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Performance Analysis and Rehabilitation Prospective of Aged Small Hydropower Plant – A Case Study of Fewa Hydropower Plant (1 MW)

Mahesh Bashyal [a], Laxman Poudel [b]

[a, b] *Department of Mechanical and Aerospace Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] 075msmde011.mahesh@pacampus.edu.np, [b] laxman@ioe.edu.np

Abstract
Fewa Hydropower Plant is under operation since more than 50 years. Due to continuous deterioration of hydro mechanical and electromechanical components, efficiency of the plant has been reduced significantly. The study investigates the plant rehabilitation prospective after conditional assessment status of power plant along with evaluation of performance indices which indicates current operational scenario. In engineering project investments, financial analysis has been regarded of paramount importance. So, overall financial analysis for assessment of rehabilitation along with performance improvement approaches by increasing efficiency, better operational practices, safety and regulatory capacity of hydropower plants results to improve operational stability and reliability of power supply system thus illustrating main objective of rehabilitation of hydropower projects. One lesson of this exercise is to include hydro plants in rationally planned rehabilitation cycles despite of emergency rehabilitation. Energy generation per annum from rehabilitated plant is 5.35 GWh greater than existing plant and difference in Annual Revenue is NRs.35.21 Million. Financial Analysis indicators BC ratio, IRR, NPV and Payback period indicates project feasibility. Thus, the investigations have shown that the project holds great scope for rehabilitation.

Keywords
hydropower, rehabilitation, performance, financial analysis

1. Introduction

Hydropower as a sustainable largest renewable source of energy is non-polluting, low operation maintenance cost, flexible and reliable operation accompanied with high efficiency and longer life. The role of hydropower leading to a renewed concern with the rise of energy prices in the global market, climatic changes as seen in present scenario and water resources aiding increased role for poverty alleviation and economic growth. Greenfield development is the design and construction of a totally new generating station. Noted advantages of rehabilitation schemes compared to greenfield developments are cost effectiveness, a shorter development and implementation schedule, lower hydrologic, socio-environmental and institutional risks and decreased financing risk. Significant generation benefits from improved efficiencies and improved/optimized plant operation as well as reductions in operation and maintenance costs have traditionally provided the economic justification for rehabilitation projects [1].

2. Literature Review

Literature review of aged NEA hydropower plants, performance indices for hydro scheme evaluation and condition assessment and current status of plant diagnosis of Fewa HPP has been studied and illustrated in subtopics.

2.1 Aged NEA Hydropower Plants

Name of HPP	Date (AD)	Remarks
Pharping(0.5 MW)	1911	110 years
Sundarijal(0.97 MW)	1934	87 years
Panauti(2.4 MW)	1965	56 years
Trishul(24 MW)	1967	54 years
Fewa(1 MW)	1969	52 years

Pharping Hydropower Plant, the oldest plant in the history of hydropower development of Nepal has two generating units each 250 kW with total installed capacity of 500 kW. As the water from the penstock has been diverted to drinking water supply purpose, the plant has not been operating for generation of electricity these days. Sundarijal Hydropower Station has two turbo-generator sets with total initial installed capacity of 640 kW. Recently the rehabilitation of this power station is completed along with capacity upgradation of plant to 970 kW. Panauti Hydropower Station is third oldest Hydropower Station of Nepal with installed capacity of 2.4 MW has undergone power station control, monitoring, substation and protection system upgradation works i.e complete electrical rehabilitation a few years ago. Trishuli Hydropower Plant has initial installed capacity of 21 MW having 7 units of 3 MW each. This plant had undergone rehabilitation in 1995 AD and was upgraded to 24 MW with 6 units each 3.5 MW and one unit 3 MW. Presently, the Electro-Mechanical Renovation and Modernization works of Trishuli Hydropower Station is in progress [2-5].

