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Optimization Studies on the Changeable Components of Hydroelectric Power Plants

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Abstract: The design flow rate, the dimensions of the transmission structure and the penstock size have a large impact on the cost of run-of-river type hydroelectric power plants. Equipment costs constitute a large part of the total budget of the plant. Optimum sizing, which maximizes the use of hydraulic potential, does not fit together with optimum sizing, which is necessary to obtain economic benefit from its investment. The main design parameters can be selected with the help of an optimization study in terms of both economic benefit and hydraulic potential. In this study, an easy to implement model, aimed at determining the costs associated with the different components in the structural organization of a hydroelectric power plant, is developed by a feasibility study to overcome the difficulties in practice. Gokcekoy HEPP, built in Turkey, was selected as the system. Annual energy production values were calculated by taking into account the current energy market conditions in Turkey. In addition, real situation studies were carried out regarding design flow rate selection, forced pipe diameter optimization and transmission channel sizing.

Key words: Hydroelectric power plants, optimization, investment cost, changeable components.

Hidroelektrik Santrallerin Değişken Bileşenleri Üzerine Optimizasyon Çalışmaları

Öz: Nehir tipi hidroelektirik santrallerin maliyeti üzerinde tasarım debisi, iletim kanalı ve tünelin boyutları ile cebri boru boyutunun büyük bir etkisi vardır. Ekipman maliyetleri santralin toplam bütçesinin büyük bir kısmını oluşturmaktadır. Yatırımından ekonomik faydanın elde edilmesi için gerekli olan optimum boyutlandırma ile hidrolik potansiyelin kullanımını en üst düzeye çıkaran optimum boyutlandırma birbirine uymamaktadır. Ana tasarım parametreleri hem ekonomik fayda hem de hidrolik potansiyel açısından bir optimizasyon çalışması yardımıyla seçilebilir. Bu çalışmada, ortaya çıkan zorluğu gidermek için, hidroelektrik santrali üzerindeki ekonomik bir uygulanabilirlik çalışmasıyla, bir hidroelektrik santralinin yapısal organizasyonunda yer alan farklı unsurların maliyetinin belirlenmesi için kullanımı kolay bir yaklaşım geliştirilmiştir. Ayrıca tasarım debisi şeçimi, cebri boru çap optimizasyonu ve iletim kanalı boyutlandırılmasına ait durum çalışmaları yapılmıştır.

Anahtar kelimeler: Hidroelektrik santraller, optimizasyon, yatırım maliyeti, değişken bileşenler

1.Introductıon

Hydroelectric energy is a renewable energy source which is relatively inexpensive, reliable, sustainable and that can be produced without toxic waste and with greenhouse gas emissions that are significantly lower than fossil fuel energy plants [1-6]. The world's technically feasible hydropotential is 14,370 TWh / year. This value is almost equal to our global electricity demand. [7,8]. According to the report published by the International Hydroelectric Association in 2019 [9]; In 2018, it was stated that approximately 22 GW installed capacity was added to the hydroelectric projects worldwide and thus the total capacity increased to 1292 GW. In the same report, it was stated that the electricity generated from hydroelectric power plants in 2018 was approximately 4,200 terawatt hours (TWh) [9]. Figure 1 shows that the installed capacity of hydroelectric power plants increases day by day in the world.

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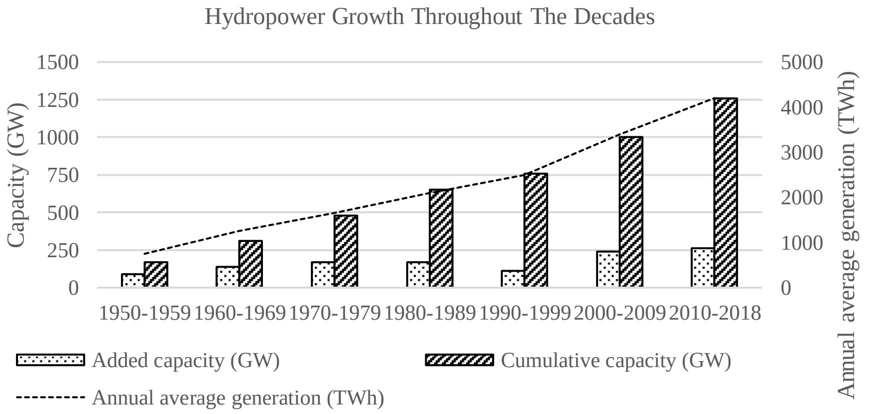

Figure 1. Change of the installed power of hydroelectric power plant in the world by years, adapted from [9]

A good economic analysis is necessary for the energy resource with such great potential to the benefit of the national economy. The decision to develop a hydroelectric project is made for economic reasons. However, factors such as environmental, cultural and physical features of the region and the costs and availability of technological and engineering solutions should be thoroughly examined. Initial investment costs of hydroelectric power plant installation are quite high. In contrast, operational and maintenance costs are low. This means that most of the overall budget of the project will be spent during the development phase. In relation to that it is important to balance the installation costs with the amount and speed and the energy outcome to assess if the project is worth to realize and, if the answer is yes, to plan the next budget. The applicability of each hydroelectric project is site-specific and depends on local characteristics. The amount of power generated depends on the water flow, the hydraulic head and the efficiency of the electromechanical equipment.

