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

by

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " **Performance Analysis and Rehabilitation Prospective of Aged Small Hydropower Plant – A Case Study of Fewa Hydropower Plant (1 MW)** " submitted by Mahesh Bashyal in partial fulfillment of the requirements for the degree of Master of Science in Mechanical System Design and Engineering.

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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 and it has generated less energy/power than designed generation. 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 resulted with BC ratio: 1.61, IRR: 19.91%, NPV: 84.5 million NRs and Payback period: 8 years, which indicates project feasibility. Thus, investigations have shown that the project holds great scope for rehabilitation, renovation and modernization.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BCR	Benefit Cost Ratio
COD	Commercial Operation Date
DoED	Department of Electricity Development
EA	Electricity Act
IRR	Internal Rate of Return
GoN	Government of Nepal
IPPs	Independent Power Producers
HPP	Hydro Power Project
NEA	Nepal Electricity Authority
NPV	Net Present Value
PPA	Power Purchase Agreement
Pvt.	Private
SHPP	Small Hydropower Project
WB	World Bank

CHAPTER ONE: INTRODUCTION

1.1 Background

Hydropower as a sustainable 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. Among the available energy sources, hydroelectric energy is regarded as the largest renewable source of energy.

In 2020, total hydropower installed capacity increased by 1.6 percent to 21 GW, up from 20 GW the previous year. In the five years between 2016 and 2020, the average year-on-year growth in installed capacity was 1.8 percent. It's worth noting, though, that annual growth can vary significantly depending on when huge projects, which have been in the works for years, are finally completed.

Regardless, if the world is to combat climate change, it will require substantially more hydropower to be created at a far faster rate. Multilateral organizations such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) have previously stated that approximately 850 GW of new hydropower is required to keep global warming below 2 degrees Celsius. To achieve this goal, annual growth of approximately 2% each year would be required on average.

With over 370 GW of installed hydropower capacity, China continues to lead the world. The top five are Brazil (109 GW), the United States (102 GW), Canada (82 GW), and India (50 GW). Japan and Russia are just behind India, followed by Norway (33 GW) and Turkey (31 GW). (Hydropower status report, 2021)

In the context of Nepal, there are various major risks associated with the development of any new hydro project such as geographical issues, construction related issues, clearance risk, social issues etc. These problems and the risks not only increase the gestation period of the project but also delay the return on the investments. However, these risks are not at all associated with the Renovation Modernization & Upgradation (RMU) of old aged hydro plants.

After decades of continuous operation, the components of hydro power plants are susceptible to severe wear and tear, necessitating repair and maintenance at regular intervals. For hydropower plants which are being aged, a periodic stage will come when the alternative of Renovation Modernization and Upgrading (RM&U) appears to be more technically and economically feasible than continuing with routine Operation and Maintenance (O&M).

1.2 Fewa Hydropower Plant (1.0 MW)

Fewa hydropower plant is a canal drop type station with 1 MW of installed capacity and an annual design generation of 6.5 GWh. It is located in Pardi, Birauta, Pokhara. This plant consists of four horizontal Francis turbines and generators with brush-type excitation systems, each generating 250 kW. It was commissioned in 1969 AD and developed jointly by the governments of India and Nepal, which has already been in use for more than 50 years. The station's power generation has attained 99.52 GWh from its first operation till last F/Y 2077/78. Fewa HPP generates energy by harnessing the stream water flow from Fewa Lake.

Table 1: Salient Features of Fewa HPP

Type	Canal Drop
Installed Capacity	1 MW
Annual Design Generation	6.5 GWh
Net Head	74.7 m
Discharge	$2m^3/s$, Q_{100}
Total Length of waterway	1.73 km
Turbine:	
Type and Number	Horizontal Francis, 4
Rated Speed	1000 RPM
Generator:	
Rated output	288 kW
Frequency, Rated voltage,	50 Hz, 400 V
Power Transformer	350 kVA, 0.4/11kV, 4 Nos.
Transmission Line	11kV.

1.3. Problem Statement

Fewa Hydropower Plant has been operating for more than 50 years of time period raises various issues such as low rate of machine availability (i.e. loss of energy generation), low reliability to national grid requirements (increased unplanned and forced outages), growth on maintenance costs, and higher risk of failure of key equipment's and obsolesces of power plant components. The identification of challenges and evaluation of performance measurement indices with proper approaches of performance improvement measures are keys to assess successful rehabilitation projects. Investment cost for rehabilitation of aged hydropower plants and revenue as benefit if evaluated, the project indicates feasibility. The rehabilitation hence is a preferred option to increase the power plant's performance and efficiency along with restoring and extending its life if it is technically and financially viable.

1.4 Objectives

1.4.1 Main Objective

The primary objective of this thesis work is to carry out the performance evaluation and rehabilitation prospective case study analysis of Fewa Hydropower Plant.

1.4.2 Specific Objectives

i. To analyze current performance and operation regime of the power plant

ii. To study the various performance indicators/criteria currently being used across the power industry for power plant evaluation.

iii. To determine rehabilitation costs and revenue benefit after rehabilitation.

iv. To assess the plant for rehabilitation & conduct financial analysis.

CHAPTER TWO: LITERATURE REVIEW

2.1 Aged NEA Hydropower Plants

Nepal Electricity Authority (NEA), Generation directorate, is accountable for the development of new electrical power production/generation projects as well as the optimal operation and maintenance of existing hydropower plants. This organization oversees twenty generating hydropower stations and two thermal power stations. The Generation Directorate's objective is to generate electricity by maximizing the use of available resources while performing routine Overhauling, major corrective and preventive maintenance, and rehabilitation projects on generating stations. Under this directorate, the total installed capacity of Hydropower Stations and Thermal Power Stations has reached 573.29 MW and 53.41 MW, respectively. (Generation Directorate, NEA, 12th issue, 2020). The generation history of a particular hydropower plant represents the current status of generation, breakdown/corrective maintenance outage durations, inflow trends, and hydrology of the location, load dispatch conditions and turbine/generator efficiencies. (A Year in Review, NEA, 2020)

Aged hydropower plants under Nepal Electricity Authority (NEA) which has exceeded 50 years of normal operation of plant have been listed in Table 2.

Table 2: Aged Hydropower Plants of Nepal

S.N	Name of Hydropower Plant	Commissioning Date (AD)	Remarks
1.	Pharping Hydropower Plant (0.5 MW)	1911	No Operation
2.	Sundarijal Hydropower Plant (0.97MW)	1934	87 years
3.	Panauti Hydropower Plant (2.4 MW)	1965	56 years
4.	Trishuli Hydropower Plant (24 MW)	1967	54 years
5.	Fewa Hydropower Plant (1 MW)	1969	52 years

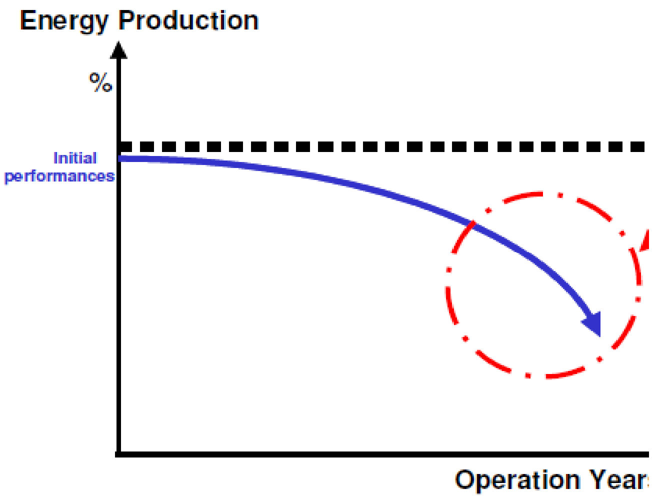
The Pharping Hydropower Plant features two generating units, each of which is capable of producing 250 kW, for a total installed capacity of 500 kW. In our country's history of hydropower development, this is the oldest facility. The power station has been producing electricity since 1982 AD (2038 BS). The plant has not been working for the generation of power these days because water from the penstock has been transferred to Kathmandu's drinking water supply, though it has been placed in standby mode to operate sometimes and to demonstrate to tourists being one of the most historic plant.

The Sundarijal Hydropower Station is equipped with two turbo-generator sets with a total installed capacity of 640 kW. Under the joint support of ADB and GoN, the restoration of this power station was recently completed, including capacity upgradation of the plant to 970 kW, Plant Control System, and civil enhancement work at the intake and head pond.

Panauti Hydropower Station is Nepal's third-oldest hydropower station, having been operational since 1965. This is a run-of-river scheme hydroelectric plant with a 2.4 MW installed capacity. The station was built with the dual objective of generating electricity and providing irrigation. However, the canal's water has also been used as a source of drinking water. A few years ago, this plant underwent upgrades to its power station management, monitoring, substation, and protective systems.

Trishuli Hydropower Plant, built with Indian government assistance was completed in 1967 AD. It has a total installed capacity of 21 MW, with seven 3 MW units. In 1995 AD, this plant was refurbished and upgraded to a capacity of 24 MW, with six 3.5 MW units and one 3 MW unit. Trishuli Hydropower Station is currently undergoing electro-mechanical renovation and modernization. (Generation Directorate, NEA, 12th issue, 2020)

2.1.1 Key issues of aged Hydro Power plants:



(Goldberg, 2004)

Figure 1: Graph showing Performance vs. Operation years

Aged hydropower plants generally suffer with the following problems

- Low rate of availability (loss of generation)
- Low reliability to answer to grid request (increase of outages)
- Increase of maintenance costs.
- Obsolescence of components.