An approach for case study of rehabilitation on NEA based aged small HPP's which has not undergone rehabilitation and refurbishment till date except regular general maintenance is selected. Fewa Hydropower Plant is a canal drop type power station having an installed capacity of 1.0 MW and located at Pardi, Birauta, Pokhara with an annual design generation of 6.5 GWh. The Power Station consists of 4 units of horizontal Francis turbines and generator sets with brush-type excitation system, each producing 250 kW at the generator terminal. It was commissioned in 1969 AD and developed jointly by Government of India and Government of Nepal thus marking above 52 years in operation. The cumulative generation of the station has reached 99.52 GWh till 2077/78 from its first run. FHS harnesses the water discharge from Fewa Lake to generate electricity. The lake is stream-fed with a dam regulating the water reserve.

2.2 Performance Indices

There are various indices for performance evaluation for hydro plant with the use of available operation data. They are listed with determination way as [6-7]:

- Availability factor
  $$= \frac{\text{(Total Hours – Outage Hours)}}{\text{Total Hours}}$$
- Plant Factor
  $$= \frac{\text{Annual energy generation}}{\text{Maximum Possible energy generation}}$$
- Capacity Factor
  $$= \frac{\text{Actual annual energy generation}}{\text{Designed annual energy generation}}$$
- Performance Factor
  $$= \frac{\text{Targetted or Forecasted Energy Generation}}{\text{Actual Energy Generation}}$$
- Annual Energy Generation per Installed Capacity
  $$= \frac{\text{Annual Energy Generation}}{\text{Installed capacity in MW}}$$

2.3 Conditional Assessment of Fewa HPP

Technical and economic life of civil structural components of hydropower plant is found to be on the range of 80-100 years while power house electrical and mechanical components is on the range of 40-60 years [1]. The various components of Fewa HPP with their present conditional status is listed as:

Main Intake Gate: Leakage was observed on all sides of the gates even in the closed position. The hoisting system was in poor condition. Both embedded part and the gate panel were found to be corroded. The railing posts in the intake structures are damaged.

Headrace Channel: The stone masonry lining is damaged in some stretches and facing the slope stability problems in the right bank whereas in some stretches, it is in complete failure state. The concrete of the concrete lined canal has suffered from surface scouring and the reinforcements is exposed and need maintenance

Figure 1: Canal Bifurcation

Forebay: Forebay structure has suffered from the aging, scouring of the concrete surface and some cracks in the structure.

Power house and Equipment Foundations: Due to vibrations suffered by base concrete on running of equipment for over 50 years, it may require reinforcements. The machine foundation from the Main Inlet Valve (MIV) to the Draft Tube Bottom level need to be demolished and re-constructed as per new equipment's dimensions.

Figure 2: Fewa Powerhouse

Tailrace: The tailrace is in proper condition. The tailrace might need to be modified with the change in design for submergence for draft tube during rehabilitation.

Gate and its Hoisting System: Conditions of the gates as well as the hoisting of gates are very poor and need immediate maintenance.

Power Canal Gate: Mud deposited in front of the gate to stop the water leakage implies that it has leakage problems.

Forebay Gates: Embedded guide frames of the gate were found to be exposed due to deteriorated concrete walls. Gate panels as well as the exposed surface of the embedded steel structures were found to be corroded. Legs of the housing of hoisting pinion block were found to be broken for two blocks out of four. There was a remarkable gap between side rubber seal and side sealing frame which will lead to water leakage.

Trash Rack and Trash Rack Cleaning Mechanism: The problem of floating debris was quite evident as the water flows through open canal. So modern trash rash cleaning machine is required.

Penstock Pipes: It was observed that the penstocks were basically intact with some painting deficiency and corrosions in some areas. The thickness of the penstock varies from maximum 5.8 mm to minimum 4.5 mm. Painting with Proper surface preparation sand blasting, coating with zinc riched thin primer, epoxy based intermediate paint and final coating with Polyurethane is required on penstock. Penstock segment from forebay to bifurcation point is good to use even after rehabilitation but due to corrosion and wearing of bifurcation block and branched pipes they are required to be replaced since this portion is located in trench and hadn't painted yet and had suffered high corrosion rate and significant thickness reduction.

Draft Tube: It is found to be corroded with severe wear.

