave. Take ρ = 1025 kg/m^3 as the density of seawater.
(A) T = 5.7 sec; E = 505 kJ/m
(B) T = 5.7 sec; E = 1010 kJ/m
(C) T = 11.4 sec; E = 505 kJ/m
(D) T = 11.4 sec; E = 1010 kJ/m

Problem 25. A submerged tidal turbine is located in a stream with its hub at a height of 20 m above the seafloor. The radius of the blades is 8 m. The velocity of the stream varies with height z (meters) above seafloor according to the power law $U(z) = 1.6(z/5)^{1/10}$ m/s. The thrust coefficient has been established as 0.54. What is the overturning moment on the support structure at the bottom of the turbine? Take ρ = 1025 kg/m^3 as the density of seawater.
(A) 770 kN·m
(B) 1.54 MN·m
(C) 2.69 MN·m
(D) 3.77 MN·m

Answer key is on the next page! Problem solutions also begin on the next page.

ANSWER KEY

Problem	Answer	Problem	Answer
1	B	14	C
2	D	15	A
3	C	16	B
4	B	17	B
5	C	18	D
6	A	19	C
7	B	20	B
8	A	21	A
9	D	22	B
10	C	23	A
11	C	24	B
12	B	25	D
13	B		

SOLUTIONS

1 ➡ B

The insolation in the northern hemisphere is greatest during the summer solstice, which usually occurs on, or within a few days of, June 21.

2 ➡ D

We first compute the photon flux:

$$\phi_{ph} = I_S\left(\frac{\lambda}{hc}\right) = 900\times\left[\frac{800\times10^{-9}}{\left(6.63\times10^{-34}\right)\times\left(3\times10^{8}\right)}\right] = 3.62\times10^{21}\ \text{m}^{-2}\text{s}^{-1}$$

For a quantum efficiency *EQE* = 0.85, the electron generation rate becomes

$$\psi_{el} = EQE\times\phi_{ph} = 0.85\times\left(3.62\times10^{21}\right) = 3.08\times10^{21}$$

The light current follows as

$$I_L = A\times q\times\psi_{el} = \left(10\times10^{-4}\right)\times\left(1.6\times10^{-19}\right)\times\left(3.08\times10^{21}\right) = \boxed{0.493\ \text{A}}$$

3 ➡ C

The power output is given by the product of sunlight intensity I_S, electrical efficiency η, fill factor *F*, and cell area *A*:

$$\Pi = I_S\times\eta\times F\times A = 500\times0.15\times0.61\times\left(5.0\times10^{-4}\right) = 0.0229\ \text{W}$$

$$\therefore \boxed{\Pi = 22.9\ \text{mW}}$$

4 ➡ B

Note that the 50-Ω load line and the characteristic curve for 500 W/m^2 intersect at an output voltage of 0.51 V and an output current of 11 mA. For a connection of cells in parallel, the output voltage is the same for all cells, namely *V* = 0.51 V. the total current, in turn, is 30 × 11 = 330 mA. The total power dissipated by the cells follows as

$$\Pi = 330\times0.51 = \boxed{168\ \text{mW}}$$

5 ➡ C

We begin by computing parameter *m*:

$$m = \sqrt{\frac{U_c}{kt}} = \sqrt{\frac{8.0}{390\times0.0005}} = 6.41\ \text{m}^{-1}$$

Then, the fin efficiency becomes

$$\eta_f = \frac{\tanh\left[m(\ell - D)/2\right]}{m(\ell - D)/2} = \frac{\tanh\left[6.41\times(0.2-0.024)/2\right]}{6.41\times(0.2-0.024)/2} = \boxed{0.906}$$

6 ➡ A

The dimensionless capacitance rate is

$$\frac{\dot{m}c_p}{A_c U_c F'} = \frac{0.09\times 4180}{6\times 8.0\times 0.88} = 8.91$$

This can be used to determine the flow factor *F″*:

$$F'' = \frac{\dot{m}c_p}{A_c U_c F'}\left[1-\exp\left(-\frac{U_c F' A_c}{\dot{m}c_p}\right)\right] = 8.91\times\left[1-\exp\left(-\frac{1}{8.91}\right)\right] = 0.946$$