The maximum electrity that a river basin can produce technologically is defined as a hydroelectric potential. Losses are excluded when determining the hydroelectric potential. The economic potential of a river basin is defined as annual energy that can be developed at competitive costs compared to other energy sources. The economic potential shows the economic optimization of electricity production of a river basin [7,10-12].

Optimization of run-of-river hydroelectric power plant design has been investigated in various studies. Topics covered in these research are:

(I) Determination of optimum plant capacities of power plants [13-26].
(II) Development of special equations that adequately represent the economic performance and power generation of power plants [18, 22, 27-35]
(III) Determination of effective optimization that can be solved quickly for optimum plant design [18, 19, 21-24, 26, 36-40]
(IV) Determination of the effect of flow processes total productivity of the power plant [41-68]
(V) Investigation of the design and performance of turbines [6, 53, 69-76] .

The purpose of this study is to optimize variable components to maximize the generated energy and to minimize the initial investment cost of a hydroelectric project. In scope of this study, an easy-to-use approach was developed to determine the cost of different elements of the structural organization of a hydroelectric power plant and to determine its impact on the total cost. In this context, a real case study was carried out using hydrological and economic data of Gökçeköy HEPP project built in Turkey. The results of this study are not only theoretical but can be used by applying the local unit costs of that region to a hydroelectric power plant to be built anywhere in the world. In addition, the results of this study will not be only theoretical, in contrary to some studies in the literature, but will provide the advantage of being used in real practice.

2. Optimization Methodology

The primary objective in the optimization study is to determine the appropriate plant conformation that minimizes or maximizes the value of some operation or economic parameters [23]. The purpose of this article is to develop an optimization to achieve maximum power in return for minimum capital investment. The layout of a typical run-of-river project that has been considered is as shown in Figure 2.

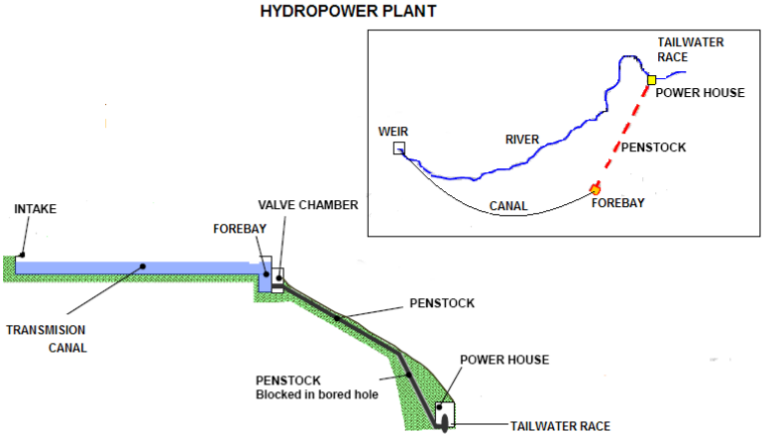

Fig. 2. General scheme of a hydropower plant.

2.1 Important parameters in the optimization study

The design flow rate, the dimensions of the transmission canal or tunnel and the penstock dimension are the three most important optimization parameters on the cost of river-type hydroelectric power plants. The design flow rate affects both energy and power capacity. For this reason, hydroelectric plants have a significant impact on the cost. A reduced design flow rate leads to reduced power capacity and initial investment cost. The percentage of decrease in installed power is almost identical to the percentage of decrease in the design flow rate. However, the percentage of increase in the cost-benefit ratio is not as significant as the decrease in power capacity. Consequently, a too small the design flow rate prevents the optimal utilization of hydroelectric potential, on the other hand a too high the design flow rate may render the project financially unfeasible.

The second important parameter is the selection of channel types and dimensions, which are also related to the design flow. Canals are usually excavated and follow the contours of the existing land. Increasing channel excavation and dimensions significantly increases the cost rate. The cost of the channel is based on the total volume of rock and soil excavated.

The third important parameter is the penstock. The penstock that carry pressured water are usually made of steel. The penstock of a hydropower project, which serves to transmit water with optimum hydraulic losses to create the head, are included in the optimization study. The cost of penstock depends on the approximate weight of the penstock.

Easily fictionalized, simple-designed and well-worked structures are crucial to minimize costs in terms of optimal design in a hydraulic project.

2.2 Transmission structure optimization

It is necessary to be careful in sizing as the conditions of construction of the channels that will transmit water to hydroelectric plants affect both initial investment costs and operating expenses. When the slope is selected small in this type of transmission channels, the speed decreases and the wet cross-sectional area increases. Thus the channel construction costs increase. However, energy losses are reduced since the load losses occurring along the channel will be low. In open channels, when the slope is selected large, the speed will increase and the wet section area will decrease, so the construction costs will decrease. However, the energy loss will increase as the load loss along the channel will be high. This will increase operating costs. Therefore, there is an optimum channel size and slope in the channels that act as transmission in hydroelectric plants. The aim is to dimension the transmission structure in the most economical way under the most favorable conditions.