Turbine: There was a substantial water leakage through shaft seal and head cover. Guide vanes had suffered a heavy wear over the years; therefore, the unit efficiency has decreased significantly and operates below rated output. Turbine runners have undergone some pitting due to cavitation. Guide bearing of turbine has also suffered severe wear. On operation, the shaft vibrates, which affects the units' stability.

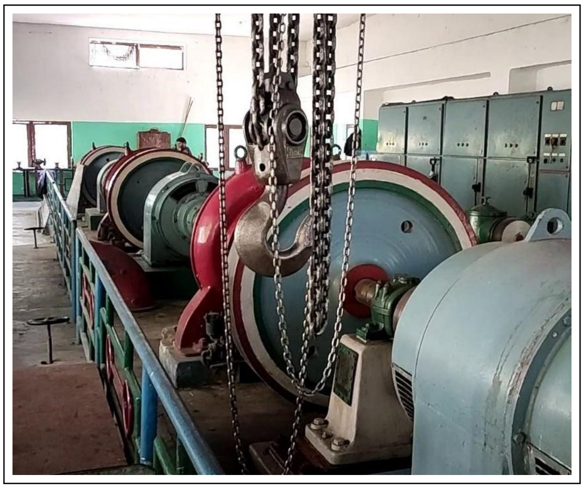

Figure 3: Existing turbine generator units

Generator: The generators are found to be aged with deteriorated insulation quality and wear and tear problem in the bearings, frequent rise up of bearing temperature.

Main Inlet Valve: It has severe corrosion, bad sealing, and low efficiency under manual operation.

Governor: Mechanical operation governor which is obsolete and its spare parts are not available.

Main Transformer: Transformers are suffering from some oil leakage, poor insulation, and surface corrosion, increased no-load and load loss.

11-kV Switchgear Panels: Main components have problems of poor insulation, bad performance and poor reliability.

11 kV Outgoing Line Equipment:Drop-out fuses, lightning arresters are very old and give problems during operation.

Excitation and Control System: Rheostat type AVR is used in FHS which are obsolete and having frequent breakdown problems.

Protection System: All protection relays are of electromechanical type and many of them are not functioning properly.

Crane: It is quite old and can be modernized with latest features.

Thus from the plant diagnosis and conditional assessment of Fewa HPP, rehabilitation assessment implementation is justified.

3. Methodology

Condition assessment is done during the site visit by observation, questioning, interviews, and historical data collections. Since the plant has undergone more than 50 years of operation, conditional status and current performance of civil, hydro mechanical and electromechanical components of the power plant is inspected.

The primary data collected has been taken on the basis of hourly analogue data maintained by operation personals on daily operational log sheets and coded into digital data. Data stored on memory of computers has also been collected.

Secondary data have been collected from various offices of Nepal Electricity Authority (NEA) viz. System Operation Department, Fewa Hydropower Plant and Department of medium generation operation and maintenance office, Generation Directorate, reports, etc. have been referred along with related web portals.

All the quantitative data obtained via primary and secondary mode have been encoded in Microsoft Excel Program and important variables have been studied and analyzed as well as compared with other hydropower plants.

Different performance indices, such as availability of units, plant capacity, capacity factor, performance factor etc., have been calculated at the existing scenario. Cost estimation and benefit of rehabilitation and renovation are studied. The discounting techniques such as Net Present Value (NPV), BC ratio (B/C), Internal Rate of Return (IRR) and Payback Period are calculated for Financial Analysis.

For generation and reliability improvement, in general there are three performance levels for hydropower facilities evaluation and thus these are studied.

(1) The Installed Performance Level (IPL)

(2) The Current Performance Level (CPL)

(3) The Potential Performance Level (PPL)

4. Results and Discussion

Performance evaluation is determined with various power plant performance measuring indices

4.1 Power Plant Evaluation Indices

Energy Generation Profile:

Energy generation profile has been studied considering average of energy generation from F/Y 2070/71 to 2077/78, generation data of last F/Y 2077/78 along with initial designed generation data.