The heat removal factor F_R follows as

$$F_R = F'\times F'' = 0.88\times 0.946 = 0.832$$

The amount of useful heat, Q_u, is (note that factor 3.6, or 3600/1000, was included because I_S is given in MJ/m^2, or 1000 kJ/m^2, and the time span considered is one hour, or 3600 sec):

$$Q_u = A_c F_R\left[I_t(\tau\alpha) - U_c(T_i - T_a)\times 3.6\right]$$

$$Q_u = 6\times 0.832\times(2900\times 0.83 - 8.0\times 10\times 3.6) = 10{,}600\text{ kJ} = 10.6\text{ MJ}$$

Finally, the collector efficiency becomes

$$\eta_c = \frac{Q_u}{A_c I_t} = \frac{10.6}{6\times 2.9} = 0.609 = \boxed{60.9\%}$$

7 ➡ B

In the commercially available silicon solar cells, when a photon from the solar spectrum is absorbed, the exciton binding energy is so small that the electron and hole can separate, and thus a current can be produced. However, in an organic material, the absorption of a photon creates a strongly bound exciton, which is basically a neutral electron-hole pair. This means that absorbed photons produce a neutral excitation, not free carriers, and thus a dissociation interface is required. Within most organic solar cells, for example in the case of the well-known P3HT/PCBM heterojunction, the necessary steps required to convert sunlight into electricity are:

1. Absorption of sunlight and formation of the exciton;
2. Exciton diffusion to the donor-acceptor interface;
3. Exciton dissociation into free charges (electrons and holes);
4. Charge transport to and collection at the electrodes;

8 ➡ A

The counterelectrode of dye-sensitized solar cells is generally constituted of platinum.

9 ➡ D

This is a straightforward application of the formula

$$R = \sqrt{\frac{\Pi_{\text{rated}}}{\frac{1}{2}\rho V_{\text{rated}}^3 C_{p,\text{rated}}\pi}} = \sqrt{\frac{1.8\times 10^6}{0.5\times 1.225\times 16^3\times 0.24\times\pi}} = \boxed{30.8\text{ m}}$$

10 ➡ C

We first compute the input power Π_w:

$$\Pi_w = \frac{1}{2}\rho A V^3 = \frac{1}{2}\times 1.225\times\left(\frac{\pi\times 45^2}{4}\right)\times 15^3 = 3.29\times 10^6\text{ W}$$

The overall efficiency is determined as

$$\eta = \frac{1.4}{3.29} = 0.426$$

But

$$\eta = \eta_{\text{gb}}\eta_{\text{gen}}C_p$$

so that, solving for power coefficient,

$$\eta = \eta_{\text{gb}}\eta_{\text{gen}}C_p \quad \to \quad C_p = \frac{\eta}{\eta_{\text{gb}}\eta_{\text{gen}}}$$

$$\therefore C_p = \frac{0.426}{0.95\times 0.95} = \boxed{0.472}$$

11 ➡ C

The area swept by the rotor is

$$A = \frac{\pi D^2}{4} = \frac{\pi\times 30^2}{4} = 707\ \text{m}^2$$

Per Froude-Rankine momentum theory, the thrust is given by

$$F = 2A\rho V_1^2 a(1-a) = 2\times 707\times 1.225\times 8^2\times 0.4\times(1-0.4) = 26{,}600\ \text{N}$$

The thrust coefficient follows as

$$C_F = \frac{F}{\frac{1}{2}\rho V_1^2 A} = \frac{26{,}600}{0.5\times 1.225\times 8^2\times 707} = \boxed{0.960}$$

12 ➡ B

The phenomenon in question is called tower shadow.

13 ➡ B

Noting that the turbine is operating at an overall efficiency of 40%, the wind power is found as

$$\Pi_w = \frac{2\times 10^6}{0.4} = 5\times 10^6\ \text{W}$$

The rotational speed is converted as

$$\omega = \frac{2\pi n}{60} = \frac{2\pi\times 20}{60} = 2.09\ \text{rad/s}$$

The torque imparted on the shaft is

$$T = \frac{\Pi}{\omega} = \frac{5\times 10^6}{2.09} = 2.39\times 10^6\ \text{N}\cdot\text{m}$$

From the torsion formula,

$$\tau = \frac{2T}{\pi r^3} \quad \to \quad r = \sqrt[3]{\frac{2T}{\pi\tau}}$$

$$\therefore r = \sqrt[3]{\frac{2\times\left(2.39\times 10^6\right)}{\pi\times\left(50\times 10^6\right)}} = 0.312\ \text{m}$$