2.3 Economic dimensioning

In the most economical section, the construction and operation costs of the channels are asked to be reduced to a minimum. Usually a portion for air is left on top of the water flow line in the canals [77]. In practice, the sizing process is completed by adding an air portion in accordance with the water depth after the channel dimensions are selected according to the most appropriate hydraulic section. With the subsequent addition of air portion, the concept of economic cross-section is eliminated, construction and operation costs increase and deeper channel cross-sections are obtained.

In order to reduce the size of the canal, the flow rate needs to be increased. However, by increasing the flow rate and hence the severing power, erosions will be encountered in the canal inner walls and at the base. For this reason, coatings are used in the canals to prevent the caving in the walls and the base of the canal. Channel coating thickness is selected between 10-25 cm. It is already a structural necessity to coat the transmission channels that carry water to hydroelectric facilities. Because it is not desirable to have any foreign matter in the pressurized water supplied to the turbines by means of penstock, especially in high slope plants.

Generally, the incline of slope is chosen according to the structure of the land. b/h ratio is selected between 3 and 6. It is more suitable to select b/h ratio as 3 for the canal to have a suitable size. This way, z=1 and b/h=3. With the depth h, the base width b, the bevel slope z and the flow cross-section A in the trapezoid canals, the following relation could be provided;

$$A = \frac{h^2}{[b/(h+z)]} \tag{1}$$

$A_{grs} = 4h^2$ is obtained from this relation. With $Q = V.A$ $R = \frac{A}{b + 2h\sqrt{1+z^2}}$, and replacing $A = 4h^2$ and $b = 3h$, then $R = 0,68.h$

Taking the coating thickness e into consideration for the coated canals;

$Q = V.A \longrightarrow A_{net} = 4(h-e)^2$ and $R = 0,68.(h-e)$

Replacing these values in the Manning formula, the following relation is obtained

$$V = k.R^{2/3}J^{1/2}, \longrightarrow J = \frac{v^2}{k^2.[0.68(h-e)]^{4/3}} \tag{2}$$

k: smoothness coefficient, taken as 60 for concrete; e: coating thickness

For the canal cost;

$$M_k = U.e.L.f_b.a.100 \tag{3}$$

M_k : canal cost per meter (USD); $U = b + 2h\sqrt{1+z^2}$ U: wetted perimeter ;f_b :unit price of concrete (USD); The canal cost share per annum;

$$M_i = A_{brt}.L.f_h.a/100 \tag{4}$$

M_i :Canal cost per annum (USD); A_{grs}: gross area (m^2); f_h :Unit price for 1 m^3 of excavation; a: depreciation coefficient; The annual cost of the energy loss due to the slope is;

$$M_e = 8.Q.J.L.T.f_e \tag{5}$$

M_e :cost of energy loss per annum (USD); Q : flow rate (m^3/s)

T : annual number of operation hours of the plant (hr); L: canal length (m); f_e:electricity price (USD/KWH)

Thus the annual cost of the canal is obtained as;

$M = M_i + M_e.$

The total canal cost is then;

$M_t = M_k + M_i + M_e$

Cost studies performed at different flow rates are given in tables below. The cost analyses carried out at different flow rates are provided in the tables below. The annual amount of canal excavation is provided in Table 1, the annual amount of canal concrete coating was provided in Table 2 and the energy losses and the total cost are provided in Table 3. The change in the total canal cost with respect to varying operation flow rates and canal heights are displayed in Figure 2.

Table 1. Amount of canal excavation per annum (k:60, e:0.15)

Q	h	A_{grs}	A_{net}	a/100	f_h	L	M_i
(m^3/s)	(m)	$A_g=4.h^2$	$A_n=4(h-e)^2$	0.08	($/m$^{3)}$	(m)	($)
3	0.9	3.24	2.25	0.08	25.5	5000	33048.00
	1.0	4.00	2.89	0.08	25.5	5000	40800.00
	1.1	4.84	3.61	0.08	25.5	5000	49368.00
	1.2	5.76	4.41	0.08	25.5	5000	58752.00
	1.3	6.76	5.29	0.08	25.5	5000	68952.00
5	0.8	2.56	1.69	0.08	25.5	5000	26112.00
	0.9	3.24	2.25	0.08	25.5	5000	33048.00
	1.0	4.00	2.89	0.08	25.5	5000	40800.00
	1.1	4.84	3.61	0.08	25.5	5000	49368.00
	1.2	5.76	4.41	0.08	25.5	5000	58752.00
	1.3	6.76	5.29	0.08	25.5	5000	68952.00
	1.4	7.84	6.25	0.08	25.5	5000	79968.00
	1.5	9.00	7.29	0.08	25.5	5000	91800.00
7	1.0	4.00	2.89	0.08	25.5	5000	40800.00
	1.1	4.84	3.61	0.08	25.5	5000	49368.00
	1.2	5.76	4.41	0.08	25.5	5000	58752.00
	1.3	6.76	5.29	0.08	25.5	5000	68952.00
	1.4	7.84	6.25	0.08	25.5	5000	79968.00
	1.5	9.00	7.29	0.08	25.5	5000	91800.00
	1.6	10.24	8.41	0.08	25.5	5000	104448.00
10	1.2	5.76	4.41	0.08	25.5	5000	58752.00
	1.3	6.76	5.29	0.08	25.5	5000	68952.00
	1.4	7.84	6.25	0.08	25.5	5000	79968.00
	1.5	9.00	7.29	0.08	25.5	5000	91800.00
	1.6	10.24	8.41	0.08	25.5	5000	104448.00
	1.7	11.56	9.61	0.08	25.5	5000	117912.00
	1.8	12.96	10.89	0.08	25.5	5000	132192.00
15	1.5	9.00	7.29	0.08	25.5	5000	91800.00
	1.6	10.24	8.41	0.08	25.5	5000	104448.00
	1.7	11.56	9.61	0.08	25.5	5000	117912.00
	1.8	12.96	10.89	0.08	25.5	5000	132192.00
	1.9	14.44	12.25	0.08	25.5	5000	147288.00
	2.0	16.00	13.69	0.08	25.5	5000	163200.00
	2.1	17.64	15.21	0.08	25.5	5000	179928.00

