

Design and Optimization of the Micro-Hydro Power System for Remote Areas of Pakistan

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Abstract- The electricity price escalation in Pakistan is increasing with an exponential rate because of the dominance of the foreign imported conventional source of energy. The consumer must pay an extra tax as the fuel adjustment in every month's electricity bill. Being the renewable energy source abundant country, Pakistan needs to exploit these energy sources for electricity production. This paper presents a micro-hydro energy system at the Jalala Disty canal in KPK Pakistan. A site specific scheming of the planned microhydro project is introduced. RETScreen based modeling and optimization of the project are discussed. Net Present Value (NPV) and the Cost of Energy (COE) of the intended microhydro system is calculated. RETScreen optimization assessment confirmed the viability of the planned micro-hydro energy system built on the COE and the NPV. The arrangement is anticipated to retrieve all the expenses incurred in the 4th year of the total period of the planned project. Comparing with the baseline energy mix of the country, the proposed energy project is 100 % greenhouse gases (GHG) emission free project.

Keywords :Microhydro; RETScreen Expert; Renewable energy; GHG emissions; Pakistan

1. Introduction

Industrial development, growing population, and expansion of urban areas have augmented the energy requirements in all divisions of Pakistan for the past two decades. Among the energy mix of Pakistan, 37 % of the electricity is generated on imported oil carrying a major portion of the foreign payments to the oil rich countries [1,2]. The success of short term planning of the electricity generation to encounter the growing energy requirements has shifted the energy mix from hydro dominance to the thermal dominance as shown in Figure 1. Regrettably, in spite of having plentiful renewable energy sources, Pakistan is confronting a serious power deficit even in its on grid countryside and city zones. The topographical position of Pakistan creates a country prosperous in sustainable and renewable energy sources such as geothermal, solar PV, solar thermal, biomass, hydro, and wind. Bearing in mind the sustainable and green energy outlook, being an inexpensive, tidy, and ecosystem friendly resource of energy, hydro is the best solution of the prevailing conditions of electricity. Pakistan initiated exploiting the potential of hydro power since its presence. Corresponding to an assessment, 59GW potential of hydro power is available in Pakistan [2]. Table 1 classifies the types of turbines based on their applications and size of the hydro project. Small and micro hydro power are getting admiration in the world for remote/off grid hamlets, isolated and rough areas [3–5] which are yet out of the national flow of improvement. About 50million people in Pakistan are deprived of admission to the grid [6]. Erection of such hydro power system do not require a bigger water sink and storage. In these off grid regions, micro/mini hydro power locations are practicable results [7,8] where the flowing water at a specific head of the canal or any adjacent water source is depleted to a nearby lake and thrown to the rotating turbine to transfer into electrical energy using a connected

electrical alternator. The passing water in the tailrace after exhausting its potential through the turbine to the electrical generator can also be sent for adjacent agrarian lands and local determinations [9,10] and directed to the conventional flow. Jawahar et al. [9] have introduced an assessment analysis on turbines of micro hydro power and, Haidar et al. [11] has categorized type of turbines regarding head as following:

1. Low head (40 m): Kaplan, Propeller
2. Medium head (40 to100 m): Cross Flow, Pelton wheel, Francis and Pump as turbine.
3. High head (>100 m): Pelton Wheel and Turgo

Hofken [12] recommended the development of rural tenants’ social and commercial life cycle in Pakistan by launching micro/mini hydro plants in far off countryside regions where latent potential is accessible and utilized the phrase “small is beautiful” for micro/mini hydropower. Vyaas et al. [13] performed a viability study for applying micro/mini hydropower in drylands of different states of India and determined it unsurpassed for self-adequacy in energy. Zeema et al. [14] assessed the technical and economical practicality of micro hydro power in the agrarian fields and discovered it lucrative in the Italian power marketplace. Kamran et al. [15] anticipated the designing and economic optimization of a micro hydro system on link canal of Balloki barrage and Sulamanki barrage. They designed the system for the proposed location, performed the sensitivity analysis of the hydro power and optimized the economics by using HOMER Pro.

The project is located at Sakhakot, Malakand agency, Khyber Pakhtunkhwah Province. The area belongs to the lesser Himalayas, Malakand Agency. In the current study project layout, capacity, water availability, area to be benefited and the needed infrastructure for the accomplishment of the project were assessed. The conducted study recommends a micro hydro power plant on Jalala Disty Canal (RD: 18+051) Sakhakot, Malakand taking a generous potential of electricity to gratify the energy requirements of the neighboring areas.

The paper is designed as: Section 1 comprises of an introduction and overview of the microhydro in Pakistan, section 2 deliberates the energy position of the Pakistan and discusses the prospects of hydro power potential available in the country at large and small capacity level. Section 3 illustrates the project location where the micro hydropower plant is projected. The designing of the anticipated micro hydro project has been discussed in Section 4. In section 5, cost estimation of the planned system is presented. Section 6 describes the RETScreen optimization of the system. Section 7 is the conclusion of the study.

2. Energy scenario of Pakistan

Pakistan’s existing electricity condition is, regrettably, experiencing a serious shortfall of almost 5000 MW that has directed to a comprehensive blackout from nearly 13-17 hours a day [17–19]. The source-centered energy mixture of Pakistan (2008-16) is displayed in

Table 2. Existing energy blend of the countryside is thermal assertive taking the cost of electricity too high as the thermal operated power plants are normally conventional and imported fossil fuel based (37.5 % oil, 30.17 % gas) in 2016 controlled by Private Power Producers. Percentage of the electricity generated from thermal sources since 2009 has been advanced than other conventional energy sources already in practice in Pakistan. Energy resources that replenish themselves like biomass, wind, solar, and hydro capacity are in profusion in Pakistan. Amongst the renewables, hydro power is the low-appraised one and environmentally outgoing. Pakistan is rich in water resources having a 59000 MW workable micro, small and large hydro energy potential [2]. Successively bulky hydro power plants are Nelam-Jhelum (950MW), Tarbela (3478MW), Ghaazi Brootha (1450MW), Mengla (1000MW), Warsik (240MW), and Chshma (184MW) [20,21]. Apart from these, several hydro power projects, Kalabaagh (3600MW), Bhaasha (4500MW), Bunjji (5400MW), Dasoo (4000MW), Kohaala (1100MW), Thakoot (2800MW), Pataan (2800MW), Munnda (750MW) and Akhore (600MW) [22], are either at several stages of project expansion or in future lined up. For the unwarranted postponement in execution of the projects, hydro power possibly will not survive its development. The hydro percentage in the national electricity mix of the country has been condensed from 71% in 1961 [2] to 29% in

2016 [23]. Batool et al. [24] has debated the grounds for prolonging the hydro power ventures in the country. Micro hydro is the top alternate source of power for off grid communities to electrify the village. Such micro hydro power ventures can electrify the isolated areas from the electricity grid and adjacent the farming lands having irrigation channels with a high level head.