2.1.2 Criteria used to assess quality of components:

The various components of hydropower plant such as civil structures, hydro mechanical and electromechanical structures deteriorate while undergoing continuous operation for decades of years. In general these components have technical and economic lifetime which can be illustrated with rapid assessment rating as indicated in table 3.

Table 3: Rapid Plant Components Assessment Rating

Plant Components	**Economic Lifespan (Yrs.)**	**Technical Lifespan (Yrs.)**	**Evaluation Rating**			**Fewa HPP Rating**	
			Good (<=)	**Fair (<=)**	**Poor (>)**	**Economical Rating**	**Technical Rating**
Electrical Systems							
Transformers & Generators	40	60	25	45	45	Poor	Poor
Control Equipment's, Auxiliary Equipment, Switchgear, etc.	25	40	20	35	35	Poor	Poor
DC Equipment's, Batteries	20	30	10	25	25	Poor	Poor
Mechanical Systems							
Hydro-Turbines							
Francis and Kaplan Turbines	40	60	30	45	45	Poor	Poor
Pelton Jet Turbine	50	70	40	55	55		
Storage Pumps and Pump turbines, etc.	33	50	25	33	33	Poor	Poor
Mechanical Components: Gates, Butterfly valves, special valves, auxiliaries	40	50	25	37	37	Poor	Poor

(Source: Goldberg, 2004)

2.2 Site Observation and Plant Diagnosis of Fewa HPP

Fewa HPP generates energy by harnessing the water flow from Fewa Lake which is regarded as semi-natural freshwater lake, stream-fed with a dam regulating the water reserve. It has an average depth of about 8.6 m (28 ft.) and a maximum depth of 24 m (79 ft.). Maximum water capacity of the lake is approximately 43,000,000 m^3.

From the field observation, it is found that the canal from Fewa Lake up to the diversion point requires repair and maintenance along with fencing but the power canal up to forebay is basically intact with fencing requirement. The forebay and powerhouse may warrant some modifications in civil structures. Being a power station crossing fiftieth year of operation, most of the Power Station equipment have aged and have surpassed their designed lifespan, thereby, causing safety concern, low efficiency, and increased operation and maintenance cost.

Existing Status of Structures and Components

Fewa HPP possess various civil structures, hydro mechanical and electromechanical components. Their current existing status are listed as:

Head works

The head works consist of a Gravity Dam and a common intake for withdrawal of total 8 m^3/s of water; 2 m^3/s of it is for power generation and remaining 6 m^3/s is for irrigation. As the dam has been made with the main purpose of Lake Impoundment, its regulation and maintenance is not relevant in the current rehabilitation. The common intake is without any control structure. The intake gate is in operation but needs regular maintenance. 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

Fewa HPP has a common intake and a common canal meant for both irrigation as well as the power generation. The common intake draws 8 m^3/s water through Fewa Lake and after 730 m length, the canal branches out into three canals: two for irrigation and the other for power generation. 2m^3/s of water is used for power generation which flows through an open channel to meet the Forebay, upstream of Powerhouse. The canal from intake to the branching point is termed as the main canal and the canal only for power generation is termed as the power canal in this report.

The main canal is designed for open channel flow with stone masonry linings in some stretches, reinforced concrete lining in others whereas some stretches are left unlined. Some stretches of the unlined canal are suffering from the slope instability and blockage by the debris. 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 slope stability problem has led to the slope failure and it is damaging the roads which is constructed on the bank of the main canal. The concrete of the concrete lined canal has suffered from surface scouring and the reinforcements is exposed and need maintenance. Also, since the channel is open, the problem of floating debris like plastic bottles, polyethylene bags is quite prominent.

Figure 2: Bifurcation of canal into Irrigation Canal and Power Canal

Forebay

The Reinforced Concrete structure forebay is constructed at the end of power canal to provide necessary submergence and reduce the water hammer pressure for penstock pipe. Forebay structure has suffered from the aging, scouring of the concrete surface and some cracks in the structure. The scouring in the concrete is not severe and the reinforcements are not exposed. The wall of the spillway is damaged and need maintenance. The Spillway water need to be properly conveyed to the nearest stream. Forebay is not fenced and elevation level is not marked. The strength of Concrete seems satisfactory from the non-destructive tests conducted during site visit but this requires further tests to determine the actual strength of the concrete and the actual condition of rusting in the reinforcement bars.

Power house and Equipment Foundations

There is a surface powerhouse with four horizontal Francis turbines with enclosed switchgear and control panels in a single hall. There is not a separate erection bay but the space is adequate for installation and maintenance propose. Due to vibrations suffered by base concrete on running of equipment for over 50 years, it may require reinforcements. The strength of concrete from the non-destructive tests during site visit seems satisfactory but this needs further tests to determine the actual strength of the concrete and the actual condition of rusting in the reinforcement bars. The submergence of draft tube is maintained by rising the water level in tailrace by placing the Stop logs in Tailrace. The machine foundation from the Main Inlet Valve (MIV) to the Draft Tube Bottom level need to be refurbished after demolition of existing foundation so as to comply with the new equipment’s dimensions.

Tailrace

The tailrace is of open channel cascade type which lets the water flow out of the system. 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

There are in total, four number of gates in the Fewa HPP: First gate at the Intake of Main canal, second at the canal bifurcation point (Main and power canal) and remaining two at the Forebay outlet. Conditions of the gates as well as the hoisting of gates are very poor and need immediate maintenance.

Power Canal Gate:

The power canal gate has suffered corrosion and wear, the 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 Cleaning Mechanism

The problem of floating debris was quite evident as the water flows through open canal. Debris including mainly polyethylene bags, plastic bottles were found embedded in the trash rack panel which may pose a serious problem to the plant. Due to the unusual nature of the debris, it has become a one-of-a-kind problem that a conventional trash rack mechanism is unable to address. Although the trash rack at the inlet of forebay was repaired and maintained earlier, there are still problems with debris management. As of now, the trash rack is being cleaned manually but it seemed to be lacking a regular cleaning schedule.

Penstock Pipes

Two penstock pipes each of 150 m length and 660 mm diameter, convey the water to the surface powerhouse generating a net head of 74.7 m.

From visual inspection, it was observed that the penstocks were basically intact with some painting deficiency and corrosions in some areas even though the penstock pipes seemed to be painted recently.

The bifurcation couldn't be inspected as there was no manhole or inspection hole over or near it. The penstock immediately after the bifurcation block was observed to be in a much corroded state with no painting whatsoever.

Penstock can be made more durable and long lasting with sand blasting and surface preparation, zinc riched primer coating at first stage, epoxy coating at intermediate layer and finally with polyurethrene coating.

Turbine

Fewa HPP has four sets of horizontal Francis Turbines each of 288 kW capacity. The turbines were manufactured in Germany.

Figure 3: Turbine-generator units at Powerhouse

Specifications of existing Turbine units:

Rated head	: 71.5 m
Rated water flow	: 0.496 m^3/s
Rated output	: 288 kW
Speed	: 1000 rpm

Out of four power generating units of Fewa HPP, Presently, only two units are in operation but rest other two units are under partial and non-operational status. In last fiscal year i.e. 2077/78 this plant had achieved 1.85 GWh energy. The turbines have aged and suffered substantial wear over 50 years of continuous operation since its commissioning in 1969 AD. Moreover, the spare parts for the outdated equipment are unavailable in the market. Without spare parts, units has stopped operating altogether. And the remaining units have been operating in low efficiency requiring frequent shutdowns. The problems diagnosed at this stage are as follows:

- There is a substantial water leakage through shaft seal and head cover.
- Guide vane has 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.
- Additionally, the deteriorated turbine poses a safety hazard.

Draft Tube

Draft Tube seems to be corroded as it has been working for last 50 years. Moreover, Stop log panels were found to be used to maintain the submergence for the draft tube.

Generator

The Power Station has 4 units of generators, each with 250 kW rated capacity, producing power at 400 V and 0.8 power factor. The generators are found to aging with deteriorated insulation quality, thus giving rise to safety concerns. The generators are found to have serious wear and tear problem in the bearings. An increase of bearing temperature forbids longer operation.

Main Inlet Valve

The existing main valve of power station is a manual operation gate valve which is already in operation for 50 years and has exceeded the service life. It has severe corrosion, bad sealing, and low efficiency under manual operation crew. Although it has been functioning with years of repairs, it is found to be in vulnerable state.

Governor

Fewa HPP has a mechanical operation governor which is outdated and its spare parts are not available anymore. Since new technology will be implemented during rehabilitation, it is more likely to be replaced with latest modern features with automation.

Main Transformer

Fewa HPP has four sets of three phase, 0.4/11 kV, 350 kVA main transformers, manufactured in Germany. The transformers have been in operation for long period. Due to long periods of operation, these transformers are suffering from some oil leakage, poor insulation, and surface corrosion, increased no-load and load loss.

11-kV Switchgear Panels

Four chambers of 11 kV high-voltage switch cabinets with fuse system are installed in the power station. Through 53 years operation, the insulation is aged and the performance is decreased, requiring frequent equipment shutdowns and maintenance. Eight chambers of 0.4 kV low voltage distribution cabinets and fixed low voltage switch cabinet are installed and in operation since 1969 A.D. The cabinet structure is outdated. Main components have problems of poor insulation, bad performance and poor reliability. The cabinets have severe safety hazard and so they need to be replaced entirely.

