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Determination of the optimal installation capacity of small hydro-power plants through the use of technical, economic and reliability indices

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Abstract

One of the most important issues in planning Small Hydro-Power Plants (SHPPs) of the "run-off river" type is to determine the optimal installation capacity of the SHPP and estimate its optimal annual energy value. In this paper, a method to calculate the annual energy is presented, as is the program developed using Excel software. This program analyzes and estimates the most important economic indices of an SHPP using the sensitivity analysis method. Another program, developed by Matlab software, calculates the reliability indices for a number of units of an SHPP with a specified load duration curve using the Monte Carlo method. Ultimately, comparing the technical, economic and reliability indices will determine the optimal installation capacity of an SHPP. By applying the above-mentioned algorithm to a sample SHPP named "Nari" (located in the northern part of Iran), the optimal capacity of 3.75 MW is obtained.

Keywords: Installation capacity; Small Hydro-Power Plant (SHPP); Economic analysis; Monte Carlo method

1. Introduction

Small Hydro-Power Plants (SHPPs) have found special importance due to their relatively low administrative and executive costs, and a short construction time compared to large power plants. These SHPPs are in the "run-off river" category because their generated capacity is based on the deviated water flow of river run-off and consists of a diversion dam, conveyance of water system, headpond, forebay, penstock, power house, and tailrace structure of the body of the SHPP as well as other electrical and mechanical equipment (see Fig. 1). The deviated flow of a river reaches the forebay after running in a path to the diverted point, and then enters into the SHPP structure via penstock pipes. Daily regulation of the water volume in the headpond is used to get maximum power from the SHPP during peak hours. The amount of energy generated during different daily hours and/or different seasons of the year are the most important issues worthy of study in the run-off river SHPP studies. In other words, calculating the optimal installation capacity (optimal designed flow) is one of the most important factors in planning SHPPs.

2. Determination of the optimal installation capacity

To determine the optimal installation capacity of SHPPs all technical, economic and reliability indices are considered in a trade-off relation. Using this approach, the amount of annual energy is determined by using categorized statistics of the flow duration curve in different months. Then, after specifying the income and costs of the plant, the economic indices of different alternatives are extracted. The reliability indices are then calculated and ultimately, through comparison of the technical, economic and reliability indices, a superior alternative can be selected, determining the optimal installation capacity. This method of calculating the technical, economic and reliability indices and the subsequent processes used in the planning of an SHPP will be further discussed and described.

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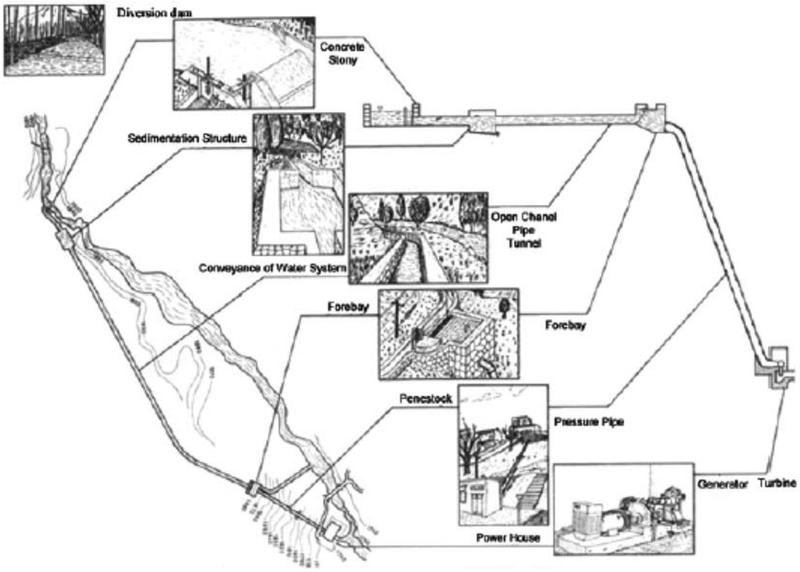

Fig. 1. Schematic diagram of a typical small hydro-power plant.