Table 1. Size based types of hydro power plants [16]

Sr. No.	Hydro power plant type	Size assortment
I	Pico	<5kW
II	Micro	5kW-100kW
III	Mini	101kW-2MW
IV	Small	2001kW-25MW
V	Medium	25001kW-100MW
VI	Large	>100MW

The distant off grid societies from the national grid and close the agricultural lands and irrigation channels with an extraordinary head can be captivated by these micro hydro power ventures. Alternative Energy Development Board (AEDB) projected about 3100MW micro hydro power capacity projects at expected collapses and water canals in

Pakistan. Gilgit only has 1300 MW prospective at 200 sites. The administration of Kheber Pakhton Kha (KPK) finalized 87 micro hydro projects varying from 15 kW to 100 kW in distant and hard landscapes of KPK in 2016.

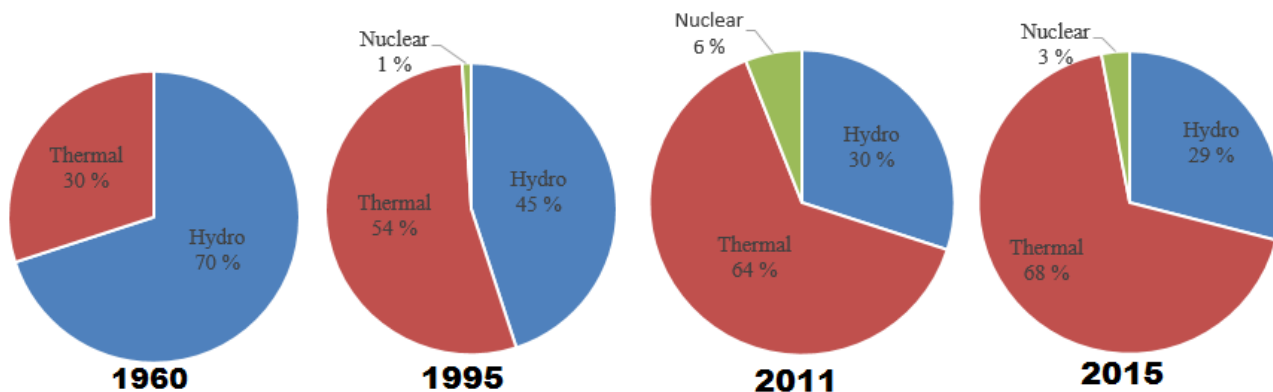


Figure 1: Transition of Energy Mix of Pakistan

Table 2. Energy mix of Pakistan [23,25,26] in GW

	2008	2009	2010	2011	2012	2013	2014	2015
Thermal	13.539	14.576	15.047	16.363	16.069	16.041	16.366	16.814
Wind	0	0	0	0	0.001	0.50	0.106	0.106
Nuclear	0.462	0.462	0.462	0.787	0.787	0.787	0.787	0.787
Hydro-electricity	6.555	6.555	6.555	6.645	6.730	6.947	7.116	7.116
Installed capacity	20.23	20.55	22.06	23.79	23.58	23.82	24.37	24.82
Peak supply	12.44	13.63	12.75	13.19	12.32	14.60	16.17	16.50
Peak demand	16.83	17.85	18.46	18.52	18.94	18.82	20.57	21.70
Deficit	(4.39)	(4.21)	(5.71)	(5.32)	(6.62)	(4.22)	(4.40)	(5.20)

Table 3. Pakistan micro-hydro power potential [27]

Sr. No.	Area	Potential (MW)	Number of potential locations	Total available potential (MW)	Available location
1	Gilgit	0.1 - 38	200	1300	Natural falls
2	Punjab	0.2 - 40	300	560	Canals
3	Sindh	5 - 40	150	120	Canal falls
4	Khyber Pakhtun Khawa (KPK)	0.2 - 32	125	750	Micro based falls
5	Azad Kashmir	0.2 - 40	40	280	Natural falls
	Total			3100	

Table 4. Functioning micro hydro power stations [24]

Power plant	Capacity (MW)	starting date
Chicoki	13.2	1959
Renala	1.1	1925
Shadiwal	13.5	1961
Rasul	13.8	1952
Dargai	20	1951
Nandipur	13.8	1963

Table 3 illustrates the hydro potential at micro level in various provinces of the country. Functioning small hydro power projects in Pakistan are comprehensively given in

Table 4. Figure 1 shows the image of the scenario how the transition of energy mix took place from hydro dominant to thermal dominant.

3. Project site description

The project area is covered by a thick sequence of alluvium and shown in Figure 2 and is generally comprising of silt, clay, sand gravel and organic material. Hence the alluvium of project area comprises mostly of weathered material from schistose rocks. The soil of the project area is very fertile and is used for agriculture purposes.



Figure 2: Satellite view of the project proposed location

For the feasibility level of the study of the proposed project, the geotechnical investigations conducted by Hydro Electric Planning Organization (HEPO) have been used as a reference. The geotechnical investigations carried out by HEPO are in the vicinity of proposed project and therefore may be utilized for the Savvy Links Machai Hydro power Project. However, for detailed engineering design, it is recommended that the following geotechnical investigations may be carried. The general geology of the project area is shown in Figure 3.

4. Designing of micro hydro system

4.1. Resource assessment

The flow rate data was measured at the proposed location and accordingly a flow duration curve format was developed by the flow rate shown in table 5. Using the data of the table 5, flow duration curve was drawn as discussed in section 4.2.1.