Graph below shows the energy generation trend which shows that plant has been generating less energy/power than designed value and average value. The main reason of decrease in energy generating capacity is due to ageing and high efficiency losses.

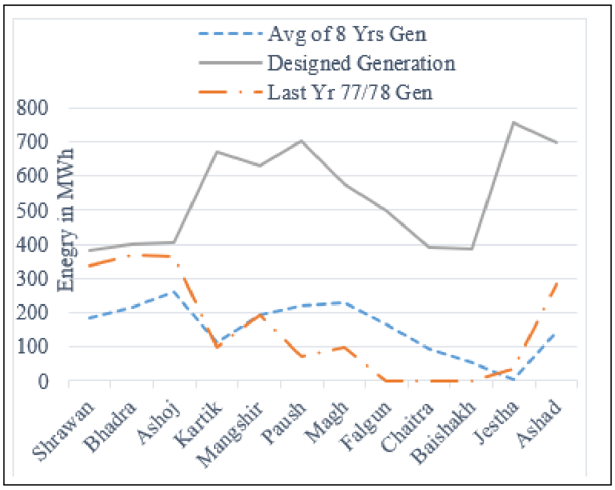

Figure 4: Energy generation profile

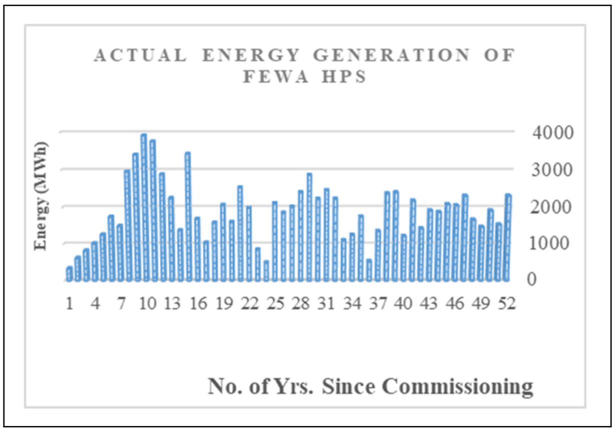

Figure 5: Actual Energy generation over the years

Capacity Factor

Table 1 illustrates the capacity factor for each year which indicates that maximum of 36% of energy has been actually generated with reference to designed energy. The main reason of decrease in energy generating capacity is due to unavailability of generating units, increase in machine breakdown problems and operational issues.

Table 1: Determination of Capacity Factor

SN	F/Y	Annual Design Generation (MWh)	Annual Energy Generation (MWh)	Capacity Factor (%)
1	70/71	6500	2050.14	32%
2	71/72	6500	2310.74	36 %
3	72/73	6500	1664.77	26 %
4	73/74	6500	1467.69	23 %
5	74/75	6500	1911.68	29 %
6	75/76	6500	1531.68	24%
7	76/77	6500	2314.63	36 %
8	77/78	6500	1850.94	28 %

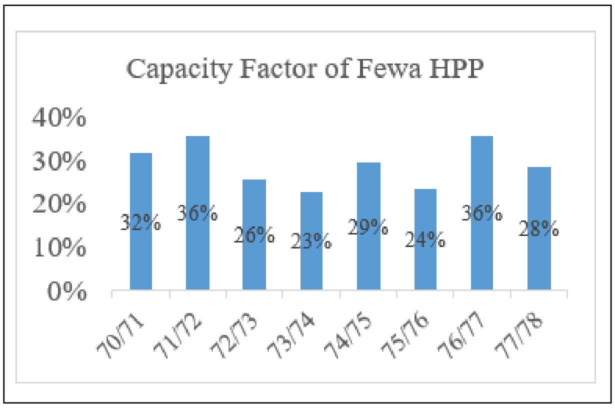

Figure 6: Capacity factor of Fewa HEP

Plant Factor

Table 2 illustrates the plant factor for each year which indicates that maximum of 26% of energy has been actually generated with reference to maximum possible energy that the plant can generate. The main reason of decrease in energy generating capacity is due to unit and plant outages, machine breakdown problems and maintenance issues.

