UNIVERSITY OF WEST ATTICA
FACULTY OF ENGINEERING
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

MSc by Research in Electrical and Electronics Engineering
Indicative final exam in the course: MRES.B.02.07- Small Hydro-electric power plant
Duration**: 75 minutes** Athens, ….
Surname: .... Name: ....
Register number:**............................**

Issue 1

A small hydroelectric plant with one hydro-turbine (Francis or Pelton or Kaplan) is constructed on a river at a specific location. The available stream flow at the intake is given by Figure 1 for the last decade. The maximum available flow is equal to 10 m^3/s. The available hydraulic head is h=90 m. The following data are given:

- the nominal operation point of the turbine symbolized with index "N",
- the nominal operation flow is equal to: $Q_N = Q_{35}$, where Q_{35} is determined by the flow duration curve as the typical value for the proportion of time 35% during which the flow exceeds or equals certain value Q_{35},
- typical operation flow range for Francis turbine varies from $0.50 \cdot Q_N$ to $1.15 \cdot Q_N$, while the respective nominal efficiency factor of the turbine is 92% (for nominal flow),
- typical operation flow range for Pelton turbine varies from $0.15 \cdot Q_N$ to $1.15 \cdot Q_N$, while the respective nominal efficiency factor of the turbine is 89% (for nominal flow),
- typical operation flow range for Kaplan turbine varies from $0.10 \cdot Q_N$ to $1.15 \cdot Q_N$, while the respective nominal efficiency factor of the turbine is 91% (for nominal flow),
- nominal efficiency factor for generator is 97%,
- nominal efficiency factor for transformer is 99.1%,
- nominal power factor for generator inductive load is 85%,
- efficiencies of turbines, generators and transformers remain stable and are equal to the nominal ones for different flows
- the hydraulic losses $h_{\alpha\pi QN}$ are equal to 5 m for nominal operation flow,
- the hydraulic losses $h_{\alpha\pi}$ varies according to the square of operation flow,
- the net hydraulic head H is calculated if the hydraulic losses $h_{\alpha\pi}$ are subtracted from the available hydraulic head h. In the case of a reaction turbine 2 m should be subtracted additionally because there is a height difference between nozzle and tailrace.
- water density = 1000 kg/m^3, gravity acceleration 9.81 m/s^2.

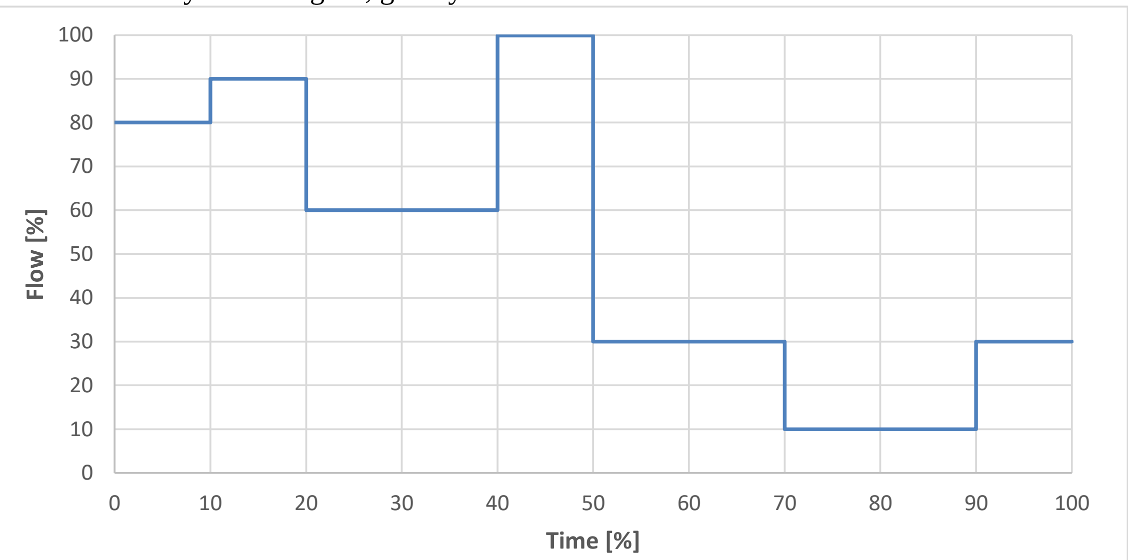

Figure 1: Equivalent annual chronological available stream flow curve

Questions:

(a) Design the available stream flow duration curve. (1.0 marks)

(b) Select the proper hydro-turbines (between Pelton, Kaplan, Francis) for the nominal flow and the nominal net hydraulic head according to Figure 2. (0.5 marks)