Table 2. Amount of canal concrete cost per annum (k:60)

Q	h	e	A_{net}	V	f_b	L	J	M_k
(m^3/s)	(m)	0.15	$A_n=4(h-e)^2$	Q/A_n	(\$/m^3)	(m)	$\frac{v^2}{k^2.[0.68(h-e)]^{4/3}}$	(\$)
3	0.9	0.15	2.25	1.33	66.6	5000	0.001065637	20859.12
	1.0	0.15	2.89	1.04	66.6	5000	0.000546663	23176.80
	1.1	0.15	3.61	0.83	66.6	5000	0.000302072	25494.48
	1.2	0.15	4.41	0.68	66.6	5000	0.000177137	27812.16
	1.3	0.15	5.29	0.57	66.6	5000	0.000109046	30129.84
5	0.8	0.15	1.69	2.96	66.6	5000	0.006349531	18541.44
	0.9	0.15	2.25	2.22	66.6	5000	0.002960103	20859.12
	1.0	0.15	2.89	1.73	66.6	5000	0.001518509	23176.80
	1.1	0.15	3.61	1.39	66.6	5000	0.000839090	25494.48
	1.2	0.15	4.41	1.13	66.6	5000	0.000492046	27812.16
	1.3	0.15	5.29	0.95	66.6	5000	0.000302905	30129.84
	1.4	0.15	6.25	0.80	66.6	5000	0.000194172	32447.52
	1.5	0.15	7.29	0.69	66.6	5000	0.000128807	34765.20
7	1.0	0.15	2.89	2.42	66.6	5000	0.002976278	23176.80
	1.1	0.15	3.61	1.94	66.6	5000	0.001644617	25494.48
	1.2	0.15	4.41	1.59	66.6	5000	0.000964411	27812.16
	1.3	0.15	5.29	1.32	66.6	5000	0.000593695	30129.84
	1.4	0.15	6.25	1.12	66.6	5000	0.000380578	32447.52
	1.5	0.15	7.29	0.96	66.6	5000	0.000252461	34765.20
	1.6	0.15	8.41	0.83	66.6	5000	0.000172460	37082.88
10	1.2	0.15	4.41	2.27	66.6	5000	0.001968186	27812.16
	1.3	0.15	5.29	1.89	66.6	5000	0.001211622	30129.84
	1.4	0.15	6.25	1.60	66.6	5000	0.000776690	32447.52
	1.5	0.15	7.29	1.37	66.6	5000	0.000515227	34765.20
	1.6	0.15	8.41	1.19	66.6	5000	0.000351960	37082.88
	1.7	0.15	9.61	1.04	66.6	5000	0.000246621	39400.56
	1.8	0.15	10.89	0.92	66.6	5000	0.000176696	41718.24
15	1.5	0.15	7.29	2.06	66.6	5000	0.001159261	34765.20
	1.6	0.15	8.41	1.78	66.6	5000	0.000791910	37082.88
	1.7	0.15	9.61	1.56	66.6	5000	0.000554897	39400.56
	1.8	0.15	10.89	1.38	66.6	5000	0.000397566	41718.24
	1.9	0.15	12.25	1.22	66.6	5000	0.000290489	44035.92
	2.0	0.15	13.69	1.10	66.6	5000	0.000215985	46353.60
	2.1	0.15	15.21	0.99	66.6	5000	0.000163116	48671.28