11 kV Outgoing Line Equipment

The 11-kV side of 350 kVA 11/0.4 kV transformers are connected to overhead 11 kV ACSR Bus Bar through XLPE cable. The outgoing 11 kV line bay consists of 11 kV drop-out fuses, 11 kV current transformers, and 11 kV Potential Transformers and surge arresters. These drop-out fuses are very old and give problems during operation. These drop-out fuses, lightning arresters need to be replaced.

Excitation and Control System

Rheostat type AVR is used in Fewa HPP 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.

Station Auxiliaries

The station auxiliaries are supplied at 400V from 50 kVA station auxiliary transformer. The earthing and lightning protection of the powerhouse can be maintained with proper correction measures and modernized.

Crane

Overhead travelling crane of 5-ton capacity was found to be in a working condition. The rails were also functionally intact. However, it is quite old and can be modernized without major deviations.

2.3 Performance Analysis of Hydropower Plant:

Main Objective of Performance analysis of hydropower scheme owes for quantifying plants generating units' improvement, examine optimal operational basis, maintenance- and existing equipment's potential improvement zones so as to increase energy extraction and improved reliability. Generating unit's availability is an important indicator for weighing the overall performance of the plant.

In general there are following performance levels of every hydropower plant:

i. Installed Performance Level (IPL)

ii. Current Performance Level (CPL) &

iii. Potential Performance Level (PPL).

The Installed Performance Level (IPL) is the maximum level that the facility can achieve under intended conditions right after testing & commissioning (which exactly matches with installed details name plate). Due to continuous wear and tear of working equipment and/or changes in the limits placed on a facility that prevent it from operating as originally designed, the current Performance Level is often lower than the Installed Performance Level. However, if the plant has undergone some modernization/ renovation or has used improved operation and maintenance procedures, CPL can be higher than IPL. The maximum level of performance that could be achieved under current operating conditions is known as the potential performance level.

The performance of a hydropower plant is assessed using a variety of performance metrics. (Joshi 2015, Aminu 2011). The main goal of the plant rehabilitation is to increase power supply operational stability and reliability by boosting capacity, efficiency, and safety (Raut, 2018). Going thoroughly with the energy generation data of fewa hydropower for last three years as compared to the annual design generation i.e.6500 MWh, it has generated 1531.68 MWh, 2126.54 MWh and 1850.52 MWh annual energy in last three fiscal years respectively. (Generation Directorate, NEA, 12th issue, 2020)

Data for Performance Analysis

Generating unit's characteristics data, plant operational data, and existing hydrological data are the most important data sources for performance assessments. (Dahal, 2013). The next subsections go over each of these data kinds.

Generating Units Characteristics Data

Hydroelectric power plants utilizes the potential energy of stored water and the kinetic energy of flowing water into electricity, which is a useful source of energy. The efficiency equation, defined as the ratio of the power delivered by the unit to the power of the water moving through the unit, describes this essential process for a hydroelectric generating unit. P is the output power, g is the acceleration of gravity, Q is the water flow rate to the turbine, and H is the net head across the unit.

$$\eta = \frac{P}{\rho g Q H} \dots \dots \dots (i)$$

Plant Operational Data

Plant personnel, central engineering staff, and load control personnel are all common sources of operational data for facilities (if applicable). It's a good idea to conduct a preliminary data survey to figure out "what, how, where, and who:"

- What performance-related metrics are being tracked?
- How accurate are the parameters?
- What is the location of the archive data?
- Who should be contacted in order to access archival data?

Hydro power station operation and maintenance should attempt to reduce failure rates by ensuring the power utility's smooth operational levels. This can be accomplished by establishing a regular preventive maintenance program for all critical areas of the power plant. So that the total performance of the hydro plant can be maximized.

For the performance analysis of hydropower plants the following performance indices are generally examined: (Raut 2018 & Joshi 2016)

1. Annual Energy Generation per Installed Capacity
2. Station Loss
3. Economic Efficiency
4. Staffing Level (No. of employee per MW)
5. Availability Factor
6. Plant Factor
7. Capacity Factor
8. Performance Factor

1. Annual Energy Generation per Installed Capacity

It is a measure of energy generation achieved by the power plant on annual basis to its installed capacity. It can be compared with designed value for analysis purpose.

It can be expressed as:

$$\text{Annual Energy Generation per Installed Capacity} = \frac{\text{Annual Energy Generation Capacity MWh}}{\text{Installed Capacity MW}} \dots\dots\dots (ii)$$

2. Station Loss

It is expressed in percentage which indicates the energy consumed by energy generating power station itself under consideration with respect to the available generated energy.

It can be expressed as:

$$\text{Station Loss} = \frac{\text{Available energy} - \text{Utilized energy}}{\text{Available energy}} \dots\dots\dots (iii)$$

3. Economic Efficiency

Economic Efficiency refers to the generation cost developed during the generation of one unit of electricity (i.e. 1 kWh) from the power plant. It includes various costs such as fixed assets, O&M expenditures, royalty, taxes, depreciation, interest and overhead expenses.

It can be expressed as follows:

$$\text{Economic Efficiency} = \frac{\text{Generation cost}}{\text{Energy generation kWh}} \dots\dots\dots (iv)$$

4. Staffing Level

Staffing Level expressed as Staff/MW, is the ratio of the number of staffs/employees allocated, at a given point in time, divided by the designed plant capacity.

$$\text{Staffing Level} = \frac{\text{No. of Staffs}}{\text{Installed capacity MW}} \dots\dots\dots (v)$$

5. Availability Factor

The availability factor of a power plant is duration of time (measured in hours), the unit/machine that is available to produce electricity, divided by the amount of the total time in that period. It can be expressed as:

$$\text{Availability Factor} = \frac{(\text{Total Hours} - \text{Outage Hours})}{\text{Total Hours}} \dots\dots\dots (vi)$$

6. **Plant Factor**

It is the ratio of energy generation of hydro power plant to its maximum possible energy generation on annual basis. It can be expressed as:

$$\text{Plant Factor } = \frac{\text{Annual energy generation}}{\text{Maximum Possible energy}} \ldots\ldots\ldots (vii)$$

7. **Capacity Factor**

It is calculated with the ratio of energy generation to initially designed energy generation on annual basis. It can be expressed as:

$$\text{Capacity Factor } = \frac{\text{Actual energy generation}}{\text{Designed energy generation}} \ldots\ldots\ldots (viii)$$

8. **Performance Factor**

Performance Factor is calculated with targeted or forecasted energy generation divided by the actual energy generation achieved by the power plant on annual basis. It can be expressed as:

$$\text{Performance Factor} = \frac{\text{Targetted or Forecasted Energy Generation}}{\text{Actual Energy Generation}} \ldots\ldots\ldots (ix)$$

2.4 Hydro Plant Rehabilitation and Renovation

The major goal of rehabilitation and renovation is to extend the life of existing facilities and return them to their original performance levels. In contrast, including upgrading the equipment (efficiency, output) that delivers more output but at higher costs can often be justified by the additional revenue during the equipment's service life. (Goldberg, 2004). The goal of rehabilitation is to keep and preserve what is presently working, and then to consider gradual improvements in capacity at existing facilities, ideally at a low cost and with little delay. Significant generation gains from increased efficiency and optimized plant operation, as well as cost savings from operations and maintenance, have generally been used to justify rehabilitation initiatives.

Following listed points are various benefits after rehabilitation and modernization of power plants:

- Effective, efficient & quality Operation/ Maintenance
- Reliability
- Downtime Reduction
- Higher availability
- Better Safety Concerns
- Modern Technological adoption
- Life enhancement/extension
- Generation Benefits with less expenditure rather than equivalent new projects in short time frame basis.

Steps and measures for rehabilitation analysis includes the following tasks:

❖ A site visit to the powerhouse to inspect the producing unit, preferably during a period of routine maintenance, is one of the most common duties involved with rehabilitation analysis.

❖ Interviews with plant maintenance employees and review of past turbine/generator status assessments and maintenance records

❖ Assessing the state of equipment is an important aspect of the restoration process. This data can be used to determine the equipment's representative age rather than its physical age.

❖ Cost estimates and timetables for life extension and/or upgrading options should be developed.

❖ Create efficiency curves for current units as well as units that will be upgraded or extended in life.

