Hydropower Plants: Generating and Pumping Units
Series 2

GENERAL STUDY OF HYDRO POWERPLANT

The studied hydro-electric installation, whose layout is shown in Figure 1, is located in South America.

Figure 1: Layout of the hydro-electric installation

The rated discharge of the power plant Q is 50 m3 s-1. The gross head is considered as constant throughout the year and equal to 300 m. The value of the water density is ρ = 1’000 kg.m-3 and the gravity acceleration is g = 9.805 $m.s^{-2}$. The global efficiency of the power station (i.e. without considering the losses between B and I) is η = 0.91. For the purpose of simplification, the piping system is considered as a simplified penstock line, as illustrated in Figure 2. In this section, the only considered specific energy losses in the hydraulic circuit from B to I are the regular specific energy losses between III and II. Use the length of the penstock L = 5’400 m.

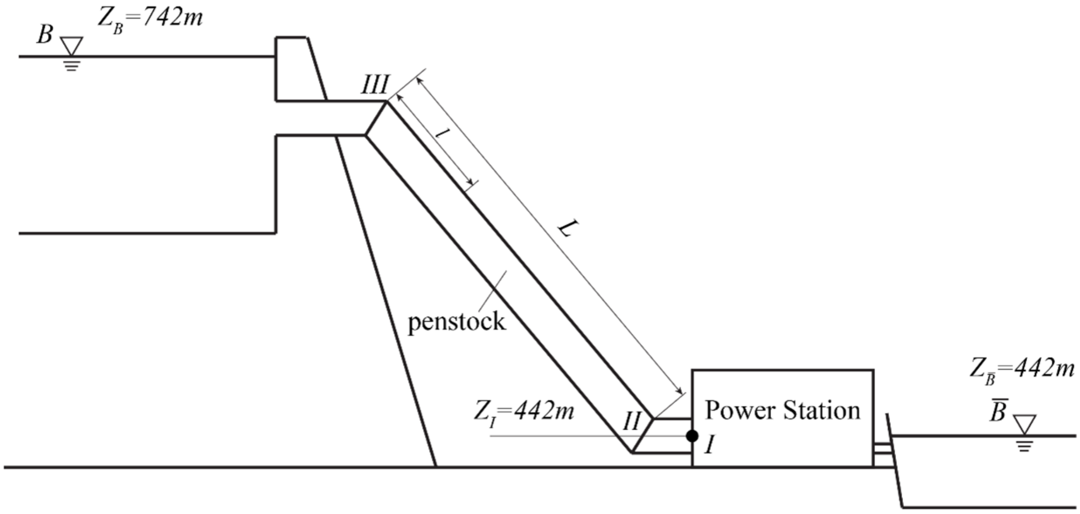

Figure 2: Simplified schematics of the hydro-electric installation

1) Express the potential power by using the relevant variables.
2) Express the distributed specific energy losses in the penstock $gH_{r\_penstock}$ as a function of the local loss coefficient λ, the length of the penstock L, the penstock diameter D, and the discharge Q.
3) Considering the distributed specific energy losses in the penstock, express the hydraulic power P_h at point I.
4) The global efficiency η is the result of a combination of several phenomena which limit the use of the hydraulic power P_h by the hydraulic machine, thus reducing the final output power P. Provide an answer to the following questions:
   a. Is the transferred power P_t, also called extracted power, larger or smaller than the hydraulic power P_h? Justify your answer by giving a list of the phenomena that are responsible for this difference, and indicate which efficiency sub-terms η_i of the global efficiency η are involved.
   b. Is the mechanical power P_m larger or smaller than the output power P?

      Why?
   c. To evaluate the electrical power which is actually provided to the grid, calculating the output power P is not enough. A further efficiency sub-term (which is however not included in the global efficiency η) must be considered. Why?
5) Using the global efficiency η, express the output power P using the parameters introduced in questions 1) and 2).
6) Let's move now to the energy state of the flow discharge. Start by expressing the gauge pressure of a fluid in function of the absolute and the atmospheric pressures.
7) Performing an energy balance between the pressure, kinetic energy and potential energy components of the discharge flowing in the penstock, express the total gauge

pressure $p_{tot}(l) = p_{gauge}(l) + \frac{1}{2}\rho u^2(l)$ as a function of L, *l*, Z_I and Z_{III}. Consider *l* as the coordinate which describes the longitudinal position in the penstock (*l* = 0 in *III*, and *l* = L in *II*), $p_{gauge}(l)$ the gauge pressure and $\frac{1}{2}\rho u^2(l)$ the dynamic pressure. Assume that the elevation in III is approximately the same as at the surface of the upper reservoir, $Z_{III} \cong Z_B$, and neglect the specific energy losses term.

8) In your opinion, could the dynamic pressure term be replaced by a constant? If yes, which geometrical characteristic must the penstock have?
9) Let's now put some numerical values on these results. Considering a pipe diameter *D* = 3 m and using the values listed in Table 2, calculate the following values :
    a. The output power *P* in kW.
    b. The electricity generation in kWh for one year.
    c. The annual sales of the electricity (neglecting the energy losses in the generator).

Table 2. Specific values of the penstock

parameter	value
λ	0.0100
Annual productivity	50%
Electricity Unit Price	0.06 CHF/kWh