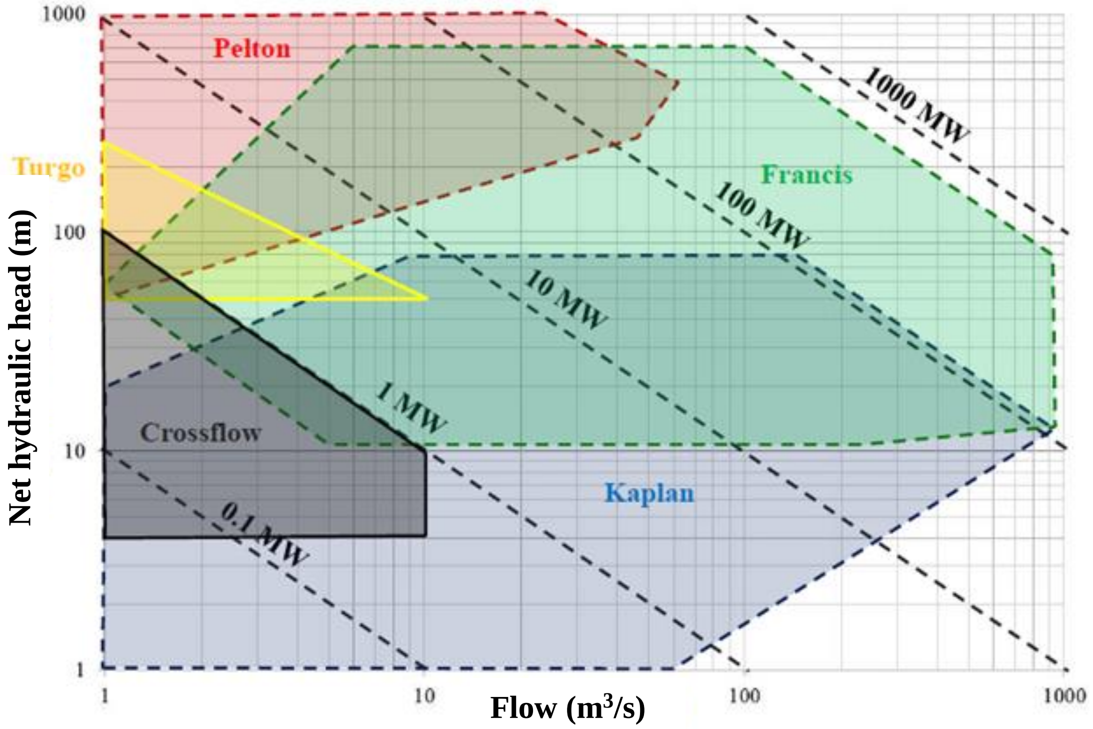

Figure 2: Tubrine pre-selection chart

(c) Calculate for each possible hydro-turbine the annual water volume which is exploited (in m^3) by the small hydro-electric power plant and the energy exploitation degree. (1.0 marks)

(d) Calculate the nominal power of hydro-turbine, the nominal active power and the apparent power of generator, the nominal active power and the apparent power of transformer. (0.5 marks)

(e) Select the category of electrical generator (between direct current, asynchronous and synchronous) according to the apparent nominal power. Select the grid connection (low voltage distribution network, medium voltage distribution network 20 kV, high voltage transmission network 150 kV). The respective answer should be justified. (0.5 marks)

(f) Design the produced active power duration curve by the small hydroelectric power plant with respect to time duration for each possible hydro-turbine, calculate the annual produced energy and the respective capacity factor. (1.0 marks)

<u>Issue 2</u>

The construction of a small hydroelectric plant is examined from the economic point of view. The nominal net hydraulic head is 150 m. The following configurations can be formed:

i. one Francis turbine with nominal power of 8.0 MW and annual produced electric energy of 28 GWh,
ii. two Francis turbines with nominal power of 4.0 MW each one and total annual produced electric energy of 35 GWh,
iii. one Pelton turbine with nominal power of 7.7 MW and annual produced electric energy of 33 GWh.

The electricity market cost are equal to 0.10 €/kWh, the annual expenses is equal to 15% of the annual revenue. The following data are also given:

- the costs of the electromechanical equipment per kW C_{EM1} (including the cost of turbine, generator, governor, transformers, switchboards, etc.) for one Francis turbine is given by $C_{EM1} = 10513 \cdot N^{-0.287} \cdot H^{-0.34}$ in €/kW, where N is the nominal power of the turbine in kW, H the nominal net hydraulic head in m, in a cost range of ±50% with 67% probability.
- the costs of the electromechanical equipment per kW C_{EM1} (including the cost of turbine, generator, governor, transformers, switchboards, etc.) for one Pelton turbine is given by $C_{EM1} = 21597 \cdot N^{-0.364} \cdot H^{-0.10}$ in €/kW, where N is the nominal power of the turbine in kW, H the nominal net hydraulic head in m, in a cost range of ±50% with 67% probability.
- The total cost of the electromechanical equipment C_{EM} (including the installation cost and the commissioning cost) for z similar turbines of nominal power N (each one) is given by: $C_{EM} = 1.15 \cdot C_{EM1} \cdot N \cdot z^{0.95}$.

- The total cost of the investment is given by $C = S \cdot C_{EM} + K_Y$ in €, where S is the position factor (in this case equal to 2.86), K_Y is the cost for supplementary constructions (in this case 200 k€).

(a) Calculate the total investment cost for case (i) and the respective simple payback period (1.0 marks).
(b) Calculate the total investment cost for case (ii) and the respective simple payback period (1.0 marks).
(c) Calculate the total investment cost for case (iii) and the respective simple payback period (1.0 marks).
(d) Select the best solution from the economic point of view and justify your selection (0.5 marks).

Issue 3

(a) Describe the starting process for a small hydro-electric plant with one turbine (1.0 mark)
(b) What is the runaway speed of a hydro-turbine? If it is equal to 2.0 in the case of a Francis turbine and 1.9 in the case of a Pelton turbine, what is the connection with the nominal rotational speed? Can the runaway speed of the turbine affect the generator specifications and how? (1.0 mark)