40.26 Three 90% efficient secondary chilled water pumps operate in a parallel redundant N+1 configuration supplying a total of $1500gpm$ against $200ft$ of total dynamic head. In normal operation with all three pumps running, the pumps have a speed of $900rpm$. When one pump fails, the remaining pumps increase speed to provide consistent uninterrupted flow to the cooling loads. During a pump failure, what brake horsepower is required to drive each of the two running pumps?

A. $28hp$

B. $42hp$

C. $63hp$

D. $95hp$

Make a table to organize the information comparing the normal mode of operation to the failure mode described. The values in the table are per individual pump.

Normal	Failure
$Q_1 = 500gpm$	$Q_2 = 750gpm$
$h_{A,1} = 200ft$	$h_{A,2} = 200ft$
$n_1 = 900rpm$	n_2 ?
bhp_1 ?	bhp_2 ?

Look up the pump affinity laws. Recall the relationship between volume flow rate and speed is linear. Therefore, a 50% increase in speed must be required to produce a 50% increase in the flow rate.

$$\frac{n_2}{n_1} = \frac{Q_2}{Q_1}$$

$$n_2 = n_1 \left(\frac{Q_2}{Q_1}\right) = (900rpm)\left(\frac{750gpm}{500gpm}\right) = 1350rpm$$

Brake horsepower changes with the cube of the speed. However, before applying another pump affinity law, first calculate the brake horsepower by finding the water horsepower, whp, which is determined by the flow rate and head added by the pump, then include the efficiency to account for the pumping losses. Assume the pump efficiency is constant over a range of speeds.

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

$$bhp = \frac{whp}{\eta_p} = \frac{Q_{[gpm]} h_{A[ft]}}{3960 \cdot \eta_p}$$

$$bhp_1 = \frac{(500)(200)}{(3960)(.9)} = 28.06hp$$

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.