4.2. Flow duration curve

Flow Duration Curve is a method of establishing the expulsion information of a flow at a water channel in a curve look that presents an approximation of the portion of the period at which the flow rate matches or surpasses some value of concern. FDC is gained by organizing the flow percentage and sketching it on the y-axis at equivalent periods of proportion on the x-axis. To well introduce the expulsion performance with higher precision, daily time step dimensions are required to get FDCs [30]. Though, FDCs is plotted for a particular time period and for any specific year. The collected data of discharge are represented in % of the time and is presented in table 4.3 and plotted in Figure. The annual closer period for the canal is the same as that for the other canal, i.e. the month of January. However. From the data collected it was observed that in the flow was recorded for some years in the past due to the availability of water at the head regulator. But in the current project, the calculation for the month of January is neglected and is considered zero discharge value for the calculation of power and energy.

The collected data was analyzed, and it was found that the minimum discharge of 73 ft³/s is available for 75 % of the time. However, the maximum discharge of 132 ft³/s is available for approximately 8.33% as shown in Figure 4.

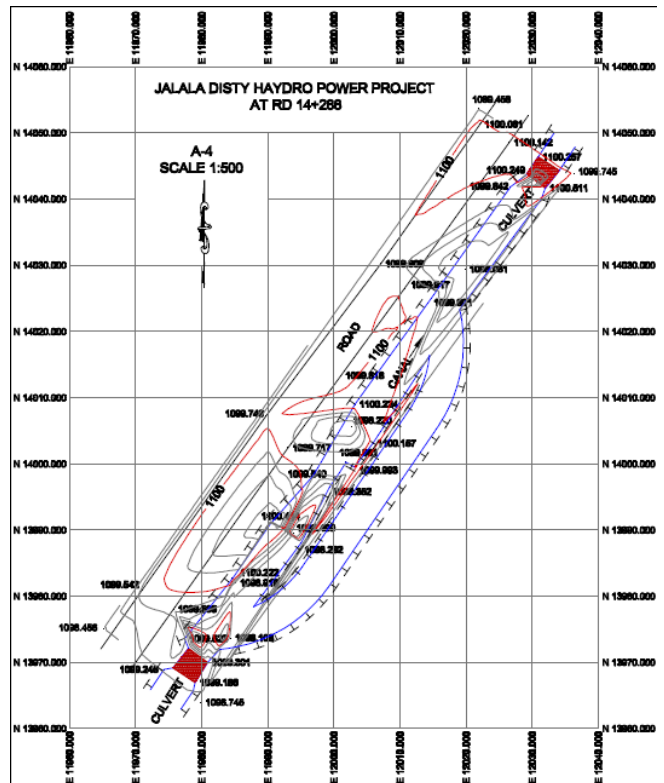


Figure 3: General geology of the project area

Various outlets were taken from the main canal between the head regulator and the proposed project site. But the data presented in the above tables were taken at the project site

and therefore, no need for subtracting the outlets' data from the calculated discharge levels. Hence, the design discharge at the project site is 73 ft³/s.

$$\text{Discharge at head regulator} = 73 \text{ ft}^3/\text{s} = 2 \text{ m}^3/\text{s}$$

The detail of discharge calculation at the project site is carried out below:

Table 5: Availability of discharge at the head regulator in % of the time.

% Time Flow Exceeded	Percentile (Flow rate)	% Time Flow Exceeded	Percentile (Flow rate)
8.33	132.5	58.33	89
16.66	132.5	66.66	76
25	128.5	75	73
33.33	108.5	83.33	73
41.66	100	91.66	59.5
50	98.5	100	0

h weir height
W weir width

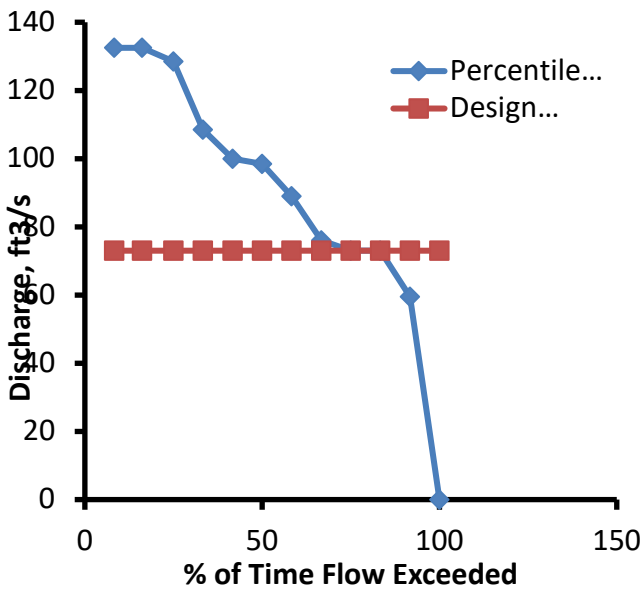


Figure 4: Flow duration curve and the designed flow rate

4.3. Weir and open channel

A weir/barrage exhibits a fence crossway the water flow specifically expected to alter the water flood features. Hydrologists utilize the barrier to gauge the volumetric stream proportion in moderate and minor waterways. Typically, it is a small fence or a small dam with a cut to drain the water. The emission of water can be designed by simply determining the level divergence amid the higher flow of water and the inferior side of the channel. Considering the type of the material and the structure, several types of trenches are employed such as Vee, trapezoidal, and rectangular invented of metal and wood. Eq. (i) [31] is utilized to determine the water flow-rate at the nick.

$$Q = (1.8) \times (W - 0.2h) \times h^{3/2} \quad (\text{m}^3/\text{s}) \quad (i)$$

Nasir [31] explained by constructing the height and the width of barrage in a one ratio three (1:3) proportion, aspects of the barrage, and the water flow can be determined. In the proposed investigation it is 5.040 m²/s.