2.1. Method of energy calculation

After determining the downstream water flow and environmental needs and rights, the energy calculation is done with respect to the water flow categorized data of the river. To estimate the generated energy, a range of flow rate is specified based on a level of adjustment. Then, based on the daily and/or monthly statistics of the flow duration curve and the water flow with different probability percentages (e.g., 20%, 30%, 40%, 50%, 60% and 70%), the monthly optimally generated energy is calculated. The amount of optimal annual energy generated is obtained by determining the sum of the monthly energies. It should be noted that in these calculations, different sizes of headponds are also involved. The locations of projects and river water flow are constrained by the availability of established headponds whose size is an important determining factor.

In addition, with respect to the by-laws of the Ministry of Energy regarding energy purchases, energy generation must be divided into three different types: peak load (4 h a day), normal load (12 h a day) and low load (8 h a day). The high value of energy is categorized based on the peak, normal and low loads, respectively, so the planner can choose different alternatives with the highest energy generation relative to the load. While coordinating between energy in peak and base states, the technical indices such as the plant factor of an SHPP should be within a reasonable and acceptable limit. With respect to the role of an SHPP in the load power system network, the recommended index size with a headpond should be a figure between 30% and 45%, and without a headpond, a figure between 45% and 60% (Energy Ministry of China, 1990).

2.2. Economic calculation method

In this section, the method of evaluation of income and costs and ultimately, the economic analysis of SHPPs are described (Hosseini and Forouzbakhsh, 2003). The costs of the project are divided into two categories: investment and annual costs. Investment costs include civil costs, electro-mechanical equipment, power transmission line, and other indirect costs. Annual costs include the depreciation of equipment, operating and maintenance, and replacement costs. The income of the project is based solely on the sale of electrical energy.

2.2.1. Investment costs

Civil costs consist of the construction and hydro-structural costs of the project, including a dam, conveyance of water system, the water penstock structure, a headpond, the forebay, the power house, the tailrace structure, the access road and any future unpredicted costs taken from the preliminary designs of a feasibility study.

Electro mechanical equipment costs include turbines, generators, governors, gates, control systems, a power substation, electrical and mechanical auxiliary equipment, etc. With respect to the nature of SHPPs (lower than 5 MW), the costs are evaluated to be approximately US\$500/kW of power installation. Note that the control system is assumed to be manual, and the costs of using remote control would naturally be higher (Hosseini and Forouzbakhsh, 2003; Aab-niroo Co, Studies Management Office, 2003).

Power transmission line costs include a power transmission line for delivering generated energy from power plant to power transmission network. The transmission line cost depends on the location, type of existing system (overhead line or cable system), and capacity of SHPP as well as length of transmission lines, which have a very high affect on project costs.

Indirect costs include Engineering and Design (E&D), Supervision and Administration (S&A) and inflation costs during the construction period.

E&D costs: These costs are affected by many parameters, such as type, size and the location where the project is being constructed. The E&D costs are usually expressed as a percentage of construction costs, including civil and equipment costs, and the amount of this percent differs from one location to another. Recently, a case study on these SHPPs has shown that this figure could range from 5% for small and medium sized projects, to 8%, for very large sized projects (Hosseini and Bathaei, 2001; Department of the Army, 1985).

S&A costs: These costs include the purchase of land, management, inspection and supervision costs, and other miscellaneous costs in the region. Similar to the E&D costs, the S&A costs are expressed as a percentage of the construction costs. A recent case study on SHPPs has shown that this figure could be anywhere from 4% to 7% (Hosseini and Bathaei, 2001; Department of the Army, 1985).

Inflation costs during construction: To precisely calculate the investment cost of a project, it is necessary to take into consideration the inflation rate during the course of the project and adjust the investment cost with respect to the inflation rate. The inflation rate of future years should be determined by obtaining the average of previous years' inflation rate.

2.2.2. Annual costs

To obtain the net benefit of a project, annual costs, in addition to investment costs should be calculated. Annual costs include depreciation of equipment, Operating and Maintenance (O&M), and replacement and renovation costs.

Depreciation of equipment: In the economic analysis of the project, depreciation and other factors affecting the equipment should be considered.