Table 3. Canal energy loss and total cost analysis

Q	h	T	V	f_e	L	J	M_e	M_t
(m³/s)	(m)	(hours)	Q/A_n	$/kwh	(m)	$\boxed{\dfrac{v^2}{k^2[0.68(h-e)]^{4/3}}}$	($)	($)
3	0.9	2500	1.33	0.04	5000	0.001065637	12787.65	67833.30
	1.0	2500	1.04	0.04	5000	0.000546663	6559.96	71680.20
	1.1	2500	0.83	0.04	5000	0.000302072	3624.87	79611.37
	1.2	2500	0.68	0.04	5000	0.000177137	2125.64	89770.09
	1.3	2500	0.57	0.04	5000	0.000109046	1308.55	101402.62
5	0.8	2500	2.96	0.04	5000	0.006349531	126990.63	172753.38
	0.9	2500	2.22	0.04	5000	0.002960103	59202.07	114247.73
	1.0	2500	1.73	0.04	5000	0.001518509	30370.19	95490.43
	1.1	2500	1.39	0.04	5000	0.000839090	16781.80	92768.31
	1.2	2500	1.13	0.04	5000	0.000492046	9840.93	97485.38
	1.3	2500	0.95	0.04	5000	0.000302905	6058.11	106152.18
	1.4	2500	0.80	0.04	5000	0.000194172	3883.45	117218.82
	1.5	2500	0.69	0.04	5000	0.000128807	2576.14	129944.50
7	1.0	2500	2.42	0.04	5000	0.002976278	83335.80	148456.04
	1.1	2500	1.94	0.04	5000	0.001644617	46049.27	122035.77
	1.2	2500	1.59	0.04	5000	0.000964411	27003.51	114647.96
	1.3	2500	1.32	0.04	5000	0.000593695	16623.45	116717.52
	1.4	2500	1.12	0.04	5000	0.000380578	10656.18	123991.56
	1.5	2500	0.96	0.04	5000	0.000252461	7068.91	134437.27
	1.6	2500	0.83	0.04	5000	0.000172460	4828.89	147021.91
10	1.2	2500	2.27	0.04	5000	0.001968186	78727.43	166371.88
	1.3	2500	1.89	0.04	5000	0.001211622	48464.87	148558.94
	1.4	2500	1.60	0.04	5000	0.000776690	31067.59	144402.96
	1.5	2500	1.37	0.04	5000	0.000515227	20609.08	147977.44
	1.6	2500	1.19	0.04	5000	0.000351960	14078.39	156271.42
	1.7	2500	1.04	0.04	5000	0.000246621	9864.83	167674.20
	1.8	2500	0.92	0.04	5000	0.000176696	7067.84	181285.23
15	1.5	2500	2.06	0.04	5000	0.001159261	69555.65	209195.05
	1.6	2500	1.78	0.04	5000	0.000791910	47514.57	189707.60
	1.7	2500	1.56	0.04	5000	0.000554897	33293.80	191103.17
	1.8	2500	1.38	0.04	5000	0.000397566	23853.96	198071.35
	1.9	2500	1.22	0.04	5000	0.000290489	17429.32	208846.42
	2.0	2500	1.10	0.04	5000	0.000215985	12959.12	222367.60
	2.1	2500	0.99	0.04	5000	0.000163116	9786.96	237978.50

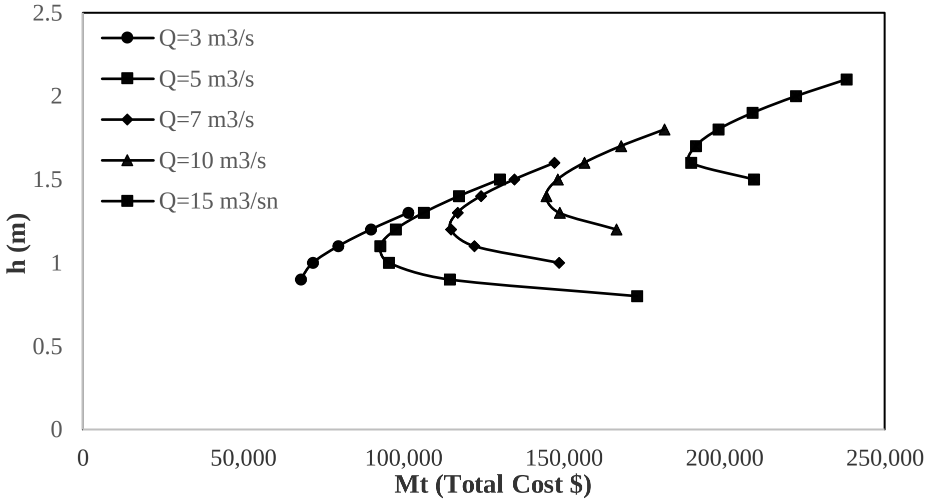

Figure 2. Variation in the canal total cost

2.4 Penstock optimization

Penstock costs account for approximately 1/3 of the total installation cost of hydroelectric plants. This structure, which is one of the most expensive items, should be chosen carefully. Penstcok optimization should minimize the total cost by taking into account the costs incurred due to load losses. In practice the estimate of an associated cost of the head losses involves predicting both an interest rate and the project life that allows the expected cash flows to be converted to a present worth.

For the best power in the Penstock design, it is necessary to determine a suitable penstock slope and determine the maximum power per unit length. To offer an economic solution, head loss flow rate and site slope must be considered. the penstock length will increase as the slope decreases. Accordingly, head losses will increase. Thus, a larger gross head would be required to provide the same power from the power plant. If penstock is selected on a small diameter, a system that is cheap but has more load losses will be installed. In addition, if penstock is selected on a large diameter, a system that is expensive but has less load losses will be installed. Penstock price typically varies directly proportionally to the length and to the second power of the diameter. For this reason, a good optimization is required. A case study for Penstock optimization is given in Table 4 and Figure 3.