Robert Manning, in 1890, presented equation (ii) substitute to the Chezy equation that oversees the open channel flowrate. Equation (ii) is associated with the consistent open channel flow and is presented in Eq. (ii) [31].

$$Q = \frac{1}{n} (s.f \times S^{1/2}) \quad (\text{m}^3/\text{s}) \quad (ii)$$

s.f section factor = $AR^{2/3}$

n Gauckler-Manning coarseness coefficient (material dependent)

S channel's bottom line slope

Eq. (ii) is updated to Eq. (iii) that determines the channel's lowest slope.

$$S = \left(\frac{Q \times n}{A \times R^{2/3}} \right)^2 \quad (iii)$$

To compute the slope of the bottom-line, we prerequisite to compute the hydraulic radius (*R*) of the cross-sectional area and the cross-sectional area of the open channel by using Eq. (iv) and Eq. (v) respectively.

$$R = \frac{A}{P} = \frac{A}{W+2h} \quad (iv)$$

$$A = W \times h \quad (v)$$

P perimeter of the rectangular channel

A Cross-sectional area of open channel

By using all the identified parameters in Eq. (iii), bottom line slope of the canal can be designed that shows an even drift. The flow rate in the open channel is $5.040 \text{ m}^3/\text{s}$ by using the Gauckler-Manning equation (ii). Whereas, the velocity in the open channel is determined by Eq. (iv) [32]. The velocity of the water in the open channel is $(1.68 \frac{\text{m}}{\text{s}})$ determined by the equation (iv).

$$V = \frac{Q}{A} \quad (\text{vi})$$

4.4. Trash Rack Designing

The obstacles that face the flow to stop the movement and submerged fragments from receiving into the opening and destructing penstock, and the turbine are known as the trash rack [33]. Slabs of explicit thickness with specific arrangement are positioned at a leaning of 61° to 81° at horizontal-axis. Nasir et al. [31] has described some distinctive standards of the bar space for diverse types of turbines (80 to 100mm for Kaplan turbines, 20 to 30mm for Pelton, 40 to 50mm for Francis turbine). The fragments accrued in the trash rack are required to be detached frequently either physically or by some methodical technique, or else, they can create some additional head losses.

4.5. Penstock design

Penstock is used to conduct the flowing water in weir to the open channel and then from head to the turbine. Penstock design is much important regarding its diameter, thickness, material, and cross-sectional area. Penstock is important in way as it is the main part where the energy of falling water is converted from potential energy to the kinetic energy of the moving water and hence moving the generator coupled turbine. Because of numerous aspects like the ambient temperature, penstock material, ground nature, ambient temperature, and environmental factors, it could be either visible or hidden below the ground.

4.6. Penstock diameter

Eq. (vii) [31] can be used to to determine the diameter (internal) of the penstock.

$$D = (2.690) \times \left(n^2 \times Q^2 \times \frac{L}{H_g} \right)^{0.1875} \quad (\text{m}) \quad (\text{vii})$$

n Gauckler-Manning coefficient (0.011 for PVC)

D internal diameter of the penstock

L penstock length

Q design flow

H_g gross head

The internal penstock diameter for the conducted study is 650 mm using equation (vii).

4.7. Penstock thickness

The stiffness of the wall of the penstock is dependent on the operating pressure, penstock material and diameter, and the ductile strength. Eq. (viii) [31] presents the least stiffness of the penstock.

$$t = \left(\frac{D+509}{400} \right) + 1.2 \quad (\text{mm}) \quad (\text{viii})$$

t minimum penstock wall thickness (mm)

Penstock thickness is 4.095 mm using eq. (viii).

4.8. Penstock Cross sectional area

$$A = \frac{\pi D^2}{4} \quad (\text{m}^2) \quad (\text{ix})$$

D penstock diameter (m)

A penstock area of the cross section

Equation (ix) gives the penstock cross sectional area as 0.33 m^2 .

4.9. Velocity through the penstock

$$V = \frac{Q}{A} \quad (6.26 \text{ m/s}) \quad (\text{x})$$

4.10. Head friction losses

While measuring the available power in the water, head/penstock losses must be considered. These are the sufferers happening because of the roughness of the water to the wall of the penstock and may be determined by Eq. (xi) [34].

$$h_f = f \times \left(\frac{L}{D} \right) \times \frac{v^2}{2g} \quad (\text{m}) \quad (\text{xi})$$

f friction factor (0.017 using eq. 12)

v average velocity (m/s)

D penstock diameter (m)

L penstock length (m)

g acceleration due to gravity (9.8 m/s^2)

The friction factor can be determined by eq. (12) [34].

$$f = 124.5 \times \frac{n^2}{D^{1/3}} \quad (\text{xii})$$

n Gauckler-Manning-coefficient (for PVC, 0.011)

By using the above stated numerical values in Eq. (xi), head friction losses can be determined and it is 0.51 m.

4.11. Inlet losses

$$h_i = f_e \times \frac{v^2}{2g} \quad (m) \quad (xiii)$$

h_i the inlet losses

f_e the inlet coefficient, (0.5 for microhydro)

Eq. (xiii) gives inlet loss as 0.98 m.

4.12. Valve losses

$$h_v = f_v \times \frac{v^2}{2g} \quad (m) \quad (xiv)$$

f_v valve type coefficient (0.1 for the butterfly valve)

h_v the valve losses

Eq. (xiv) gives valve losses as 0.196 m.

Total losses can be determined by adding all the losses given by Eq. (xv).

$$HL = h_f + h_i + h_v \quad (1.686 \text{ m}) \quad (xv)$$

$$\text{Net Head} = \text{Gross Head} - \text{Head losses} \quad (m) \quad (xvi)$$

Eq. (xvi) can be used to determine the net head. Net head is the head that is available after bearing all the losses and in the present case it comes out to be 8.3 m.

4.13. Hydro power

Micro hydro produces electricity using a generator coupled to the turbine by taking the potential energy of dwindling water that is thrown on the turbine. Micro hydro does not need any main construction work, thus having no ecological belongings. Water from the runing canal/river/natural fall is abstracted and after generating electricity diverted to the mainstream. The power of generating electricity in water is dependent upon head of the dwindling water and flow rate and that can be determined by the eq. (xvii) [35].

$$P_t = \rho g Q H_g \quad (xvii)$$

ρ water density (1000 kg/m³)

H_g gross head (m)

g gravitational acceleration (9.8 m/s²)

P_t theoretically available power (W)

Q flow rate (m³/s)

By using Eq. (xvii), hypothetical power without considering the efficiency of the system comes out in kW.

4.14. Turbine power

After considering all the power losses like penstock friction losses, valve losses, and inlet losses, and turbine efficiency, the power that a turbine can provide to the generator can be determined by using Eq. (xviii).

$$P_{act.} = \rho g Q H_n \eta \quad (W) \quad (xviii)$$

η system efficiency (75%)

H_n net head (m)

The actual electric power that the system can deliver is in kW.