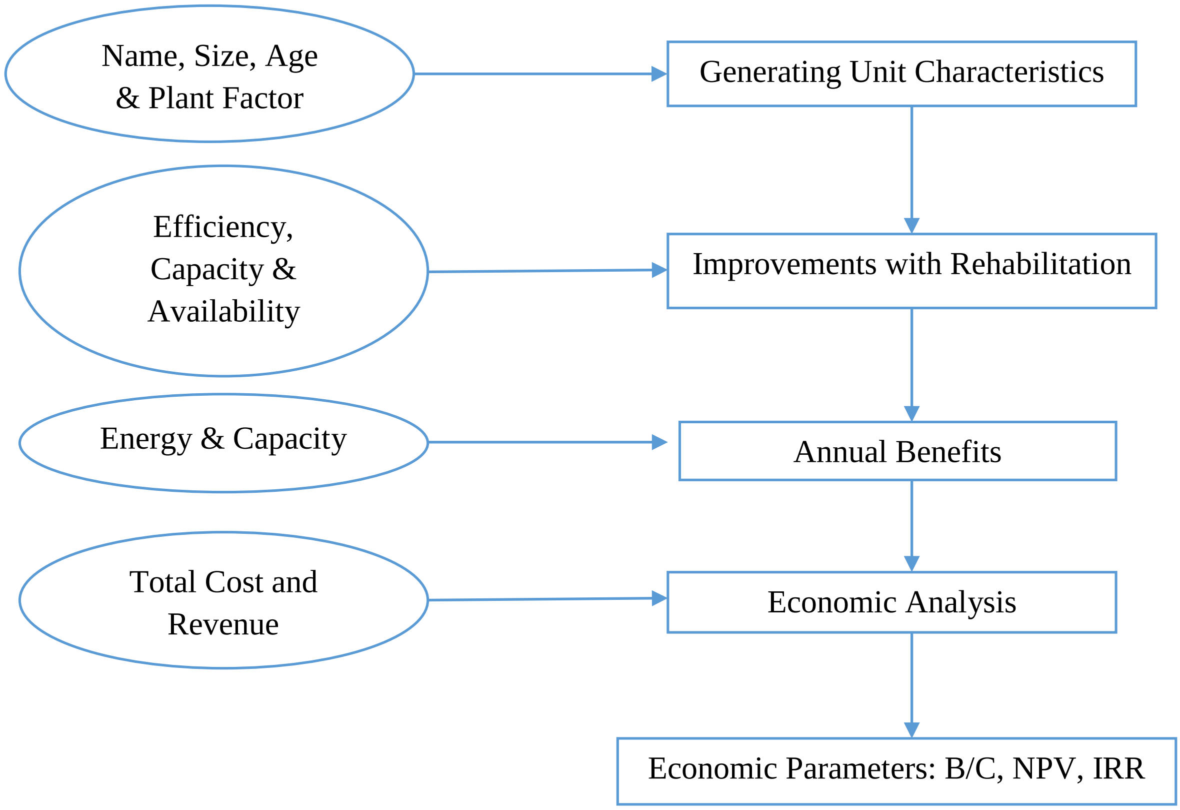


Figure 4: Flow Chart of Rehabilitation Assessment

2.5 Efficiency

The most significant factor is efficiency, and upgrading potential can be divided into three categories:

- As a result of technological advancements, today's efficiency are higher than they were 50 years ago.
- Age-related deterioration in efficiency (wear and tear).
- Changes in hydrological conditions or operations may cause the operating range to differ from the original design.

According to J.L. Gordon (2001), the following equation can be used to illustrate the change in turbine efficiency through time in terms of technology:

$$\Delta\varepsilon(year) = ((1998 - \mathrm{y}) \mid B))\hat{}x$$

Gordon claims that peak efficiency improvements are asymptotical, meaning that a unit newer than 1998 has only minor gains over 1998. (B) and (x) are used constants.

2.6 Energy Generation of Fewa Hydro plant in Existing Scenario

Fewa HPP, designed installed capacity of 1 MW with designed energy generation (on annual basis) is 6500 MWh. Table 4 below shows the energy generated by existing power plant from 2070/71 B.S. to 2077/78 B.S. years. Tabulated data clearly shows that it is producing less power/ energy when considered designed value. Ageing and high losses are the primary causes of decreased energy production capacity. If energy generation trend of other NEA hydro plants of Nepal such as Kaligandaki 'A', Marsyangdi, etc. are analyzed, it is found that they are generating more energy than their design generation in some years. The Figure 5 shows the design generation and energy generated by 1 MW Fewa HPP. Therefore, the plant possess great potential for rehabilitation as well as capacity upgradation to increase energy generation. (Generation Directorate, NEA, 12th issue, 2020)

Table 4: Energy Generation of Fewa HPP in existing Scenario

Months	Energy Generated in MWh							
	2070/71	2071/72	2072/73	2073/74	2074/75	2075/76	2076/77	2077/78
Shrawan	219.99	213.03	150.05	122.48	197.55	107.05	142.57	338.81
Bhadra	218.91	214.69	168.84	168.43	214.59	157.01	231.93	370.64
Ashoj	254.94	262.60	180.82	180.27	243.39	234.24	374.23	366.26
Kartik	121.17	104.11	122.55	86.39	130.34	67.96	157.25	97.29
Mangshir	222.90	270.38	195.60	114.53	223.82	89.09	231.96	191.48
Paush	249.58	362.94	228.59	214.88	250.41	39.28	353.00	72.09
Magh	232.50	282.77	225.15	228.40	237.35	190.00	326.46	96.69
Falgun	215.60	197.66	130.27	152.29	219.53	223.82	208.67	0.00
Chaitra	100.90	171.52	109.21	37.46	102.27	209.32	29.19	0.00
Baishakh	64.73	102.80	26.53	0.00	0.00	115.53	138.76	0.00
Jestha	0.00	0.00	0.00	0.00	0.00	0.00	4.64	33.89
Ashad	148.92	128.24	127.16	162.56	92.43	98.42	115.97	283.79
Total	**2050.14**	**2310.74**	**1664.77**	**1467.69**	**1911.68**	**1531.72**	**2314.63**	**1850.94**