O&M costs: include salary/wages of personnel, labor, insurance, tax, duties, landscape, and consumable materials. These costs are increased only by the annual inflation coefficient. A 5% inflation rate is used in the economic calculations. The costs which are related to the salary/wage and consumable materials make up one percent of annual investment costs, and insurance, tax, duties, charges and unpredicted cases are also taken as one percent of annual investment costs. It should be noted that to calculate investment costs, the interest rate during construction should also be considered (Energy Ministry of China, 1990; Department of the Army, 1985; International Atomic Energy Agency, 1984).

Replacement and renovation costs: The main parts of the SHPP, such as generator windings, turbine runners and other parts will eventually need replacement and renovation. With respect to the nature of these SHPPs, the costs of renovation and reconstruction of equipment at year 25 is taken to be approximately equal to the total value of equipment at time of purchase. To estimate the costs for large and medium sized power plants, the percentage of wear should be determined for different sections separately so that the calculation of these costs can be done in a more precise way (Hosseini and Forouzbakhsh, 2003; Aab-niroo Co, Studies Management Office, 2003).

2.2.3. Income & benefits

There are two benefits for the SHPPs: (1) tangible benefits and (2) intangible benefits. The tangible benefit is the sale of electrical energy. Based on approval by Iranian regulators, the purchase of electrical energy from SHPPs has been guaranteed by the Ministry of Energy. Based on this approval, the purchase will be done from four sectors: (1) the governmental sector without transmission lines; (2) the governmental sector with transmission lines; (3) the private sector without transmission lines; and (4) the private sector with transmission lines. In each, the electrical energy purchasing rates are being provided in different months of the year based on the peak load (4 h a day), normal load (12 h a day) and low load (8 h a day). Meanwhile, for the private sector, different purchase rates are being presented with four options, namely, 100%, 75%, 50% and 25% of private investment. Due to peak hours of energy consumption, the purchasing rate would be more attractive for the producer of energy. The annual inflation-purchasing rate is being considered to be 5% in the calculation. The intangible benefits cover the positive environmental effects, flood control, agriculture and irrigation, fish farm pools, camps and recreation centers, etc. which eventually turn into quantitative values. The intangible benefits are not included in this economic analysis of the project, but naturally a more desirable result will be obtained for the economic indices when taking these factors into account (Aab-niroo Co, Studies Management Office, 2003).

2.2.4. Financial and time specifications and methods of capital distribution

Capital depreciation period for construction costs: 50 years.

Table 1
Distribution of costs versus construction years

Construction years	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	6 (%)
1	100	—	—	—	—	—
2	77	23	—	—	—	—
3	37	56	7	—	—	—
4	16	62	18	4	—	—
5	9	49	30	9	3	—
6	6	31	40	15	6	2

Replacement and renovation of electro-mechanical equipment: 25 years.
Duration of construction: 3 years.
Annual interest rate: 10%.
Annual inflation rate: 5%.

Table 1 shows the capital distribution during the investment period. This table presents construction time from 1 to 6 years (Hosseini and Bathaei, 2001; Aab-niroo Co, Studies Management Office, 2003). In this table, the construction costs are expensed in the relevant subsequent years. Thus, with the effects of interest and inflation, the costs of the subsequent years can be predicted. Social and economic factors could also be included in this calculation. When execution activities begin, the annual payments should be expensed in the midyear, in order to lessen the effect of inflation, thus lowering the investment value. For example, according to Table 1, for a 3-year construction project, the percentage of the cost in each year are as following: 37% of capital in the middle of the first year, 56% in the middle of the second year and 7% in the middle of the third year.