The corresponding diameter is

$$D = 2r = 2\times 0.312 = 0.624\ \text{m} = \boxed{62.4\ \text{cm}}$$

14 ➡ C

The number of hours that the wind turbine will operate productively is based on the probability that the wind speed falls between cut-in and cut-out values; in mathematical terms:

$$\Pr(V_6 < V < V_{18}) = \Pr(V_{18}) - \Pr(V_6)$$

$$\therefore \Pr(V_6 < V < V_{18}) = \exp\left[-(6/9.7)^{2.34}\right] - \Pr\left[-(20/9.7)^{2.34}\right]$$

$$\therefore \Pr(V_6 < V < V_{18}) = 0.723 - 0.0143 = 0.709$$

Therefore, for a full day, the wind turbine will generate power in a number of hours equal to 0.709 × 24 = 17.0 h.

15 ➡ A

The sound propagates in a radial pattern along the radial vector, *R*. If the height of the turbine is *H* and the horizontal distance from the base of the tower to the house is *D*, we can write

$$R=\left(D^2+H^2\right)^{1/2}=\left(800^2+55^2\right)^{1/2}=802\text{ m}$$

The sound level on the ground is given by

$$L_{W_p}=L_{W_*}-10\log_{10}\left(2\pi R^2\right)-\alpha R$$

where L_{W_*} is the sound power level (dB) measured at the sound source, L_{W_P} is the propagated sound power level (dB) measured at the radial distance *R* from the sound source, and α is the frequency-dependent sound absorption coefficient; substituting the pertaining data brings to

$$L_{W_p}=106-10\times\log_{10}\left(2\pi\times802^2\right)-0.005\times802=\boxed{35.9\text{ dB}}$$

16 ➡ B

Self-starting Darrieus turbines do exist. Refer to Problem 11 in our quiz on wind energy for details.

17 ➡ B

The answer becomes obvious if the student recognizes that the term "suffusion" is often used as an equivalent phrase for "internal instability." As mentioned in the paragraph, a soil's susceptibility to suffusion is commonly associated with specific particle size distributions, as it is particularly common in broadly-graded soils with particles from silt to clay to gravel size, soils with particle size distribution curves that are concave upward, and gap-graded soils.

18 ➡ D

The measures stated are efficient approaches to strengthen the dam against seismic activity, with the exception of D. The engineer should have the dam be as wide as possible so as to better distribute stresses emanating from seismic waves.

19 ➡ C

The stream power per unit of stream length is given by the product

$$\Pi=\rho gQS=1100\times9.81\times120\times0.04=51{,}800\text{ W/m}$$

$$\therefore\ \boxed{\Pi=51.8\text{ kW/m}}$$

20 ➡ B

Firstly, the velocity of the jet is

$$V_j=\sqrt{2gH}=\sqrt{2\times9.81\times710}=118\text{ m/s}$$

The volume flow rate of water is

$$Q=\pi r_j^2V_j=\pi\times0.03^2\times118=0.334\text{ m}^3\text{/s}$$

The torque on the wheel is given by

$$T=Q\rho r\left(V_1-U\right)\left(1-k\cos\theta\right)$$

But, for an ideal Pelton turbine,

$$U=\frac{V_1}{2}\ ;\ k=1\ ;\ \theta=\pi$$

so that

$$T=Q\rho r\left(V_1-\frac{V_1}{2}\right)\left(1-\cos\pi\right)$$

$$\therefore T=0.334\times1000\times0.85\times\left(118-\frac{118}{2}\right)\times\left(1-\cos\pi\right)=33{,}500\text{ N}\cdot\text{m}$$

The power associated with the jet is, in turn,

$$\Pi=\rho gQH=1000\times9.81\times0.334\times710=2.33\times10^6\text{ W}=2.33\text{ MW}$$