4.15. Speed of the Turbine

Capacity factor (σ) governs the turbine type appropriate for the project location and if the water flow rate, turbine speed, and the head are recognized, it can be determined by the eq. (xix) [36]. Conversely, the capacity factor can be assessed if the head is known by the graph as shown in

$$\sigma = \frac{2N \sqrt{\pi Q}}{(2gH)^{3/4}} \quad (xix)$$

N speed of the turbine in r.p.m.

σ characteristic factor of the turbine

H net head (m)

Q design flow (m³/s)

g gravitational acceleration of dwindling water (9.8 m/s²)

Eq. (xix) can be reordered to Eq. (xx) [36,37] to discover the rotating speed of the turbine. The characteristic factor (σ) of the turbine is created from **Error! Reference source not found.**

$$N = \frac{\sigma (2gH)^{3/4}}{2\sqrt{\pi Q}} \quad (r.p.m.) \quad (xx)$$

The turbine specific-speed can be determined by using Eq. (xxi) [32,36,38].

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} \quad (r.p.m.) \quad (xxi)$$

4.16. Turbine selection and design

After calculating the net head, the characteristic factor and the type of the turbine is read from the graph **Error! Reference source not found.** If the head is greater than 50m, Pelton turbines are preferred. Francis turbines are applied where the head range is between 10m-50m, whereas, for the head beneath 10 m, Kaplan turbines are used [39]. Considering the interpretation from **Error! Reference source not found.**, kaplan turbine is selected for the

recommended system. However, the capital cost of the Kaplan turbine is much higher compared to the design and manufacturing of water wheel. Similarly, the manufacturing of water wheel required less expertise compared to Kaplan Turbine. Similarly, the water wheel is recommended for low head as discussed above. Based on these arguments, the breast shot water wheel was selected to produce electricity at the project site.

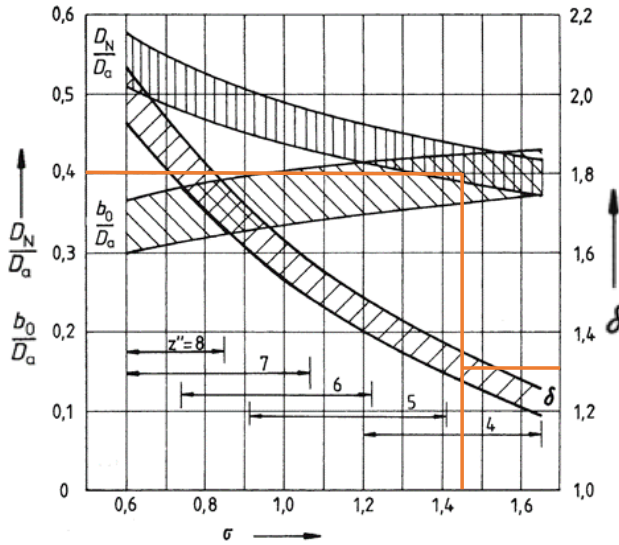


Figure 5: Design parameters of a Kaplan turbine

When the turbine type is recognized, other parameters of the turbine can be determined. Outer and inner diameter of the wheel, and the ratio $\frac{D_N}{D_a}$ are calculated by using Eq. (xxii), Eq.(xxiii) and Eq.(xxiv) respectively [37].

$$D_a = \frac{z\delta}{\pi} \times \sqrt[4]{\frac{Q^2}{2gH}} \quad (m) \quad (xxii)$$

D_a hub inner diameter
 δ diameter number

$$D_N = 4D_a \quad (m) \quad (xxiii)$$

D_N turbine outer diameter

The 2 cm thick sheet was used to cut discs of 3.2m in external diameter and internal diameter of 2.57 m. These discs were cut using the sheet metal cutting machine. The measurement was taken using the measuring tape. The reading was taken in such a way that the tape one end was put at the center of the sheet and circle was drawn on the sheet having an external diameter of 3.2m and internal diameter of 2.57 m as shown in Figure 6. The number of buckets use in the wheel is decided based on the circumference of the wheel. As per calculation of the circumference of the water wheel, one bucket at one foot was decided to be used in the final assembly. The total number of buckets to be used in the fabrication of the breast shot water wheel was 33. The positioning of the bucket was achieved by

dividing the discs into 33 equal divisions as shown in Figure 7.

A cylinder made of mild sheet having thickness of 2 cm and diameter of 2.57 m is welded to the discs to make the base face of the buckets.

The shroud of the wheel cutter in above form a metallic sheet having an internal diameter of 2.57 m and external diameter of 3.2 m and welded to the discs to form the sides of the buckets used in the fabrication of breasts hot water wheel. For checking of the cracks and holes, water test of the shroud joints was done and made sure that there should be no leakages of water during operation of the water wheel.

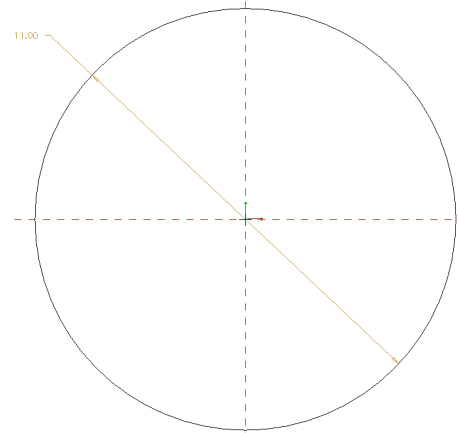


Figure 6: Water wheel discs dimension

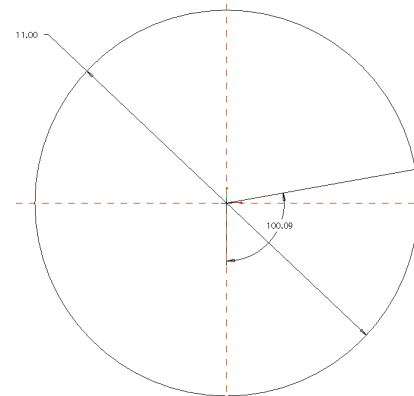


Figure 7: Buckets position on the wheel circumference

A shapper machine and welding process was used to make the buckets for the water wheel. A total of 33 buckets was made for the water wheel and was welded to the shroud of the water as shown in Figure 8.