2.3. Reliability calculations

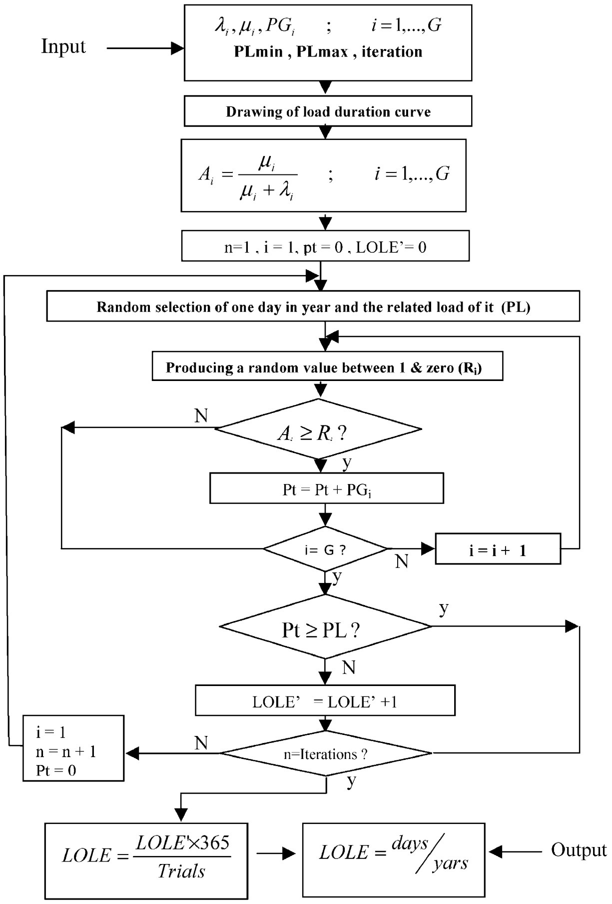

Fig. 2. The LOLE calculation algorithm, using the Monte Carlo method.

The reliability index of Loss of Load Expectation (LOLE) is calculated by using the Monte Carlo method (Billinton and Allan, 1987, 1996). The Monte Carlo algorithm is one of the strongest engineering tools that enables us to perform a statistical analysis of the uncertainties involved in engineering problems. This method is very applicable in solving complicated problems where many random variables are involved in non-linear equations. The Monte Carlo analysis can be imagined as a simulation method, which replaces a practical execution with a computer simulation. The basis of the Monte Carlo analysis is to produce a series of random numbers. The produced homogenous random numbers retain the same characteristics of the probability of their occurrences in the selected domain between 0 and 1. In this method, first, "*n*" random numbers are produced for each one of the existing random parameters in the given equation and this equation is then solved for each single random selected number. Finally, "*n*" values are obtained for the concerned equation by using the related relations to obtain the statistical information of the histogram sample. It should be noted that as the number of iterations increase, the answer would more closely approach the real value. With a decreasing probability of not supplying electricity to subscribers (customers) there is a direct relation to an increase in the number of generation units (generators) and, as a result, an increase in investment design status and/or utilization. More investment will definitely lead to an increase in utilization costs, which should be reflected in the tariff of energy sale. Subsequently, economic limitations would lead to a decrease in the reliability of the system. Therefore, there could be a compromise between reliability and economic restrictions that could lead to difficult management decisions in both the design and operational stages (Billinton and Allan, 1996; IEEE, 1985). In general, a study of the reliability of the three sections of generation, transmission and distribution of power systems should be done. In this paper, only generation reliability is being considered to meet the load demands. The transmission and distribution reliability have been assumed to be perfect (reliability = 100%). The LOLE calculation algorithm, using the Monte Carlo method, is shown in Fig. 2 (Billinton and Allan, 1987).

3. Case study

The case study of the SHPP "Nari" (small hydro power plant) is presented. This SHPP is located in the West Azarbaijan Province of Iran. The SHPP is of run-off river type and the object is to determine the optimal installation capacity.

3.1. *Energy calculation of the Nari SHPP*

In Table 2, the Nari river flow duration curve for different months is shown based on the routine daily statistics of the river. After doing feasibility studies in different specialized work groups and specifying the determination of the plant layout in the preliminary phase, a channel with a 3.6-km length and a net head of 300 m is being obtained. Furthermore, there is a suitable position for construction of the regulating daily headpond before the penstock entrance at the end of the channel (Ministry of Energy of Iran, Aab-niroo Company, 2002).