Table 2: Determination of Plant Factor

F/Y	Annual Energy Generation (MWh)	Maximum Possible Energy (MWh)	Plant Factor (%)
70/71	2050.14	8784	23%
71/72	2310.74	8760	26 %
72/73	1664.77	8760	19 %
73/74	1467.69	8760	17 %
74/75	1911.68	8784	22 %
75/76	1531.68	8760	17%
76/77	2314.63	8760	26 %
77/78	1850.94	8760	21 %

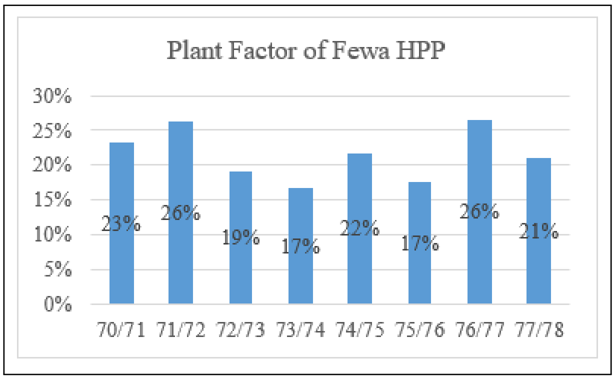

Figure 7: Plant factor of Fewa HEP

Performance Factor

NEA forecasts energy generation for every year on monthly basis considering prescheduled outages, unavailability for unit operation, maintenance activities and generation trends of previous years and evaluates the plant performance annually. Performance factor of Fewa HPP on annual basis are as shown in table 3.

Table 3: Determination of Performance Factor

F/Y	Annual Energy Generation (MWh)	Forecasted Energy Generation (MWh)	Performance factor (%)
73/74	1467.69	2214.02	66 %
74/75	1911.68	1959.55	98 %
75/76	1531.68	2990.36	51%
76/77	2314.63	2699.58	86 %
77/78	1850.94	2493.52	74 %

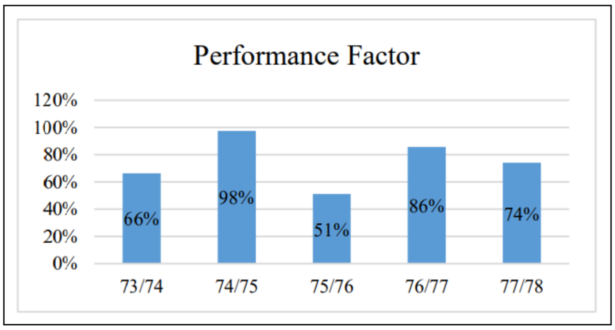

Figure 8: performance factor of Fewa HEP

Machine Availability

Machine availability is the measure for percentage availability of generating units so as to generate electricity. Table 4 shows determination of machine availability which indicates only maximum of 35% of machine on annual basis is available for loading despite of outage hours. This implies generating units frequently suffers from outages and breakdowns which impacts on operational stability of the plant and low power supply response

Table 4: Determination of Machine Availability Factor

F/Y	Actual Hours	Total Running Hours	Total Outage Hours	Machine Availability Factor (%)
70/71	35136	11985.53	23150.47	34%
71/72	35040	12409.75	22630.25	35 %
72/73	35040	9274.62	25765.38	26 %
73/74	35136	9095.00	26041.00	26 %
74/75	35040	10939.82	24100.18	31 %
75/76	35040	8506.43	26533.57	24%
76/77	35040	8506.43	26533.57	24 %