Table 4. Optimization of the penstock

Diameter D	**Friction loss**	**Net Head**	**Velocity**	**Overpres-sure**	**Wall thickness**	**Concrete cover**	**Min.Wall thickness**	**Avarage wall thickness**	**Cost**	**Annual cost**	**Lost energy friction**	**Balance sheet of the annual energy loss**	**Total annual cost**
(m)	(m)	(m)	(m/s)	(m)	(mm)	(mm)	(mm)	(mm)	($)	($)	(kWh)	($)	($)
1	11.82	88.18	10.19	97.35	8.95	2.00	6.50	8.72	343067.1	37737.4	6437743.6	386264.6	424002.0
1.2	4.47	95.53	7.07	67.60	9.78	2.00	7.00	9.39	443348.3	48768.3	2434634.1	146078.0	194846.4
1.4	1.96	98.04	5.20	49.67	10.64	2.00	7.50	10.07	554185.3	60960.4	1070000.9	64200.1	125160.4
1.5	1.36	98.64	4.53	43.26	11.08	2.00	7.75	10.42	613562.3	67491.9	740594.2	44435.7	111927.5
1.6	0.96	99.04	3.98	38.03	11.55	2.00	8.00	10.77	675578.3	74313.6	524920.8	31495.2	105808.9
1.7	**0.70**	**99.30**	**3.52**	**33.68**	**12.02**	**2.00**	**8.25**	**11.14**	**740233.3**	**81425.7**	**379903.0**	**22794.2**	**104219.8**
1.8	0.51	99.49	3.14	30.04	12.51	2.00	8.50	11.50	807527.2	88828.0	280078.9	16804.7	105632.7
1.9	0.39	99.61	2.82	26.97	13.00	2.00	8.75	11.88	877460.1	96520.6	209917.1	12595.0	109115.6
2	0.29	99.71	2.55	24.34	13.50	2.00	9.00	12.25	950032.0	104503.5	159676.3	9580.6	114084.1

Effective discharge= 4.50 m^3/s
Design flow= 9.50 m^3/s
The length of penstock= 375 m
Gross head= 100 m

Note= Effective discharge were taken into account.of the friction calculation.
g= 9.81 m/s
T_c= 8 sec
σ_y= 1.4 kg/cm^2

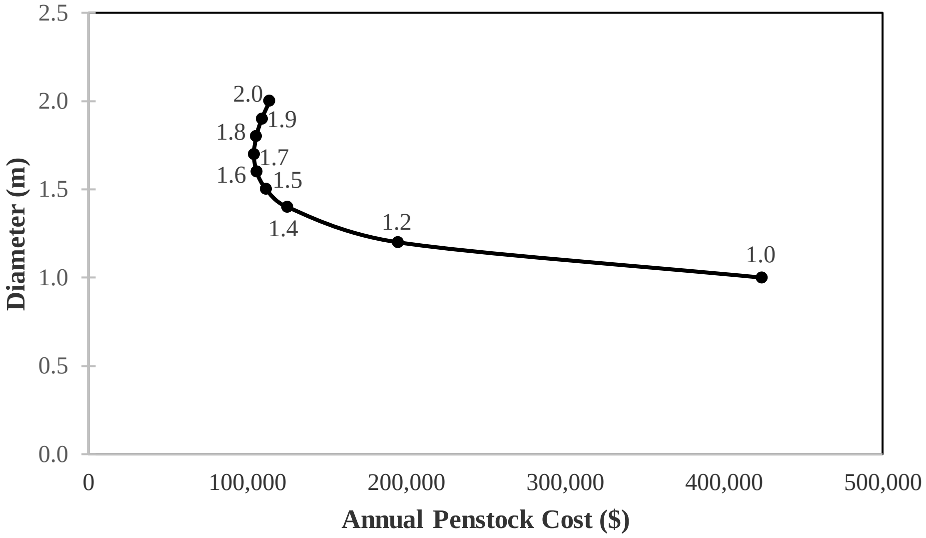

Figure 3. Change in Diameter versus Annual Cost

2.5 Design flow rate and installed power optimization

Operation works have been repeated based on the selected discharge values for energy optimization, and the discharge value which has made the utilization ratio 95% which has been calculated as firm. In order to dimension such hydroelectric power plants in the world in a healthy way, the flow rate values of at least 25 years should be known in hourly periods on the stream where the power plant will be built. Because rivers have irregular flow regimes depending on the climatic conditions of the countries. When the distribution of hourly flow rate values measured by 25-year period is made according to months, the flow rate which is present in the river at 95% of the all time is taken as the design flow rate. The ratio of time in this design flow rate can be selected in desired amount considering the development status of the countries and other economic reasons. The energy generated by this flow rate is taken into account as firm energy. Following this stage, for the optimization of power, the optimum discharge has been determined by taking into account the project values of various plants that would have been effective in the cost of power structures depending on the selected discharges. Based on this design discharge, the transmission canal dimensions, the penstock diameter and the power central size have been selected; and based on these data, the net heads have been determined from the hydraulics calculations. Together with the net head corresponding to each of the selected discharges, the installed power and the annual production have been calculated. The operational works have been carried out based on the 7.00, 7.25, 7.50, 7.75, 8.00, 8.25, 8.50, 8.75, 9.00, 9.25, 9.50, 9.75, 10.00, 10.25, 10.50, 10.75, and 11.00 m^3/s discharges values. The total cost, the annual income and the annual expense rates pertaining to each discharge and installed power have been specified. Then, the profitability and marginal profitability calculations have been done, and the optional system whose marginal profitability is closest to 1, and which has a design discharge of 9.50 m^3/s has produced the best outcome. The calculation details are given in Table 5 and Figure 4.