There are six alternatives of headpond volumes of 0, 5000, 10,000, 15,000, 20,000 and 25,000 m^3 with six different flow rate probabilities of 20%, 30%, 40%, 50%, 60% and 70% on the flow duration curve, making 36 alternatives. After surveying the flow duration curve and different sizes of headponds, 14 alternatives out of 36 are chosen as the best. Alternatives 1 and 2 have a headpond volume of 5000 m^3, a designed flow rate of 0.7 m^3/s and an installation capacity of 1.75 MW with a flow rate probability of 40% and 60%. Alternatives 3–8 have a headpond volume of 10,000 m^3, a designed flow rate of 1 m^3/s and an installation capacity of 2.5 MW with a flow rate probability of 20%, 30%, 40%, 50%,

Table 2
Monthly retrievable flow duration curve (m^3/s)

Flow rate probability (%)	April	May	June	July	August	September	October	November	December	January	February	March
5	6.050	4.550	2.840	1.750	0.640	0.423	0.500	1.900	2.010	3.130	1.830	3.020
10	1.476	2.301	2.126	1.197	0.457	0.257	0.253	0.472	0.433	0.295	0.331	0.534
20	1.153	1.855	1.720	0.924	0.349	0.225	0.210	0.325	0.291	0.255	0.262	0.415
30	0.938	1.657	1.378	0.778	0.288	0.164	0.159	0.280	0.259	0.231	0.235	0.340
40	0.791	1.562	1.218	0.573	0.238	0.135	0.156	0.251	0.240	0.213	0.216	0.290
50	0.666	1.363	1.069	0.554	0.200	0.124	0.148	0.226	0.226	0.204	0.205	0.250
60	0.557	1.245	0.948	0.433	0.172	0.107	0.139	0.200	0.212	0.195	0.193	0.238
70	0.461	1.114	0.848	0.312	0.152	0.097	0.122	0.173	0.197	0.185	0.181	0.220
80	0.391	0.941	0.674	0.251	0.136	0.083	0.107	0.162	0.182	0.172	0.169	0.200
90	0.310	0.797	0.404	0.160	0.115	0.075	0.094	0.142	0.165	0.159	0.156	0.176
95	0.186	0.630	0.295	0.110	0.073	0.053	0.063	0.102	0.144	0.126	0.109	0.119

Table 3
Obtained annual energy for different alternatives of Nari SHPP

Alternative no.	Flow rate probability (%)	Peak energy (GWh)	Base energy (GWh)		Total energy (GWh)	Plant factor (PF) (%)
			Normal load	Low load		
1	40	2.64	3.56	2.24	8.44	55.3
2	60	2.64	3.25	1.57	7.45	48.8
3	20	3.62	5.26	2.35	11.23	51.5
4	30	3.44	4.60	2.14	10.19	46.5
5	40	3.32	3.98	1.92	9.23	42.3
6	50	3.16	3.62	1.80	8.58	39.3
7	60	3.02	3.41	1.38	7.81	35.8
8	70	2.83	2.86	1.25	6.95	31.9
9	20	5.51	5.36	2.90	13.77	42.7
10	30	4.99	4.14	2.44	11.57	35.8
11	40	4.39	3.60	1.84	9.83	30.5
12	50	5.02	3.11	1.34	9.47	29.3
13	20	6.42	4.54	2.83	13.79	31.6
14	30	5.94	3.39	2.21	11.53	26.4

60% and 70%. Alternatives 9–12 have a headpond volume of 15,000 m^3, a designed flow rate of 1.5 m^3/s and an installation capacity of 3.75 MW with a flow rate probability of 20%, 30%, 40% and 50%. Alternatives 13 and 14 have a headpond volume of 20,000 m^3, a designed flow rate of 2 m^3/s and an installation capacity of 5 MW with a flow rate probability of 20% and 30%.

The optimal energy calculations have been performed for the 14 possibilities mentioned above. The energy calculation has been designed to include the best position for calculation and evaluation of energies in peak, normal and low load and have been obtained with respect to the capacity of the reserve headponds and river flow rate. In Table 3 the results of the annual energy calculation are given for different alternatives.

3.2. Economic calculations of the Nari SHPP

The calculated civil, equipment and total investment costs of the Nari SHPP have been given in Table 4. The economic analysis has been carried out considering costs and obtained incomes, according to the given algorithm. The economic basis is considered so that the investor may receive a loan from a financial source and pay it back with a specific interest rate through annual installments during the utilization stage. The economic analysis has been calculated for fully governmental, fully private and governmental–private financings, then the economic indices including benefit to cost ratio (B/C), the net present value (NPV) and US$/kWh of energy have been calculated. The interest rate has been settled as 10% in order to attract foreign investment in developing countries (Aab-niroo Co, Studies Management Office, 2003). This rate is considered a normal rate by global financial institutes for economic feasibility studies of water resource development. In any case, the effect of interest rate changes is studied by sensitivity analysis, and the results have been presented in Table 5.