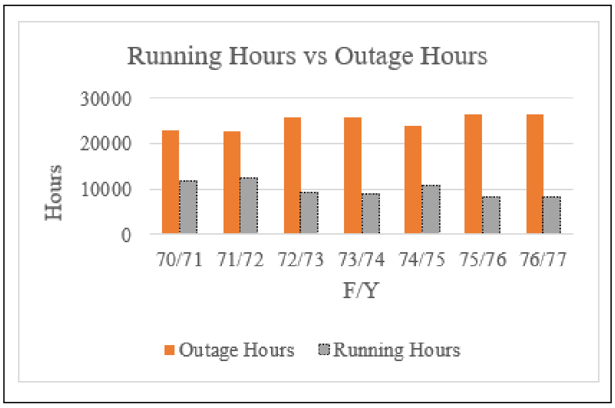

Figure 9: machine availability factor of Fewa HEP

Annual Energy Generation per Installed Capacity

Annual energy generation with respect to installed capacity of Fewa HPP for various fiscal years have been studied and tabulated as below.

Table 5: Determination of Annual Energy Generation per Installed Capacity

F/Y	Actual Energy Generation(GWh)	Installed Capacity (MW)	Energy Generation per Installed Capacity
70/71	2.05	1	2.05
71/72	2.31	1	2.31
72/73	1.66	1	1.66
73/74	1.47	1	1.47
74/75	1.91	1	1.91
75/76	1.53	1	1.53
76/77	2.31	1	2.31
77/78	1.85	1	1.85

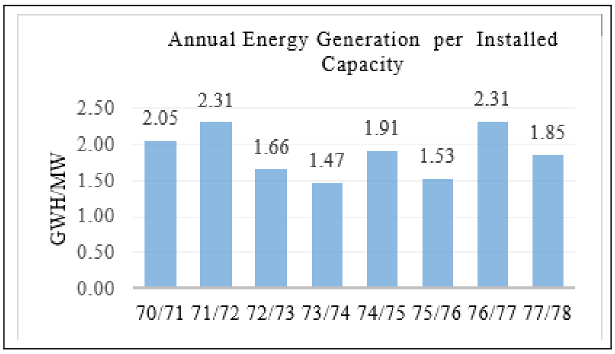

Figure 10: Annual Energy Generation per Installed Capacity

4.2 Rehabilitation Prospectives

Fewa HPP rehabilitation prospective in existing facility restoring to its initial/original performance status with civil structure maintainance works, replacement and new installation of hydromechanical components and complete electromechanical components of power house.

4.3 Rehabilitation Cost

Rehabilitation costs associated with various plant structures and components is computed on the basis of conditional assessment of the plant applied for both options. Table 6 shows the costs for civil works, hydro mechanical and electromechanical works. The scope of rehabilitation includes main canal concrete lining works, forebay maintenance, powerhouse civil maintenance, replacement and new installation of all gates, their hoisting system, trashrack and trash cleaning machine and all power house components except penstock from forebay to bifurcation point.

Table 6: Rehabilitation Costs

SN	Particulars	Total NRs
1	Civil Works	42,430,739.09
2	Electromechanical works	78,792,000.00
3	Hydromechanical Works	8,158,455.29
4	Sub Total	138,800,546.25
5	VAT (13%) on item No 1	6,012,257.03
6	Vat 13 % on 30% of Item no 2 and 3	3,391,067.76
7	Customs duty 1 % on 70% of Item no 2 and 3	608,653.19
	Grand Total	138,896,911.4

(Source: Rate Quotations from MSIPL and ZECO)

4.4 Energy and Revenue Determination

Fewa HPP in existing scenario is generating 1887.79 MWh energy while after rehabilitation it shall generate 7271.45 MWh energy on annual basis. On calculating revenue collection in existing scenario, the plant earns revenue of NRs 12.52 millions while after rehabilitation NRs 47.73 millions in annual basis.