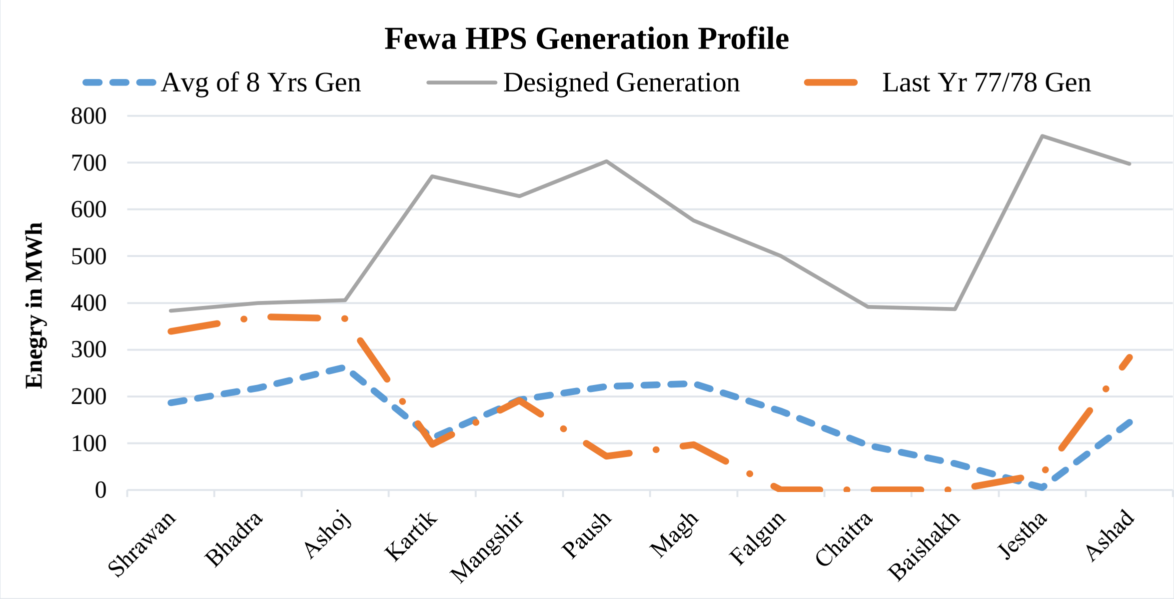


Figure 5: Graph showing design vs. actual energy generated by Fewa HPP

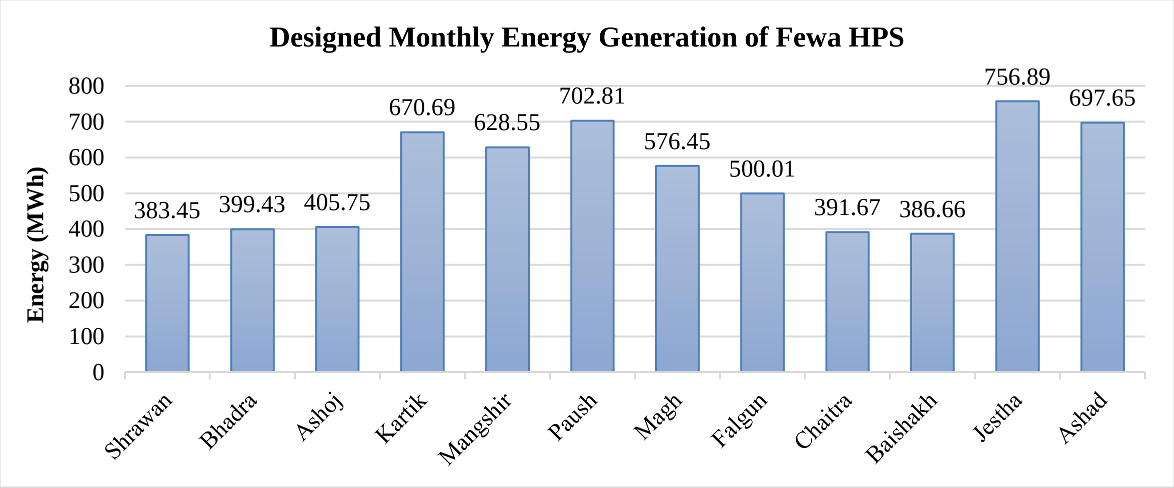


Figure 6: Designed Energy Generation on monthly basis

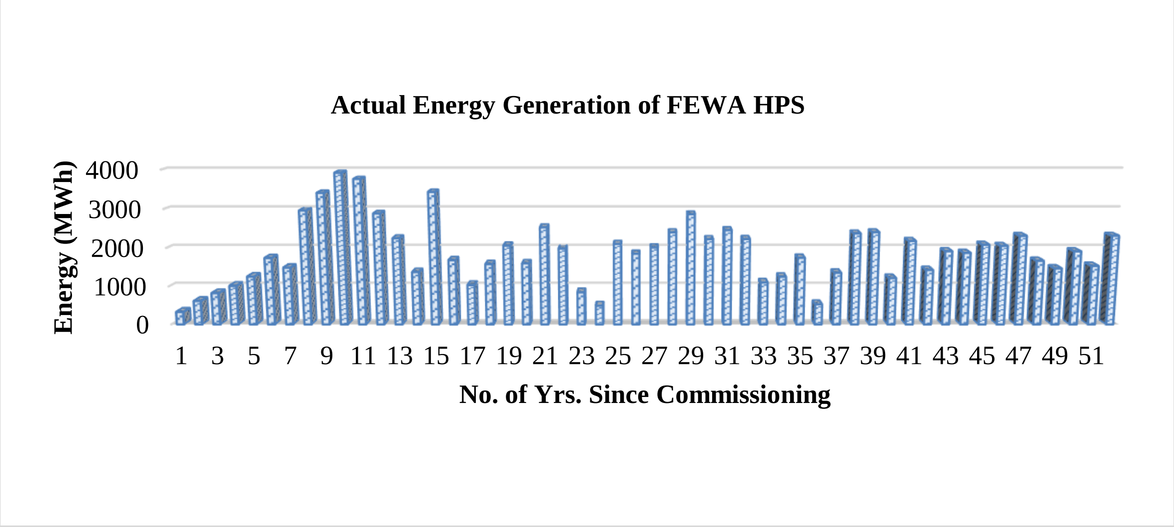


Figure 7: Energy Generation vs. No. of years since commissioning.

Thus, rehabilitation and renovation of Fewa HPP is needed due to following reasons:

- Fewa HPP currently is in operation for 53 years surpassing technical designed lifespan. Hydro mechanical and electromechanical components, in particular, are deteriorating. Their effectiveness has been severely damaged. Operating such old and degraded components is difficult and unsafe. New, high-efficient power plant components are to be installed.
- This facility has been producing less electricity than it was designed to.
- The plant's efficiency and energy output capacity can be increased through rehabilitation and upgrade using new technologies.
- Ensures system voltage stability by generating reactive power near the major load center.

2.7 Investment criteria for financial viability

Investment criteria which are commonly used to aggregate and compare costs and benefits are listed as:

Benefit Cost (BC) Ratio

The benefit cost ratio (also known as the benefit-to-cost ratio) compares the present value of all benefits to the project's costs and investments. These benefits and costs are modeled as monetary cash flows or their equivalents. Its significance is determined by the value it represents. Refer to the following three generic BCR value ranges for interpretation:

BC Value Range Ratio	General Interpretation
BCR < 1	Investment option is a loser.
BCR = 1	Investment option is no profit & no loss.
BCR > 1	Investment option is profitable

Net present value (NPV)

The difference between the current value of cash inflows and withdrawals over a period of time is known as net present value (NPV). The net present value (NPV) is a calculation used in capital budgeting and investment planning to determine the profitability of a proposed investment or project. The current total worth of a future stream of payments is calculated using net present value, or NPV. If a project's or investments net present value (NPV) is positive, it signifies that the discounted present value of all future cash flows associated with that project or investment is positive, and hence appealing. The present value of an investment's future cash flows above the investment's initial cost is calculated using net present value (NPV). If deducting the investment's initial cost from the total of current cash flows yields a positive result, the investment is beneficial.. NPV is given as

$$NPV = \frac{R}{(1+i)\hat{}t}$$

R= Net Cash Flow at time t,   i= Discount rate & t = Time of the cash flow

Internal rate of return (IRR)

The internal rate of return (IRR) is a financial statistic that is used to calculate the profitability of possible investments. In a discounted cash flow analysis, the IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero. When comparing investment choices with similar features, the one with the highest IRR is likely to be the best. The annual rate of growth that an investment is predicted to create is known as the internal rate of return (IRR). The IRR is calculated as follows:

$$0 = \mathrm{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0$$

C_t = Net cash inflow during the period t

C_0 = Total initial investment costs

IRR = Internal Rate of Return & t = Time periodin years

Payback Period

The payback period is the amount of time it takes to repay the cost of an investment or to reach breakeven for an investor. The attractiveness of an investment is proportional to its payback duration. Longer payback periods are less desirable, while shorter payback periods are more appealing. The payback period is determined by dividing the investment amount by the annual cash flow. The main distinction between a basic payback period and a discounted payback period is that the former refers to length of time it takes to recoup the cost of an investment, whilst the latter estimates the time duration it takes to recover the cost of an investment considering time value of money.

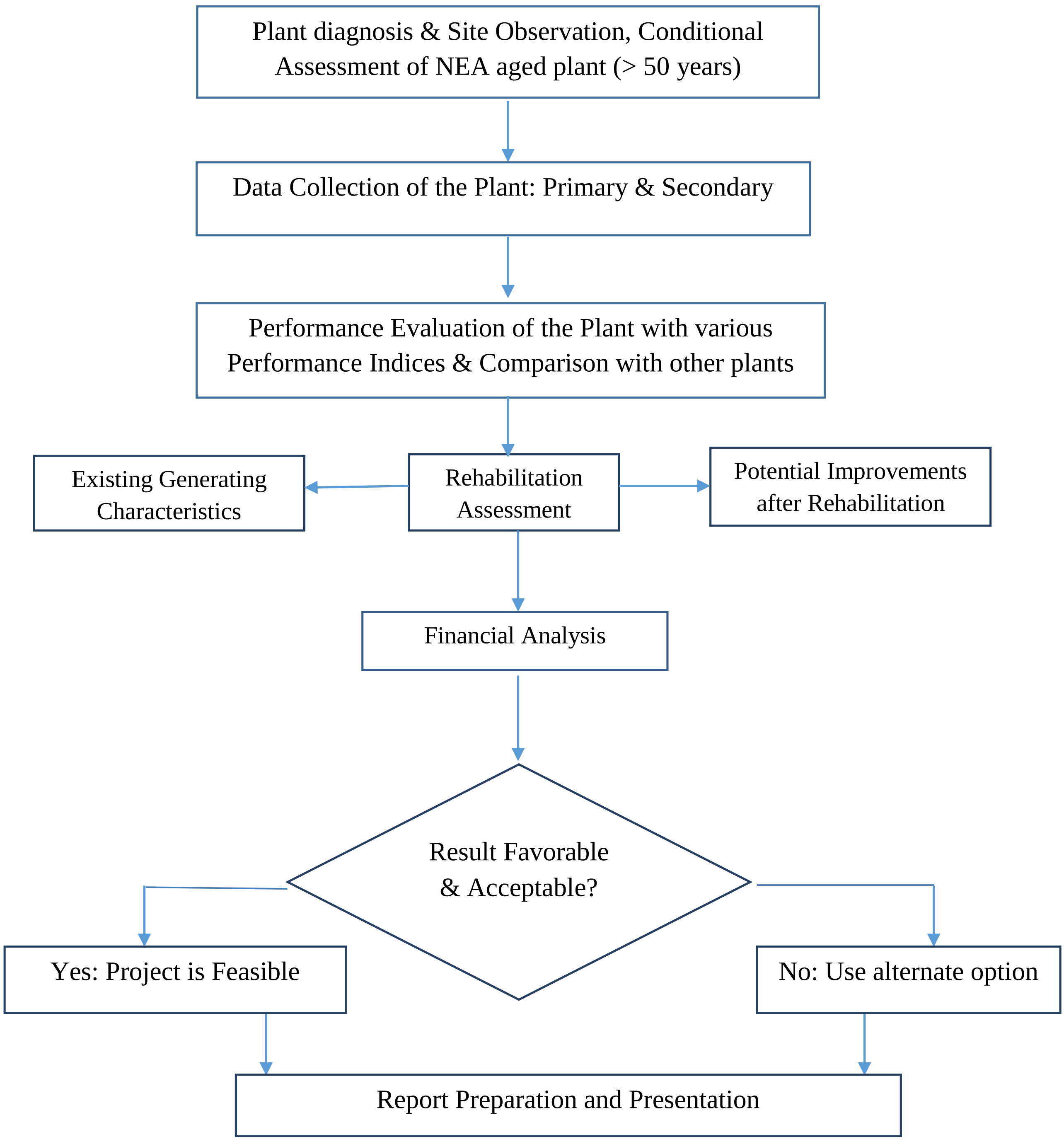
2.6 Financial Analysis Assumptions

- The rehabilitation time frame is estimated as 9 months to 1 year.
- The discount rate, often known as the opportunity cost of capital, is generally 10-12% (Harrison 2010, Zhuang 2007). Maximum value of 12% is assumed for analysis.
- According to the current NEA rate, the rate of sale of energy is NRs 4.80 per unit in wet months and NRs 8.40 per unit in dry months (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&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.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Methodological approach

This investigation is based on both qualitative and quantitative data. The information provided is based on both main and secondary data fields. Primary data was gathered from the Fewa Hydropower Plant, while secondary data was gathered from many other sources. Overall methodology is as presented in the flowchart shown below:



3.2 Hydropower Plant Condition Assessment

Observation, questionnaires with plant personnel's, and historical data collecting are used to assess the condition during the site visit. Current status of hydro mechanical and electromechanical components of the power plant is inspected. Since the plant has undergone more than 50 years of operation. The various power equipment's and hydro power parts which are to be replaced or repaired are analyzed thoroughly.