3.3. Calculation of the reliability of the Nari SHPP

To study the effect of an increase in the number of generation units and subsequently, an increase in the cost on the LOLE index, the various combinations of generation units are being used for the Nari SHPP, each with the following specifications:

$P_G = 1.25$ (MW)	rated capacity of each generating unit
$N = 50$ (years)	SHPP's life time
$\lambda = 1/25$ (f/years)	rate of failures
$\mu = 2$ (r/years)	rate of repairs

The minimum and maximum load values are considered based on the loads in different years. The specifications of the loads are as follows (a sensitivity analysis has also been performed on the load values for more assurance):

$PL_{max} = 3.5$ (MW)	average maximum of load.
$PL_{min} = 1$ (MW)	average minimum of load.

There are 2000 iterations for calculating the LOLE in the Monte Carlo algorithm (iterations = 2000). Installing different numbers of generation units created the following possible options:

Option 1. 1 × 1250 kW + 1 × 500 kW (for this option the best selection is 2 × 900 kW).
Option 2. 2 × 1250 kW.
Option 3. 3 × 1250 kW.
Option 4. 2 × 2500 kW (similar to 4 × 1250 kW). The results of these calculations are listed in Table 6.

3.4. Results of the analysis

With respect to the results presented in Tables 3, 5 and 6) and studying the technical, economic and reliability indices, the alternative No. 10 is clearly the best option, with a 3.75 MW installation capacity, 1.5 m^3/s flow rate design, 15,000 m^3 headpond, an annual energy of 11.57 GWh, a plant factor (PF) of 35.8%, a B/C that equals 2.67, an NPV that equals US$5.83 million, a USCent/kWh that equals 2.8 and the suitable LOLE index of 10 days/year. By increasing the installed capacity, the LOLE decreases so that even with a 5 MW installation capacity (option 4) the failure will reach minimum and will even become a zero value; it should be noted that with such a situation, more expense for generating a kWh electrical energy is required, obviously not desirable. Furthermore, the PF and the economic indices are also not suitable. With an installation capacity of 3.75 MW, the number of failures, PF and other economic indices are very relatively proportional and the costs of a kWh energy is also at an acceptable limit.

Furthermore, considering only alternative 10, a sensitivity analysis of interest rate from 6% to 20% have been calculated and the results are given in Table 7. Then after a 20% increase in total investment costs of the same alternative with the same interest rates, another series of calculations have been done and the received results have been given in Table 8.

4. Conclusion

One of the most important issues in designing an SHPP is to determine the optimal installation capacity. In this paper, the methods of energy and the economic and reliability calculation have been presented and

Table 4
Considering different investment costs

Headpond volume (m^3)	Designed flow rate (m^3/s)	Altrn. no.	Installed capacity (kW)	Const. costs (US$/kW)	Equipment costs (US$/kW)	Sub-total costs (US$/kW)	E&D costs (US$/kW)	S&A costs (US$/kW)	Adjustment of inflation rate during construction costs (US$/kW)	Total investment costs per kilowat (US$/kW)	Total investment costs (US$)
5000	0.7	1	1750	477.07	715.65	1192.72	69.65	58.04	−31.96	1288.45	2,254,788
		2	1750	477.07	715.65	1192.72	69.65	58.04	−31.96	1288.45	2,254,788
10,000	1.0	3	2500	352.57	603.81	956.38	55.97	46.64	−23.62	1035.37	2,588,424
		4	2500	347.62	603.81	951.43	55.69	46.41	−23.28	1030.24	2,575,601
		5	2500	342.86	603.81	946.67	55.42	46.19	−22.96	1025.31	2,563,272
		6	2500	338.10	603.81	941.90	55.16	45.96	−22.65	1020.38	2,550,943
		7	2500	335.71	603.81	939.52	55.02	45.85	−22.49	1017.91	2,544,778
		8	2500	333.33	603.81	937.14	54.89	45.74	−22.33	1015.45	2,538,614
15,000	1.5	9	3750	249.78	513.65	763.43	44.80	37.33	−16.73	828.83	3,108,131
		10	3750	247.62	513.65	761.27	44.68	37.23	−16.59	826.60	3,099,747
		11	3750	244.44	513.65	758.10	44.50	37.09	−16.37	823.31	3,087,418
		12	3750	241.27	513.65	754.92	44.33	36.94	−16.16	820.02	3,075,089
20,000	2.0	13	5000	251.67	462.62	714.29	41.85	34.87	−16.86	774.15	3,870,730
		14	5000	214.29	462.62	676.90	39.75	33.13	−14.35	735.43	3,677,162