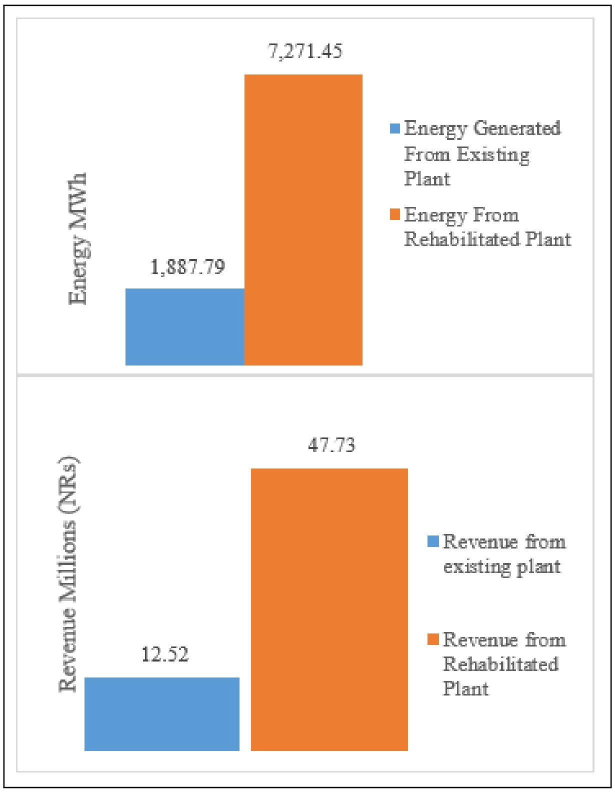

Figure 11: Energy and Revenue Determination

4.5 Financial Analysis

Investment project is analyzed financially with various indices such as B/C, NPV, IRR and Payback period. Determination of these indices helps to assure whether the project is financially feasible or not. For this analysis, existing scenario vs. modified scenario after rehabilitation is performed. Both the cases are investigated and energy generation as well as annual revenue is determined. Detail computations have been performed on the basis of following assumptions.

Assumptions for Financial Analysis

- The rehabilitation period is approximated as 9 months to 1 year.
- Discount Rate or opportunity cost of capital is taken 12 %.
- Rate of sale of energy is considered as NRs 4.80 per unit in wet months and NRs 8.40 per unit for the dry months as per present posted rate of NEA (NEA, 2020).
- The period subject to evaluation is 31 years including 30 years of expected lifetime (economic life) and one year of construction period (DoED, 2012).

- Annual operation and maintenance cost as 8 % of annual revenue with 3% increment annually in existing scenario while O and M cost of 3% of annual revenue with 3% increment annually after rehabilitation
- Outage hours is limited to 4% after rehabilitation
- Insurance cost is 5% of project cost for both existing case and after rehabilitated case.
- Royalty and Tax (overall assumption) is considered to be 20% of net revenue in both the cases.

Financial Analysis Indicators

Detail financial analysis for rehabilitation assessment results computed with rehabilitation cost and revenue collection is as mentioned in table 7.

Table 7: Results of Financial Analysis

B/C	1.61
NPV	84,507,068.11
IRR	19.91 %
Simple Payback Period (Yrs.)	5.00
Discounted Payback Period (Yrs.)	8.08

Thus obtained financial analysis result suggest the projects feasibility as:

- BC ratio (B/C) > 1.
- IRR > 12%.
- NPV > 0.
- Payback Period is less than 10 years.

5. Conclusions and Recommendations

Performance analysis, conditional assessment and financial analysis of Fewa HPP that needs to be rehabilitated shows the following results:

- Operational performance analysis results with average values of Capacity Factor: 30%, Plant Factor: 22%, Availability Factor: 29% and Performance Factor: 75%.
- Conditional Assessment of hydro mechanical and electromechanical components of Fewa HPP shows that the technical and designed life of most of the components has surpassed there by causing safety concerns, unavailability of generating units, ultimately affecting potential energy generation and overall power plant's performance.
- Financial analysis computed with rehab costs and revenue benefits resulted with BC ratio: 1.61, IRR: 19.91%, NPV: NRs 84.5 Millions and Payback period: 8 years, which indicates project feasibility.
- Aged hydro plants which are been continuously operating need to have techno-financial analysis so as to move for rational periodic Rehabilitation cycles rather than emergency Rehabilitation.
- From the case study analysis of Fewa HPP it is highly recommended to concerned organization so as to proceed towards rehabilitation, renovation and modernization. An optimal capacity upgradation with determination of optimized number of power generating units at Fewa HPP is recommended.

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