3.3. Data collection

3.3.1. Primary data collection

The primary data collected has been measured using various equipment's and devices located in the power plant. Data stored on memory of power house control room computers has also been collected. The hourly analogue data maintained by shift incharge on daily operational log sheets have taken and converted into digital data.

3.3.2. Secondary data Collection

Secondary data have been collected from various offices of Nepal Electricity Authority (NEA) viz. Load Dispatch Centre (LDC), Fewa Hydropower Plant (FHP) and Department of operation and maintenance offices, Generation Directorate. Various related publications, reports, literatures, articles, analysis studies, etc. have been referred along with related web portals.

3.4. Performance study/analysis of hydropower plant

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, availability of plant, plant capacity, capacity factor, performance factor etc., have been calculated at the existing scenario.

3.5. Rehabilitation and Renovation Assessment

From the plant diagnosis and condition assessment, the existing generating unit characteristics (age, plant factor, etc.) and potential areas of improvements (efficiency, capacity, and availability) is studied. Annual benefits in terms of energy and capacity is determined. For the assessment of rehabilitation, renovation and modernization, detail maintenance requirement of the civil structures, Hydro mechanical and Electro mechanical components is identified and accordingly rehabilitation cost is obtained from potential vendors.

3.6 Financial Analysis

Energy benefit and revenue collection of existing plant vs. rehabilitated plant has been studied. Investment criteria for financial viability of the project is analyzed. The discounting techniques such as Benefit Cost ratio (B/C), Net Present Value (NPV), Internal Rate of Return (IRR) and Payback period had been calculated for Financial Analysis.

3.7 Final report preparation and presentation

Final report is prepared based on the above data and subsequent study and analysis. The outcome of the analysis is presented applying various tables, graphs and charts.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

Among NEA aged hydropower plants exceeding more than 50 years of continuous operation, Fewa HPP has been screened out as because other aged plants had undergone significant hydropower rehabilitation works but this plant has not undergone any sort of rehabilitation schemes yet except general minor maintenances. Fewa HPP has been analyzed on the basis of conditional assessment, performance evaluation along with financial analysis. These performed tasks is described here under subtopics.

4.1 Performance Assessment of Fewa HPP

4.1.1 Energy Generation Profile

To study and analyze the energy generation status of Fewa hydropower plant it is necessary to investigate its designed monthly energy generation data and the energy generated from the plant since it was commissioned. Energy generation trend is shown with designed monthly generation vs. the average monthly power generation data for last eight consecutive years i.e. starting from F.Y. 2070/71 till 2077/78. The last year's generation trend i.e. of 2077/78 was compared with eight years average energy generation and the monthly designed energy data.

From the graph of the energy generation trend obtained since after commissioning period Fewa HPP has generated maximum energy of 3919.47 MWh at 10th year of energy generation i.e. at 2034 B.S while at other period it has generated average of 1882.80 MWh in general while observing the generation data as shown in figure 8.

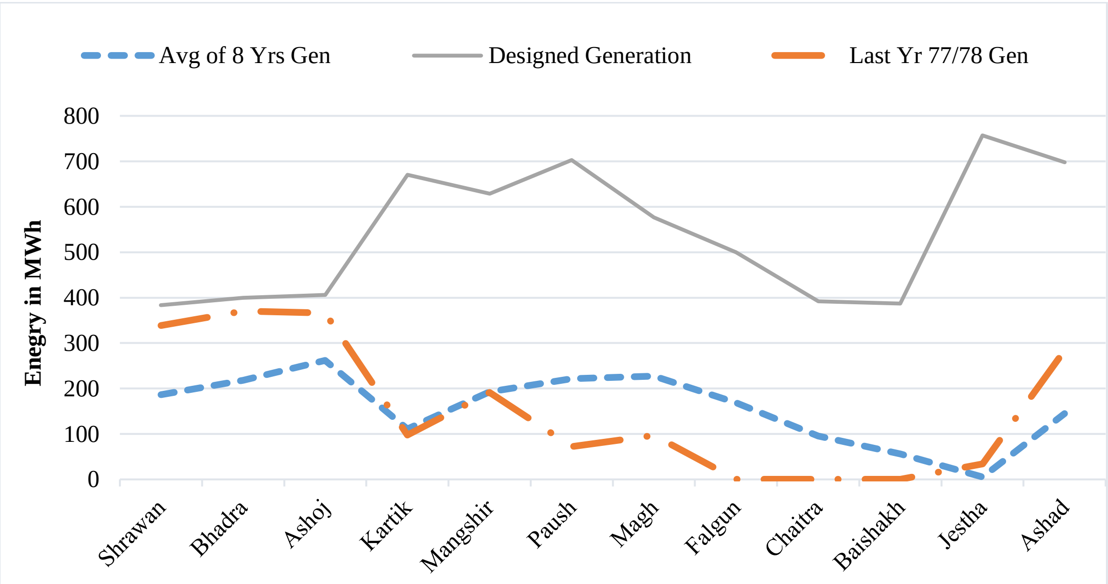


Figure 8: Energy Generation Profile of Fewa HPP.

From the above graph, Fewa power plant is neither following the designed energy profile nor eight years average i.e. eight years average as taken for reference. This is owing to an increase in plant outages, as well as unscheduled operation and maintenance procedures, and operational issues, all of which result in lower power plant performance and condition.

In order to identify the relationship between these results, Pearson's correlation coefficient was calculated. The correlation coefficient between the designed energy generation and average 8 years generation is -0.22506322, i.e., they are negatively and slightly correlated. The correlation coefficient between the designed energy generation and last year's 2077/78 generation is -0.253093425, i.e., they are negatively and slightly correlated. The correlation coefficient between the average of 8-year energy generation and 2077/78 is 0.598820434, i.e., they are positively and significantly correlated. The statistical analysis result indicates that 2077/78 data set and average of last 8-year energy generation data set have a good association.

4.1.2 Capacity Factor

Actual yearly energy generation data has been used to calculate the Capacity factor, as described in section Capacity Factor, from F/Y 2070/71 to the last fiscal year. Table 5 illustrates the determination of capacity factor of Fewa HPP for each year which shows that the maximum capacity factor has reached 36%. 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 5: Determination of Capacity Factor of Fewa HPP

S.N	F/Y	Designed Energy Generation (MWh)	Actual 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%

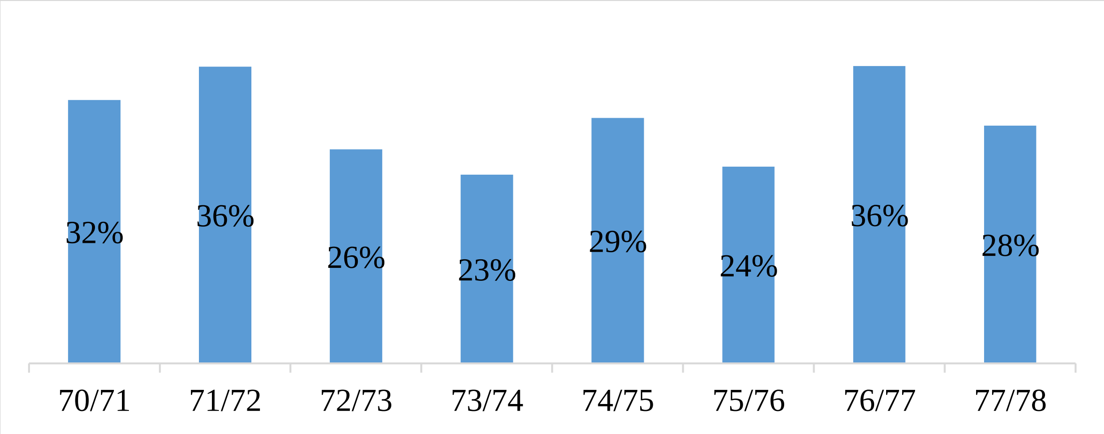


Figure 9: Graph illustrating capacity factor of Fewa HPP

While comparing with other NEA hydropower plants Fewa HPP has minimum capacity factor. Table 6 and Figure 10 compare the capacity factor of several NEA Power Plants using data from the previous F/Y 2076/77.

Table 6: Capacity Factor Calculation of NEA Plants

S. N	NEA Power Stations	Capacity MW	Annual Design Generation (GWh)	Annual Energy Generation of F/Y 076/77 (GWh)	Capacity Factor (%)
1	Kaligandaki A	144	842.57	871.466	103%
2	Middle Marsyangdi	70	397.59	446.624	112%
3	Marsyangdi	69	467.75	443.85	95%
4	Trishuli	24	163.8	128.97	79%
5	Devighat	15	113	92.05	81%
6	Modi	14.8	91	66.91	74%
7	Sunkoshi	10.05	62.68	62.24	99%
8	Fewa	1	6.5	2.12	33%

The table and graph show that Middle-Marsyangdi HPP stands out above others because its average annual energy generation exceeds its annual design energy generation, whereas Fewa HPP has the lowest value due to its largely unsatisfactory performance during rainy seasons, primarily due to debris choking problems, uncontrolled outages, and machine breakdown problems resulting in unavailability for electricity generation.