Note: All the costs of electrical transmission line system have been included in the equipment costs.

Table 5
Economic indices of different alternatives with private section contribution for Nari SHPP

Alternative no.	Flow rate probability (%)	B/C					NPV (US$million)					Final costs (USCent/kWh)
		$P/t^*=1$	0.75	0.50	0.25	0	$P/t^*=1$	0.75	0.50	0.25	0	
1	40	2.39	2.18	1.97	1.77	0.97	3.50	2.97	2.45	1.92	0.09	2.79
2	60	2.22	2.02	1.83	1.63	0.91	3.07	2.57	2.08	1.58	−0.22	3.15
3	20	2.82	2.57	2.32	2.07	1.14	5.26	4.55	3.83	3.11	0.42	2.40
4	30	2.61	2.38	2.15	1.92	1.06	4.63	3.97	3.30	2.64	0.18	2.64
5	40	2.43	2.21	1.99	1.78	1.00	4.09	3.47	2.85	2.23	−0.01	2.90
6	50	2.28	2.08	1.87	1.67	0.94	3.66	3.08	2.50	1.92	−0.17	3.10
7	60	2.13	1.94	1.75	1.56	0.88	3.22	2.68	2.13	1.59	−0.33	3.40
8	70	1.93	1.76	1.58	1.41	0.81	2.65	2.16	1.66	1.17	−0.55	3.82
9	20	3.09	2.81	2.53	2.25	2.28	7.28	6.31	5.34	4.37	0.99	2.36
10	30	2.67	2.43	2.19	1.95	1.12	5.83	4.98	4.14	3.29	0.42	2.80
11	40	2.32	2.11	1.90	1.69	0.98	4.58	3.85	3.11	2.38	−0.07	3.28
12	50	2.42	2.20	1.97	1.75	1.04	4.92	4.14	3.36	2.58	0.15	3.40
13	20	2.64	2.40	2.16	1.91	1.12	7.11	6.06	5.01	3.97	0.51	2.93
14	30	2.42	2.19	1.97	1.75	1.04	5.86	4.94	4.01	3.09	0.15	3.33

Note: P/t = Ratio of private section investment to total in percent.

Table 6
Index of reliability for the Nari SHPP

LOLE index (day/year)				Min. load (MW)	Max. load (MW)
Option 1	Option 2	Option 3	Option 4		
365	220	48	4.5	1.5	4
320	150	10	0.36	1	3.5
268	190	50	6.75	1	4
290	230	25	10.5	1	5

Table 7
Economic analysis results on alternative no. 10 with different interest rates