Table 5. Power Optimization

Q (m^3/s)	**Hnet (m)**	**Installed power (kW)**	**Produced energy-firm (GWh/year)**	**Produced energy-seconder (GWh/year)**	**The annual energy produced (GWh/year)**	**Annual income ($)**	**Total cost ($)**	**Annual expense ($)**	**Annual net income ($)**	**Income / expenditure**	**The difference comes ($)**	**The difference expense ($)**	**Marginal profitability**
7.00	95.67	5.928	37.14	10.76	47.91	2.583.930	18.903.334	1.670.944	**912.986**	1.546	377.700	82.028	4.605
7.25	95.70	6.141	37.17	11.52	48.69	2.610.253	18.993.523	1.681.122	**929.131**	1.553	26.323	10.178	2.586
7.50	95.73	6.355	37.19	12.20	49.38	2.633.782	19.083.530	1.691.285	**942.497**	1.557	23.529	10.163	2.315
7.75	95.76	6.569	37.21	12.80	50.01	2.654.925	19.173.364	1.701.433	**953.492**	1.560	21.143	10.148	2.083
8.00	95.78	6.782	37.22	13.34	50.57	2.673.664	19.263.035	1.711.567	**962.097**	1.562	18.739	10.134	1.849
8.25	95.81	6.996	37.24	13.82	51.06	2.690.440	19.352.549	1.721.688	**968.752**	1.563	16.775	10.121	1.657
8.50	95.83	7.210	37.25	14.26	51.51	2.705.613	19.441.914	1.731.796	**973.816**	1.562	15.173	10.108	1.501
8.75	95.85	7.424	37.26	14.66	51.92	2.719.443	19.531.137	1.741.893	**977.550**	1.561	13.830	10.096	1.370
9.00	95.87	7.637	37.27	15.03	52.30	2.732.183	19.620.224	1.751.977	**980.206**	1.559	12.741	10.085	1.263
9.25	95.89	7.851	37.28	15.37	52.65	2.743.928	19.709.180	1.762.051	**981.877**	1.557	11.744	10.074	1.166
9.50	**95.91**	**8.065**	**37.29**	**15.68**	**52.97**	**2.754.777**	**19.798.012**	**1.772.114**	982.663	**1.555**	**10.850**	**10.063**	**1.078**
9.75	95.93	8.279	37.30	15.97	53.26	2.764.724	19.886.723	1.782.167	**982.557**	1.551	9.947	10.053	0.989
10.00	95.95	8.493	37.30	16.23	53.54	2.773.979	19.975.320	1.792.210	**981.769**	1.548	9.255	10.043	0.922
10.25	95.97	8.707	37.31	16.48	53.79	2.782.603	20.063.805	1.802.244	**980.360**	1.544	8.625	10.034	0.860
10.50	95.98	8.921	37.32	16.72	54.03	2.790.624	20.152.184	1.812.268	**978.356**	1.540	8.021	10.025	0.800
10.75	96.00	9.134	37.32	16.93	54.25	2.798.042	20.240.460	1.822.284	**975.757**	1.535	7.417	10.016	0.741
11.00	96.01	9.348	37.33	17.13	54.46	2.804.885	20.328.637	1.832.292	**972.593**	1.531	6.843	10.008	0.684