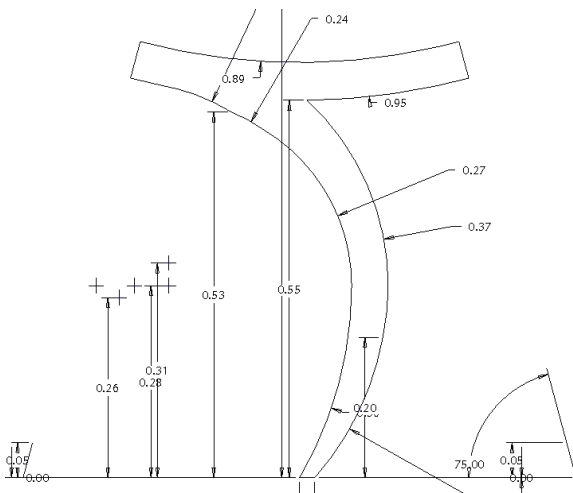


Figure 8: Bucket design

Generally, it is difficult to fabricate a new bearing for the current project due to cost and infrastructure available, however, based on the available information, 4 cm bore pillow block self-lube bearings were selected for mounting the shaft of the water wheel. Proper lubrication and maintenance of the bearing will be ensured using the standard operating procedure provided by the supplier.

- Some advantages in using lubricated bearings are that they:
- Avoid severe erosion of the shaft and bearing materials
- Can be refurbished or substituted.
- Can deliver a transitory solution to the renovation

A 10 ft long shaft was selected for the main supporting shaft of the water wheel. The shaft is mounted in bearing and is attached to the shroud of the water wheel through a metallic link welded at both ends. The metallic supports were provided to the shroud at three locations both at the extreme side of the wheel and at center location. The selected metallic links were designed to support the total weight of the water and wheel.

5. Cost estimation

The project cost estimate has been established on the basis of the current survey of the proposed project.

The cost of the project is divided into the following three sections:

- Preliminary Work
- Civil Work
- Electromechanical Work

The construction cost of the project covers all civil work associated with the project including the transportation charges, investigation charges, planning cost, engineering and administration charges. A contingency charge is also included in the cost estimation of the project as a separate item to allow surplus amount of money to cover any differences in the cost during the project completion period.

The contingency charges were taken as 10 % of the total amount of the project. The cost assessment is constructed on the following supposition that a single supplier will take total duty for the project accomplishment involving design and engineering, equipment purchasing, construction, testing and installation.

6. Components and cost estimation

6.1. Preliminary Work

Preliminary cost of the project included the land and environmental cost. The following cost have been included:

- Land acquisition
- Providing necessary equipment and facilities
- Security and other expanses
- Providing transport between the camp and construction site
- Workshop, warehouses, sheds and yards
- Providing the maintenance vehicles for construction
- Site investigation
- Mobilization and demobilization of human resource and equipment

6.2. Civil Works

The civil works includes the cost of the following activities.

- Diversion canal
- Cofferdams.
- Dewatering of powerhouse construction pit.
- Headrace canal.
- Tailrace canal.
- Powerhouse/spillway.
- Main canal Dredging/Banks Raising.
- Roads.
- Residences for operational and management staff
- Miscellaneous works
- Construction of dismantled bridges

6.3. Hydro and Electro-Mechanical Equipment.

The cost of Hydro and Electro- Mechanical equipment includes the costs of equipment their transportation to the site and erection. The costs of the following items have been considered in the estimates.

- Turbine and generator.
- Mechanical equipment.
- Electrical equipment.

6.4. Other Costs.

The other cost of the project includes:

- Grid interconnection cost
- Interest during construction
- Insurances
- Front end bank charges
- Cost for financial and legal expertise

- Engineering \supervision and management cost
- Administration audits and accounts
- Import duties
- Contingencies/ unforeseen.

7. RETScreen Expert Optimization

7.1. Climate data

RETScreen Clean Energy Management software is a software package developed and introduced by the

government of Canada in 2016. The software can simulate the renewable energy systems either as an independent energy system or in integration with other renewable energy resources. It could be either a microgrid or a grid-connected renewable energy system. RETScreen Expert takes the coordinates of the location where the project is to be implemented and takes the environmental data like the air temperature, wind speed, relative humidity, precipitation, daily solar irradiance, earth temperature, and the atmospheric pressure. Figure 9 shows the weather data at the coordinates of the location where the micro hydro project is intended.

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature
	°C	%	mm	kWh/m ² /d	kPa	m/s	°C
January	9.7	44.1%	27.90	3.08	93.7	1.7	7.6
February	11.5	48.7%	65.24	3.77	93.5	1.8	10.2
March	16.8	46.4%	67.58	4.76	93.3	1.9	16.0
April	22.8	39.7%	48.90	6.18	93.0	2.0	22.6
May	29.1	27.0%	24.18	7.31	92.6	2.1	29.7
June	33.4	23.9%	26.70	7.88	92.1	2.1	34.9
July	32.7	41.2%	75.64	6.96	92.1	2.4	34.7
August	30.7	50.4%	78.12	6.21	92.3	2.2	32.1
September	28.0	41.5%	35.70	5.87	92.7	1.9	28.5
October	22.5	30.7%	20.46	5.02	93.3	1.8	21.4
November	16.9	29.9%	15.30	3.76	93.6	1.7	14.5
December	12.0	37.3%	23.56	2.86	93.7	1.6	9.3
Annual	22.2	38.4%	509.28	5.31	93.0	1.9	21.9

Figure 9: Environmental data of the proposed location

7.2. RETScreen Technical Data

The designed micro hydro system was modeled in RETScreen Expert using the information regarding resource assessment, hydro turbine and the losses given in the table.

Table 6: characteristics parameters of hydro resources and turbine

Resource Assessment	
Proposed Project	Run-off-river
Gross Head	10 m
Maximum tailwater effect	0.5 m
Residual flow	0 %
Firm Flow	1.7 m ³ /s
Firm Flow available	9.5 %
Hydro turbine	
Design flow	2 m ³ /s
Type	Kaplan
Turbine efficiency	Standard
Design Coefficient	4.5
Turbine peak efficiency	89 %
Flow at peak efficiency	1.5 m ³ /s
Turbine efficiency at design flow	88.6 %
Losses	
Maximum hydraulic losses	16 %
Miscellaneous losses	2 %
Generator efficiency	75 %
Availability	96 %

7.3. Turbine efficiency and power curve

A graph or the efficiency curve of the no. of turbines used is shown in Figure 10. The efficiency of the turbine has been displayed against the percentage of the rated flow. The efficiency curve of the turbine indicates that the peak efficiency of the turbine is 89 % if the flow of the water is 1.5 m³/s. Between 30 and 100 % of the rated flow, the efficiency is 88 %.