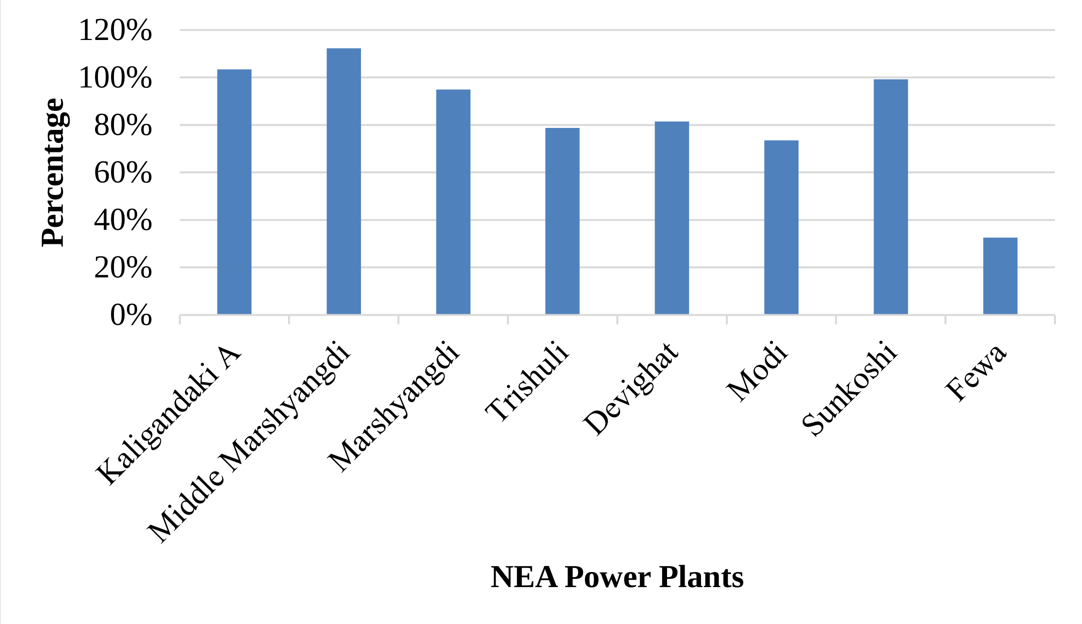


Figure 10: Capacity Factor of NEA Power Plants

4.1.3 Plant Factor

For computing the Plant factor as described in section Plant Factor, actual annual generation data of Fewa HPP from F/Y 2070/71 to final F/Y 2077/78 was used as a reference. Plant factor is represented in Table 7 and Figure 11; the energy generation trend of Fewa HPP has showed a maximum plant factor of 26%.

Table 7: Plant Factor of Fewa HPP

S.No	F/Y	Actual Energy Generation (MWh)	Gen. Units	Actual Hours	Maximum Possible Energy (MWh)	Plant Factor (%)
1	70/71	2050.14	4	8784	8784.00	23%
2	71/72	2310.74	4	8760	8760.00	26%
3	72/73	1664.77	4	8760	8760.00	19%
4	73/74	1467.69	4	8760	8760.00	17%
5	74/75	1911.68	4	8784	8784.00	22%
6	75/76	1531.68	4	8760	8760.00	17%
7	76/77	2314.63	4	8760	8760.00	26%
8	77/78	1850.94	4	8760	8760.00	21%

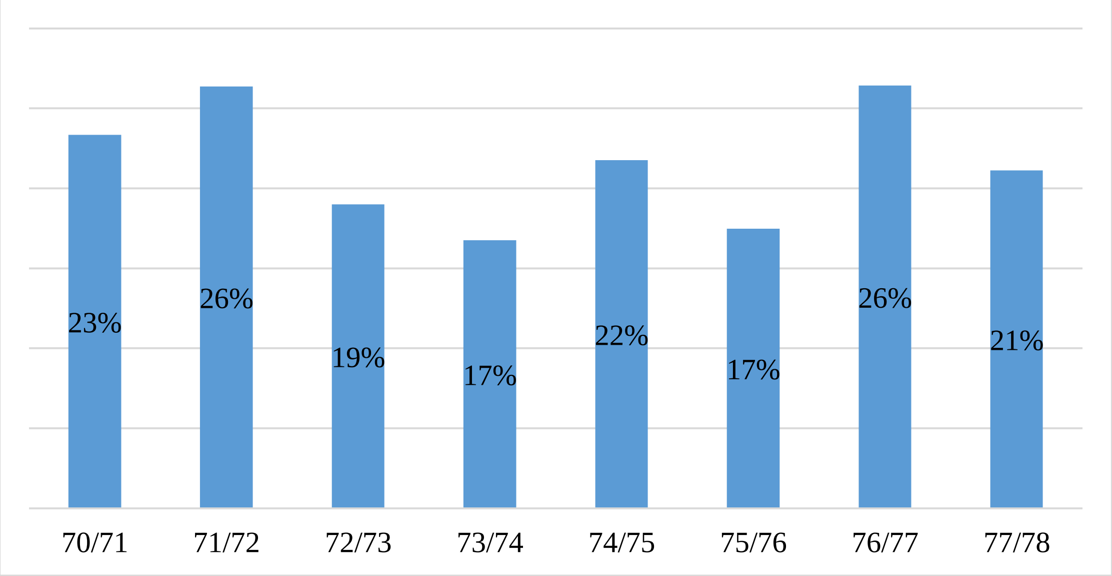


Figure 11: Graph illustrating plant factor of Fewa HPP

When comparing energy generation in the last F/Y 2076/77, Middle-Marsyangdi HPP and Marsyangdi HPP stand out above other plants because their average annual energy generation was close to that of their maximum possible energy generation, whereas Fewa HPP has the lowest value due to its degrading performance during rainy seasons, mainly due to debris choking problems, uncontrolled outages, units and plant breakdown problems, inefficiencies of hydro mechanical and electromechanical components.

Table 8: Plant Factor of Various NEA Plants

S.No	NEA Power Stations	Energy Generation (GWh)	No. of Units	Maximum Possible Energy (GWh)	Plant Factor (%)
1	Kaligandaki A	871.466	3	1261.44	69%
2	Middle Marsyangdi	446.624	2	613.2	73%
3	Marsyangdi	443.85	3	604.44	73%
4	Trishuli	128.97	7	210.24	61%
5	Devighat	92.05	3	131.4	70%
6	Modi	66.91	2	129.648	52%
7	Sunkoshi	62.24	3	88.038	71%
8	Fewa	2.12	4	8.76	24%

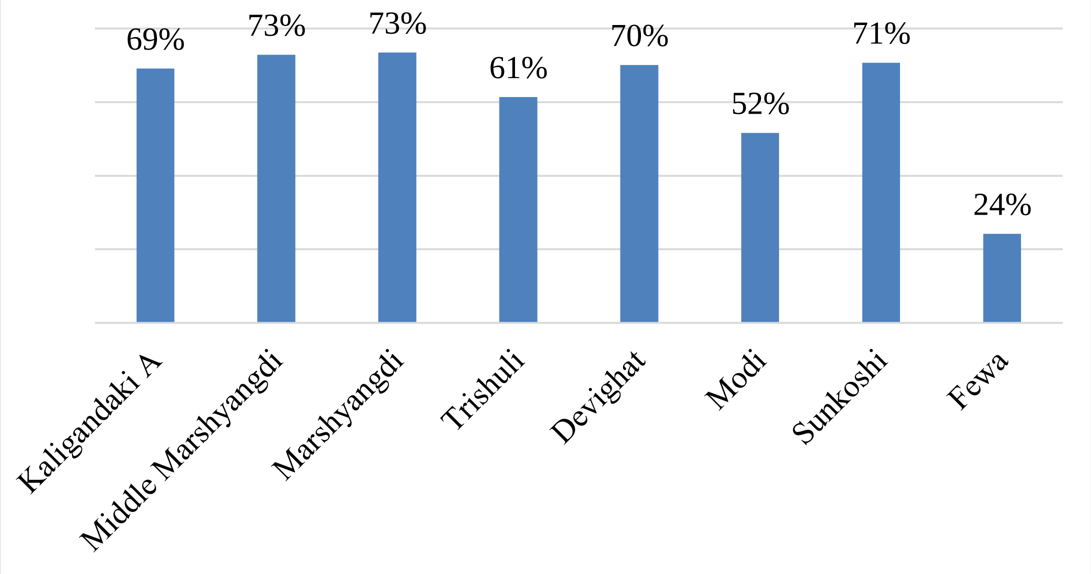


Figure 12: Plant Factor of NEA Power Plants

4.1.4 Performance Factor

On a monthly basis, NEA assigns annual target/forecast energy generation to each of the power plants. The target or forecast is allocated with considerations of factors such as maximum generation data, designed energy generation, previous generation trend, prescheduled outages, and unavailability during for unit maintenances of HPPs. Performance Factor as defined in previous section, The Performance Factor is a metric that compares to actual energy generation with the target set. Despite of considerations of various constraints in Fewa HPP, still performance of Fewa HPP is not satisfactory and it hasn’t been able to achieve its full forecasted energy. Data expressed in table 9 relies that it has achieved of 74% of forecasted energy on last fiscal year.