Interest rate (%)	Unit	6	8	10	12	14	16	18	20
Annual investment	(US$)	340,824	448,925	566,233	691,022	822,330	959,699	1,102,961	1,252,103
O&M	(US$)	6816	8978	11,325	13,820	16,447	19,194	22,059	25,042
Total annual cost	(US$)	347,640	457,903	577,558	704,842	838,776	978,893	1,125,020	1,277,145
Energy cost	(Cent/kWh)	1.76	2.27	2.80	3.35	3.90	4.46	5.02	5.58
Benefit–cost ratio (B/C) & ($P/t=1$)		5.11	3.60	2.67	2.08	1.68	1.40	1.20	1.04
Benefit–cost ratio (B/C) & ($P/t=0.75$)		4.65	3.27	2.43	1.89	1.53	1.28	1.09	0.95
Benefit–cost ratio (B/C) & ($P/t=0.5$)		4.19	2.95	2.19	1.70	1.38	1.15	0.98	0.86
Benefit–cost ratio (B/C) & ($P/t=0.25$)		3.72	2.62	1.95	1.51	1.22	1.02	0.87	0.76
Benefit–cost ratio (B/C) & ($P/t=0$)		2.15	1.51	1.12	0.87	0.71	0.59	0.50	0.44
Net present value (NPV) & ($P/t=1$)	(US$)	15,660,935	9,380,939	5,825,286	3,672,708	2,284,307	1,336,194	655,968	147,255
Net present value (NPV) & ($P/t=0.75$)	(US$)	13,895,433	8,203,013	4,981,189	3,031,021	1,773,107	913,894	297,219	−164,179
Net present value (NPV) & ($P/t=0.5$)	(US$)	12,129,931	7,025,086	4,137,092	2,389,335	1,261,907	491,595	−61,531	−475,613
Net present value (NPV) & ($P/t=0.25$)	(US$)	10,364,430	5,847,159	3,292,995	1,747,649	750,707	69,295	−420,280	−787,046
Net present value (NPV) & ($P/t=0$)	(US$)	4,360,013	1,841,067	422,247	−434,707	−987,868	−1,366,933	−1,640,376	−1,846,223

Note: P/t = Ratio of private section investment to total in percent.

finally, the above-mentioned algorithm has been studied for a sample SHPP.

1. The economic indices have been calculated based on an algorithm (by using Excel software) and by the application of sensitivity analysis.
2. The reliability indices have been calculated by employing the Monte Carlo method based on an algorithm (by using Matlab software).
3. The optimal installation capacity has been obtained by establishing a compromise between the technical, economic and the reliability indices.

Table 8
Economic analysis results with 20% increasing in sub-total investment costs on alternative no. 10

Interest rate (%)	Unit	6	8	10	12	14	16	18	20
Annual investment	(US$)	408,988	538,710	679,480	829,226	986,795	1,151,639	1,323,553	1,502,523
O & M	(US$)	8180	10,774	13,590	16,585	19,736	23,033	26,471	30,050
Total annual cost	(US$)	417,168	549,484	693,070	845,811	1,006,531	1,174,671	1,350,024	1,532,574
Energy cost	(Cent/kWh)	2.11	2.72	3.36	4.02	4.68	5.35	6.02	6.69
Benefit–cost ratio (B/C) & ($P/t=1$)		4.26	3.00	2.23	1.73	1.40	1.17	1.00	0.87
Benefit–cost ratio (B/C) & ($P/t=0.75$)		3.88	2.73	2.03	1.58	1.27	1.06	0.91	0.79
Benefit–cost ratio (B/C) & ($P/t=0.5$)		3.49	2.46	1.82	1.42	1.15	0.96	0.82	0.71
Benefit–cost ratio (B/C) & ($P/t=0.25$)		3.10	2.18	1.62	1.26	1.02	0.85	0.73	0.63
Benefit–cost ratio (B/C) & ($P/t=0$)		1.79	1.26	0.93	0.73	0.59	0.49	0.42	0.37
Net present value (NPV) & ($P/t=1$)	(US$)	14,899,767	8,659,517	5,128,907	2,992,177	1,613,850	672,161	−3,967	−510,080
Net present value (NPV) & ($P/t=0.75$)	(US$)	13,134,266	7,481,590	4,284,810	2,350,491	1,102,650	249,861	−362,716	−821,514
Net present value (NPV) & ($P/t=0.5$)	(US$)	11,368,764	6,303,663	3,440,713	1,708,804	591,450	−172,438	−721,466	−1,132,948
Net present value (NPV) & ($P/t=0.25$)	(US$)	9,603,262	5,125,736	2,596,616	1,067,118	80,250	−594,738	−1,080,215	−1,444,382
Net present value (NPV) & ($P/t=0$)	(US$)	3,598,845	1,119,644	−274,132	−1,115,237	−1,658,325	−2,030,966	−2,300,311	−2,503,558

Note: $P/t=$ Ratio of private section investment to total in percent.

4. The aforementioned method has been applied to a sample SHPP named "Nari" by comparing the PF, the B/C, NPV, USCent/kWh, and the reliability index LOLE, so the optimal installation capacity of 3.75 MW has been obtained.

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