RETScreen Expert takes the flow data at the percentage exceedance and models the proposed micro hydro energy system at the designed flow rate noting the percentage of the time the flow rate is available. Figure 11 shows the flow duration curve and the corresponding power curve at the corresponding percentage exceedance. It can be estimated from the figure that the maximum power 107 MW is available at the designed flow rate of 2 m³/s that is available 85 % time of the year. The efficiency of the turbine at the designed flow rate is 88.6 % which is only 0.4 % less than the maximum efficiency of the turbine. On the other hand, the available power changes as the flow rate are changed.

4.1. Cost Summary

All the costs discussed in section 5 were included in the initial investment in the RETScreen Expert that took all the technical and the economic parameters and performed the techno-economic feasibility of the proposed microhydro system. The project is to be constructed on a 70 % debt ratio at 7 % debt interest rate for a period of 15 years. The table shows the annual revenue and the financial feasibility of the

project. The project is expected to generate 849 MWh of electricity throughout its lifetime of 20 years which if sold to the consumers would generate an electricity export revenue of 50,917 \$. The cost of the energy production was 0.049 \$/kWh which saves an annual life cycle savings of 17,490 \$/yr. The Net Present Value (NPV) of the project is 139,280 \$ and the project is anticipated to recoup all the acquired costs in 3.1 years. The positive value of the NPV, Annual life cycle savings and the payback period confirm the viability of the project.

The RETScreen Expert determines the pre-tax internal rate of return (IRR) on the equity (%), which characterizes the true interest return given by the project equity throughout its life prior to paying income tax. It is computed utilizing the pre-tax yearly cash flows (inflows and outflows) and the project life. It is also denoted as the return on equity (ROE) or return on investment (ROI) or the time-adjusted rate of return. IRR is that interest rate at which the NPV of all the cash inflows and outflows of the project are equal to zero.

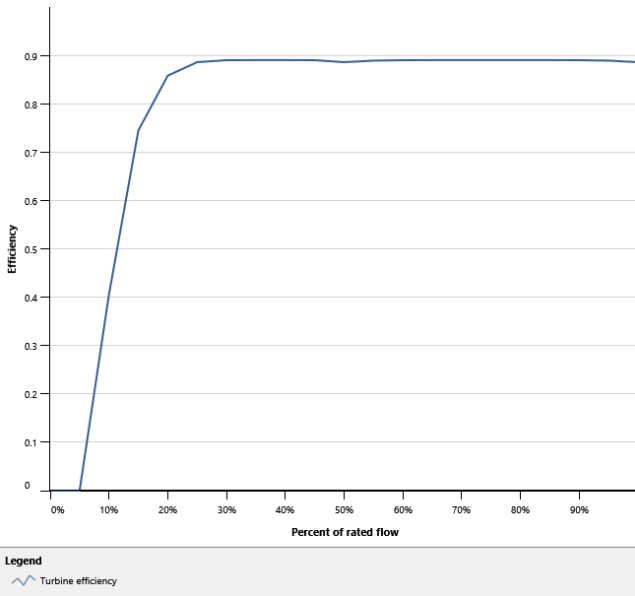


Figure 10: Turbine efficiency curve

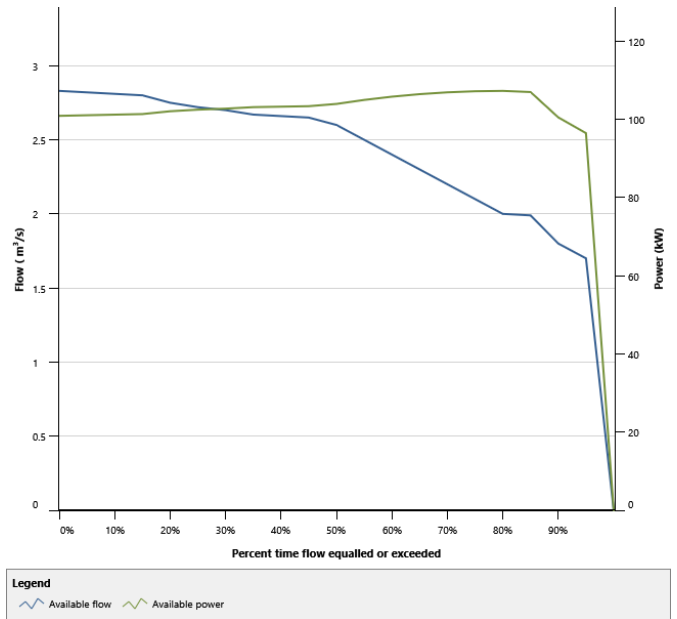


Figure 11: Flow duration and power curve

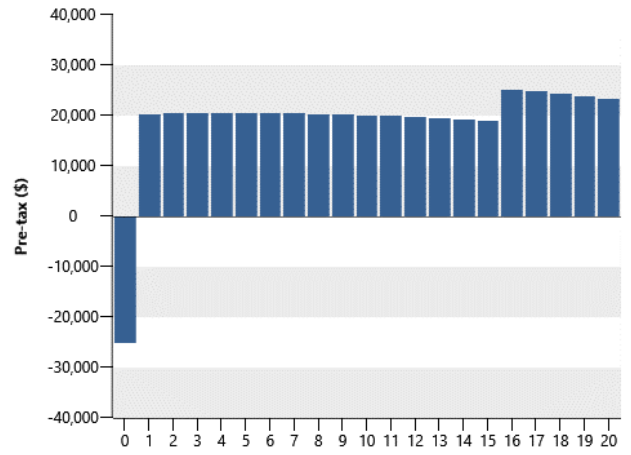


Figure 12: Yearly cash flow

Table 7: Cost summary of the project

Annual revenue	
Electricity exported	849 MWh
Electricity export-revenue	50,917 \$
Electricity export-rate	0.06 \$/kWh
Electricity export-escalation rate	2 %
Gross GHG-reduction	434 tCO ₂ /yr
Gross GHG-reduction (20 yr)	8,673 tCO ₂
GHG reduction revenue	0
Financial viability	
Pre-tax IRR-(equity)	81 %
Pre-tax MIRR-(equity)	20.6 %
Pre-tax IRR-(assets)	24 %
Pre-tax IRR-(assets)	13.5 %
Simple payback period	3.1 yr
Net Present Value (NPV)	139,280 \$
Annual life cycle savings	17,490 \$/yr