Finally, we solve for the turbine rotational speed ω:

$$\Pi=T\omega\ \rightarrow\ \omega=\frac{\Pi}{T}$$

$$\therefore\omega=\frac{2.33\times10^6}{33{,}500}=\boxed{69.6\text{ rad/s}}$$

21 ➡ A

The flow rate is given by

$$Q = 2\pi r_1 \ell_1 V_{r1}$$

where r_1 is the inlet radius, ℓ_1 is inlet height, and V_{r1} is the inlet radial flow velocity. Solving for V_{r1} brings to

$$Q = 2\pi r_1 \ell_1 V_{r1} \quad \rightarrow \quad V_{r1} = \frac{Q}{2\pi r_1 \ell_1}$$

$$\therefore V_{r1} = \frac{25}{2\pi \times 0.75 \times 0.50} = 10.6 \text{ m/s}$$

Noting that the stator angle with the radial direction was given as 65°, we compute the tangential velocity at the inlet as

$$V_{t1} = V_{r1} \tan 65^{\circ} = 10.6 \times \tan 65^{\circ} = 22.7 \text{ m/s}$$

The torque on the runner is given by

$$T = \rho Q\left(V_{t1} r_1 - V_{t2} r_2\right)$$

Neglecting the exit tangential velocity and substituting,

$$T = \rho Q\left(V_{t1} r_1 - \cancel{V_{t2} r_2}\right) = \rho Q V_{t1} r_1$$

$$\therefore T = 1000 \times 25 \times 22.7 \times 0.75 = 426{,}000 \text{ N} \cdot \text{m}$$

$$\therefore T = 426 \text{ kN} \cdot \text{m}$$

Lastly, we determine the power output:

$$\Pi = T\omega = 426 \times 40 = 17{,}000 \text{ kW} = \boxed{17 \text{ MW}}$$

22 ➡ B

The cross-sectional area of the cast-iron pipe is

$$A = \frac{\pi}{4} \times 0.2^2 = 0.0314 \text{ m}^2$$

The flow velocity is, in turn,

$$V = \frac{Q}{A} = \frac{0.032}{0.0314} = 1.02 \text{ m/s}$$

The speed of the pressure wave is calculated as

$$C = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{2.2 \times 10^9}{1000}} = 1480 \text{ m/s}$$

It remains to compute the water hammer pressure,

$$\Delta p = \rho V C = 1000 \times 1.02 \times 1480 = 1.51 \times 10^6 \text{ Pa}$$

$$\therefore \boxed{\Delta p = 1.51 \text{ MPa}}$$

23 ➡ A

The upstream Froude number is

$$\text{Fr}_1 = \frac{V_1}{\sqrt{g y_1}} = \frac{12}{\sqrt{9.81 \times 0.5}} = 5.42$$

The sequent depth ratio is, in turn,

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8\text{Fr}_1^2} - 1\right) = \frac{1}{2}\left(\sqrt{1 + 8 \times 5.42^2} - 1\right) = 7.18$$

so that

$$y_2 = 7.18 y_1 = 7.18 \times 0.5 = \boxed{3.59 \text{ m}}$$

24 ➡ B

The speed of a deep water wave is given by

$$c = \left(\frac{gL}{2\pi}\right)^{\frac{1}{2}} = \left(\frac{9.81 \times 50}{2\pi}\right)^{\frac{1}{2}} = 8.84 \text{ m/s}$$

However, wave velocity is also given by the ratio of wavelength to period; accordingly, we solve for T to obtain

$$c = \frac{\lambda}{T} \rightarrow T = \frac{\lambda}{c}$$

$$\therefore T = \frac{50}{8.84} = \boxed{5.66 \text{ s}}$$

The energy of the wave is

$$E = \frac{1}{2}\rho g A^2 \lambda = \frac{1}{2} \times 1025 \times 9.81 \times 2^2 \times 50 = 1.01 \times 10^6 \text{ J/m}$$

$$\therefore \boxed{E = 1010 \text{ kJ/m}}$$

25 ➡ D

The water speed at hub height of the turbine can be determined with the power law we were given:

$$U(z=20) = 1.6 \times \left(\frac{20}{5}\right)^{0.1} = 1.84 \text{ m/s}$$

The thrust F on the rotor follows as

$$F = C_F \times \frac{1}{2}\rho U^2 A = 0.54 \times \frac{1}{2} \times 1025 \times 1.84^2 \times \left(\pi \times 8^2\right) = 188,400 \text{ N}$$

The overturning moment acting on the base is obtained by multiplying the thrust by the height of the turbine:

$$M = 188,400 \times 20 = 3.77 \times 10^6 \text{ N} \cdot \text{m} = \boxed{3.77 \text{ MN} \cdot \text{m}}$$

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