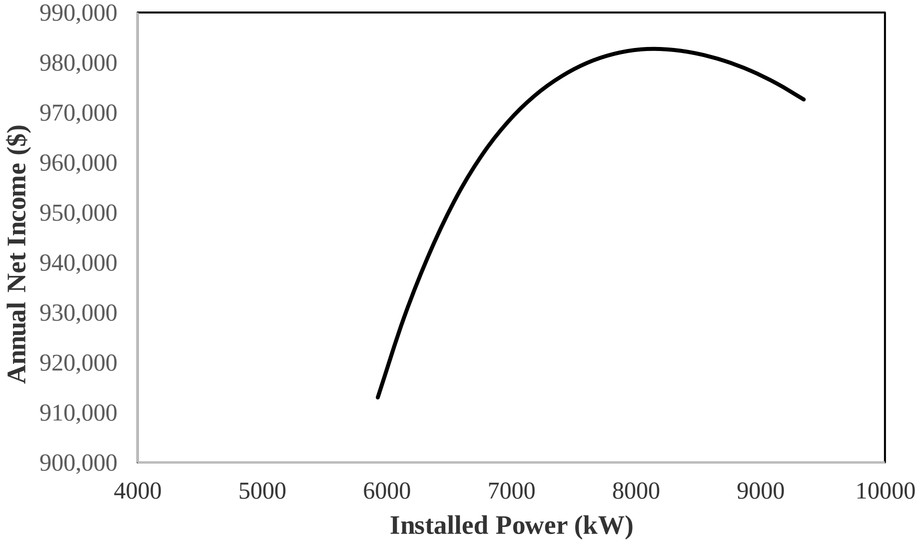

Figure 4. HEPP installed power optimization curve

3. Conclusions

In hydroelectric projects, maximum energy with minimum cost producing is the primary goal. Within the context of the present paper we have developed an easy to use approach for the definition of the cost of different parameters which take part in the structural organization of a hydropower plant. Approaches which have been developed for the cost analysis of different elements are based on a series of unitary prices which can be applied to its corresponding counterparts in any country, so that its use is not limited to any particular place.

It is crucial for the design personnel to thoroughly consider each and every pant component individually since the optimization of the replaceable elements in the hydropower plant projects significantly affects the operational costs. We can specifically conclude the following for the selection of the design flow rate, canal and the penstock optimization;

The maximum flow rate used by the turbine is the design flow. For run-of river projects, the design flow rate depends on the current flow in the field and is generally close to the flow rate that is equaled or exceeded about 30% of the time

In the event of the selection of the design flow rate to be less than that value, the flow potential of the river is not completely utilized and the profitability of the project has been decreased. In the event of the selection of the design flow rate to be less than that value, the size of the transmission structure (canal) gets larger, the penstock diameter increases and the turbine capital costs increase. In the calculations that have been carried out in this study, the maximum utility principles have been considered in hydropower plants while performing the analysis. In order to make a financially correct investment, it is necessary to consider at the design flow determination of hydroelectric power plants together not only hydrological data but also economic data.

The determination of suitable canal sizing is the most significant element in the planning and design of the canals. Parameters such as the type of the canal coating, the maximum speed at which siltation is prevented, the canal base slope, the maximum speed at which erosions would be prevented, the bevel slope and the air portion would be considered in the determination of the optimum cross-section during that process. In conclusion, it can be deduced that;

- As the canal slope increased, the capital investment costs would decrease due to the increased flow rates and decreased cross-sections. However, the operational costs would increase as a result of the increased flow rates and increased loss in load.
- As the slope increased, in addition to increases in the operational costs, the capital investment costs were decreased. Therefore, a suitable h_{opt} value existed for each flow rate.
- Increased canal height to obtain the most suitable hydraulic cross-section also increased the costs.

In order for an open canal project to be economically feasible, the topographical conditions, the equivalence of the fill-cleave amounts along the canal excavation path, the duration of construction and the most suitable and economical cross-section need to be determined in addition to the above mentioned criteria. The open canals should be built as less steep terrain as possible and steep slopes with a risk of land slip should be prevented. Canal constructions in cleavages should be preferred over the canals in the fills since they are cheap, secure and safe in terms of water leakage. The shape and the project of the canal should be constructed as much suitable for obtaining the aimed conditions minimizing the capital investment costs and the operational costs.

The penstocks, which are among the most significant components of hydroelectric power plants, also constitute a significant portion of the plant costs. Especially the optimization of the penstock diameter is very important. Selection of the diameter to be lower than the optimum value decreases the cross section and the capital investment costs, however, as a result of the increase in the flow rate of water in the canal, the friction and energy losses would increase and the energy capacity of the plant would decrease. In the case of the selection of the diameter to be larger than the optimum value, the cross-section would increase and the frictional losses would decrease, however the capital investment costs would increase. Because of this reason, there is an optimum value between the design flow rate and the penstock diameter and this optimum value, maximizing the net profit, was aimed to be determined in this study. Additionally, the route that the penstock follows is also important. Especially the geological analyses should be thoroughly carried out. The penstock should never be constructed in an area where land slips occur, along the slope back fills, in clay or similarly weak soil lands. Usually, mountain ridges pointed by the topography would be firm grounds. If firm grounds could not be identified, shaft or tunnel systems should be preferred. Penstocks should take the shortest path to the plant. Increasing the length of the penstock increases both the cost and the high slope losses. High lope losses mean energy losses. The path should be selected to have minimum bends and turns with the least amount of excavation and the curve locations should be selected to be on rocks or very firm grounds. Penstocks may be constructed as single or multiple structures. This is determined as a result of the feasibility computations. Although a single penstock appears to be more feasible, care should be taken when selecting large diameter penstocks. Penstocks that have been designed taking into consideration all of these factors would increase the profitability of the hydroelectric power plant.

The results of this study enable performing the optimizations for the maximization of the delivered energy and the minimization of the initial investment cost of a hydropower project within a short duration of time, without a detailed study. For run off river type of projects, a prefeasibility report can be obtained in a short while in comparison to the conventional feasibility studies. Moreover, the developed method can be edited all the time by changing some variables and thus different alternatives can be compared easily without extensive calculation which is really helpful for the designers.

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