GHG reduction cost	-40.33 \$/tCO ₂
Energy production cost	0.049 \$/kWh

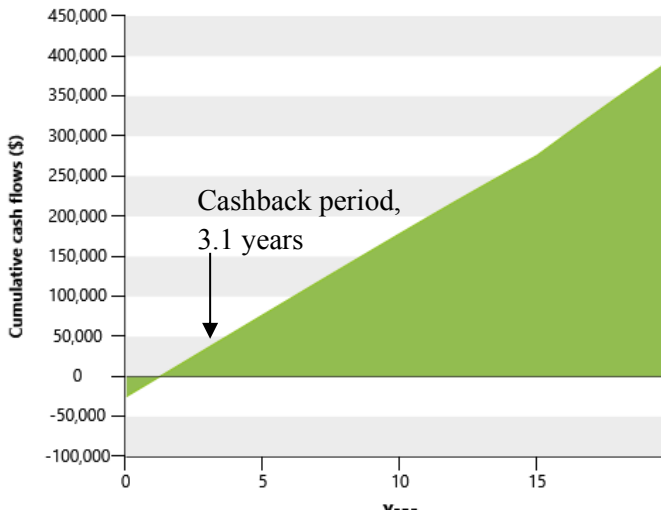


Figure 13: Yearly cumulative cash flow

RETScreen Expert takes the O&M savings, Fuel savings, Periodic savings, production credits, incentives, and GHG credits as the cash inflows whereas the equity investment, O&M payments, annual debt payments, and periodic costs as the cash outflows. In the proposed project, in Pakistan there are no carbon credits on the GHG emission reduction, and no incentives on renewable energy projects. Figure 12 shows the yearly cash flows of the project. In the 1st year there is only equity investment as cash outflow. Subsequently there is annual electricity export revenue after paying the debt payment of 6458.14 \$/yr as shown in Figure 12. After 15th year of the project lifetime, there is an increase

in the electricity revenue as the debt has been paid in first 15 years. Figure 13 shows the cumulative cash flows of the project. For a lifetime of 20 years. It can clearly be seen in the cumulative cash flow diagram that the project earns its all the occurred cost in 3.1 years. At the end of the 15th year there is a growth in the cumulative cash flow because of the absence of the debt payment.

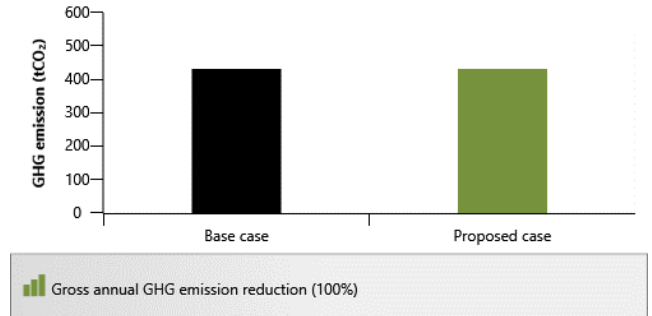


Figure 14: Gross annual GHG emission reduction

4.1. Emissions

RETScreen uses the current energy mix of the country to calculate the Green House Gas (GHG) emissions as baseline data. Figure 16 shows the calculation of the CO₂, CH₄, and N₂O emission factors by using the energy mix of the country by percentage of fuel, T&D losses and the generation efficiency of electricity depending upon the source. RETScreen also calculates the GHG emissions of the proposed project and compares it to the baseline GHG emissions. In the present case, it is shown in Figure 14 that 433.7 tCO₂ is emitted in the baseline whereas there is no emission in the proposed micro hydro energy system. There is 100 % reduction of the gross annual emissions in the proposed system.

Electricity exported to grid	Capacity kW	Electricity MWh	Initial costs \$	Electricity export revenue \$	Fuel cost \$	O&M costs (savings) \$	Simple payback yr	Include system? <input checked="" type="checkbox"/>
Power								
Hydro turbine - 100 kW (45%)	107	849	84,029	50,917	0	24,146	3.1	<input checked="" type="checkbox"/>
Total	107	849	84,029	50,917	0	24,146	3.1	

Figure 15: Summary of the proposed system

Base case electricity system (Baseline)							
Fuel type	Fuel mix %	CO ₂ emission factor kg/GJ	CH ₄ emission factor kg/GJ	N ₂ O emission factor kg/GJ	Electricity generation efficiency %	T&D losses %	GHG emission factor tCO ₂ /MWh
Diesel (#2 oil)	37.0%	70.2	0.0035	0.0104	28.4%	7.0%	0.998
Natural gas	30.0%	49.6	0.0010	0.0009	40.8%	7.0%	0.473
Coal	0.0%	92.7	0.0145	0.0029	33.8%	7.0%	1.073
Hydro	29.0%	0.0	0.0000	0.0000	100.0%	7.0%	0.000
Wind	0.6%	0.0	0.0000	0.0000	100.0%	7.0%	0.000
Nuclear	3.4%	0.0	0.0000	0.0000	30.0%	7.0%	0.000
Electricity mix	100.0%	137.7	0.0056	0.0154		7.0%	0.511

Figure 16: Base case electricity system

5. Conclusion

Hydropower is the cheapest and abundant source of energy in the country. Large hydropower is the proven technology in the country whereas the micro hydro is the old but not explored source of energy. As the micro hydro does not involve any major civil works, it is an early commissioning project. This paper presents the designing of the micro hydropower system for the proposed location of the Jalala Disty canal, and optimization of the proposed system in the RETScreen Expert. RETScreen simulated a micro hydro system of 107 kW for a lifetime of 20 years. The proposed micro hydropower project is a technically viable and financially feasible based on the Net Present Value (NPV) of 139,280 \$, Cost of Energy (COE) of 0.049 kWh/\$, cumulative cash flows of 400,000 \$, and a payback period of 3.1 years. The paper will be a source of inspiration for the local investors and will attract foreign investors in the field of renewable energy in Pakistan.

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