Having defined the brake horsepower for the normal operating state, apply the affinity law relating power and speed to determine the bhp for the failure mode:

$$\frac{bhp_2}{bhp_1} = \left(\frac{n_2}{n_1}\right)^3$$

$$bhp_2 = bhp_1 \left(\frac{n_2}{n_1}\right)^3 = (28.06hp)\left(\frac{1350rpm}{900rpm}\right)^3 = 94.7hp$$

Note the dramatic increase in power associated with a moderate increase in speed. This is one reason why energy savings can be readily achieved by running redundant pumps in parallel using variable speed drives.

Answer D

40.27 $100,000gpm$ of water falls $900ft$ through a hydroelectric turbine system with 90% efficiency. The friction loss through the system is $100ft$. How much power is generated by the system?

A. $13MW$

B. $15MW$

C. $17MW$

D. $19MW$

A hydroelectric turbine is effectively a pump acting in reverse, turning hydraulic horsepower into brake horsepower and then turning a generator, which is effectively a motor operating in reverse, turning brake horsepower into electricity. This problem gives the efficiency of the hydroelectric turbine *system*, therefore it is not necessary to analyze the detailed interaction between the turbine and the generator. Rather, the entire system can be viewed as taking water horsepower, whp, as an input, and producing electrical power, P_{elec}, as an output.

Write the form of the Bernoulli Equation suited for pumping applications:

$$h_A = \frac{P_2 - P_1}{\gamma} + \frac{v_2^2 - v_1^2}{2g} + z_2 - z_1 + h_f$$

where state 1 is located at the source on the turbine inlet side, state 2 represents the outlet side, and h_A is the head added *to the turbine* (rather than by a pump).

Both the inlet and outlet states are at atmospheric pressie. There is no need to account for the 900ft of elevation differential from a static pressure perspective. Therefore:

$$P_1 \approx P_2 \approx 1atm$$

$$\frac{P_2 - P_1}{\gamma} \approx 0$$

The velocity term may also be neglected as the velocities are likely to be close in magnitude at the two locations.

$$v_1 \approx v_2$$

$$\frac{v_2^2 - v_1^2}{2g} \approx 0$$

The height differential is given. Note the sign is negative due to how to states 1 and 2 were defined, i.e. state 2 is at the lower height:

$$\Delta z = z_2 - z_1 = 0ft - 900ft = -900ft$$

The friction loss is given:

$$h_f = 100ft$$

Calculate the head pressure removed by the turbine. Note this value is expected to be negative since a positive value would correspond to the head being *added*, as would occur using a pump. In the next step when calculating the water horsepower, it is perfectly acceptable to take the absolute value.

$$h_A = \frac{P_2 - P_1}{\gamma} + \frac{v_2^2 - v_1^2}{2g} + z_2 - z_1 + h_f = -900ft + 100ft = -800ft$$

The electrical power produced is a portion of the whp, as defined by the efficiency:

$$P_{elec} = \eta_T whp$$

Water horsepower is a function of volume flow rate and head:

$$whp = \frac{Q_{[gpm]} \Delta h_{[ft]}}{3960}$$

Combine these two equations:

$$P_{elec} = \frac{\eta_T Q_{[gpm]} \Delta h_{[ft]}}{3960}$$

Substitute, solve, and convert units to KW:

$$P_{elec} = \frac{(100,000)\,(800)\,(.9)}{3960} = 18,182hp \left(\frac{.7457KW}{1hp}\right) = 13,560KW = 13.6MW$$

Answer A