Table 9: Performance Factor of Fewa HPP

S.No	F/Y	Annual Energy Generation (MWh)	Forecasted Energy/ Target Generation (MWh)	Performance Factor %
1	73/74	1467.69	2214.02	66%
2	74/75	1911.68	1959.55	98%
3	75/76	1531.68	2990.36	51%
4	76/77	2314.63	2699.58	86%
5	77/78	1850.94	2493.52	74%

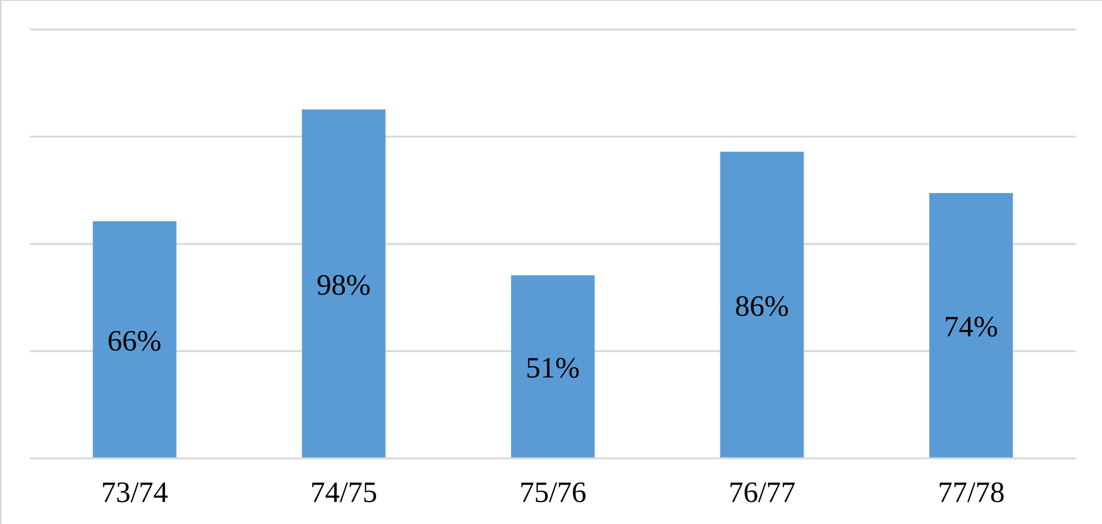


Figure 13: Performance Factor of Fewa HPP

Table 10: Actual Energy vs. Forecasted Energy Generation of Various NEA Plants

S. N	NEA Power Stations	Annual Energy Generation (MWh)			Forecasted Energy/ Target Generation (MWh)		
		2074/75	2075/76	2076/77	2074/75	2075/76	2076/77
1	Kaligandaki A	865,075.00	871,914.00	871,466.00	833,643.99	825,252.04	882,860.66
2	Middle Marshyangdi	437,286.87	471,322.51	446,624.75	433,869.81	444,915.41	463,473.21
3	Marshyangdi	447,490.30	475,176.00	443,852.10	464,734.93	471,309.63	477,698.55
4	Trishuli	121,316.50	123,741.10	128,973.11	135,082.79	137,613.64	138,964.17
5	Devighat	86,238.79	86,851.14	92,053.14	101,062.18	93,195.47	97,749.31
6	Modi	66,422.70	69,400.50	66,913.20	69,600.62	70,971.48	73,253.95
7	Sunkoshi	55,050.50	62,156.70	62,245.90	59,536.82	58,188.00	60,523.27
8	Fewa	1,911.68	1,531.68	2,126.54	1,959.55	2,990.36	2,699.58

Table 11: Performance Factor of Various NEA Plants

S.No	NEA Power Stations	Performance Factor			Average Performance Factor
		2074/75	2075/76	2076/77	
1	Kaligandaki A	1.04	1.06	0.99	103%
2	Middle Marshyangdi	1.01	1.06	0.96	101%
3	Marshyangdi	0.96	1.01	0.93	97%
4	Trishuli	0.90	0.90	0.93	91%
5	Devighat	0.85	0.93	0.94	91%
6	Modi	0.95	0.98	0.91	95%
7	Sunkoshi	0.92	1.07	1.03	101%
8	Fewa	0.98	0.51	0.79	76%

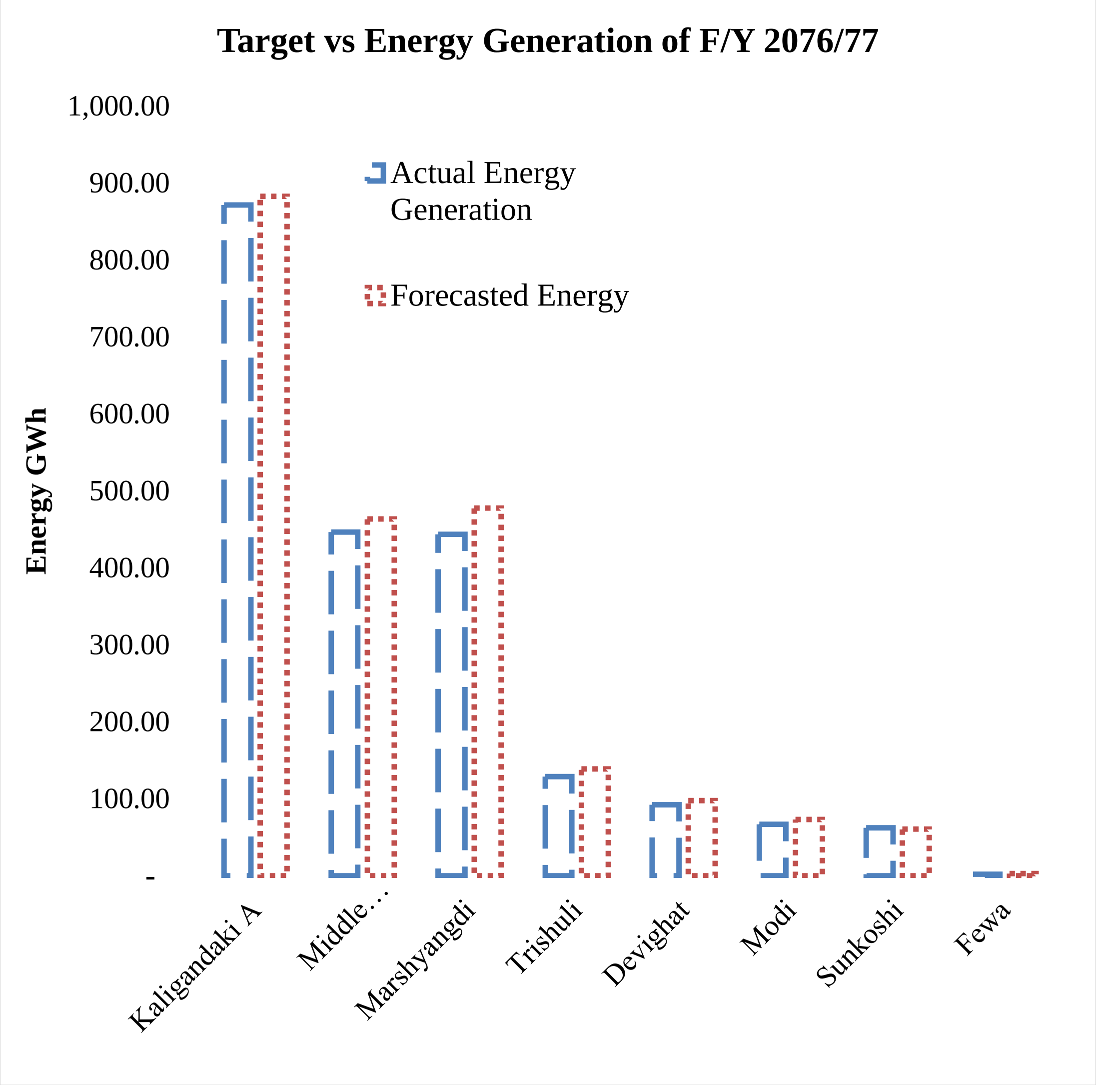


Figure 14: Actual Energy Generation vs. Forecasted Energy of Power Plants

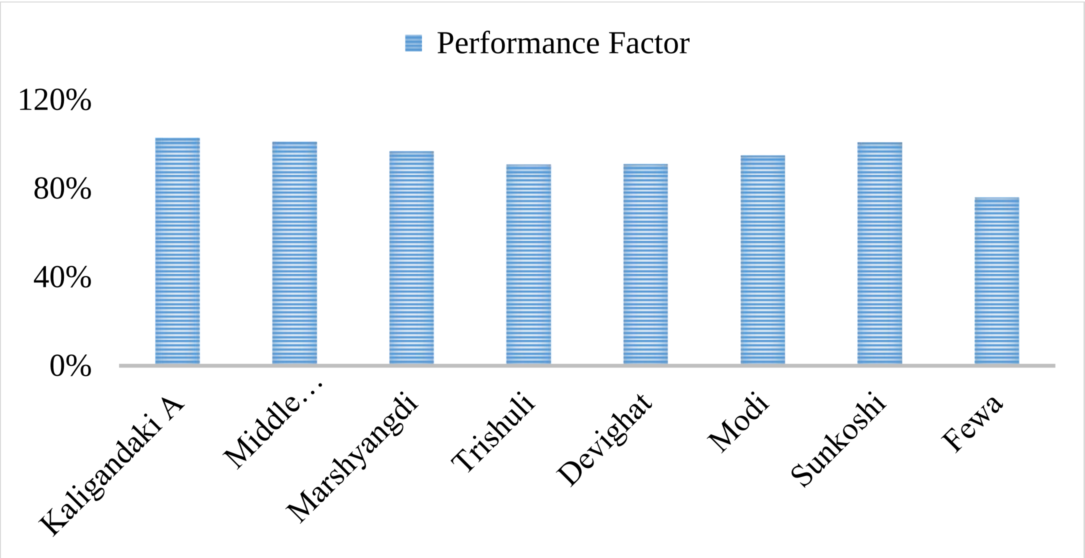


Figure 15: Performance Factor of Power Plants

The graph above shows that Kaligandaki A HPP, Middle-Marsyangdi HPP, and Sunkoshi HPP have better performance than others, as their average annual generation exceeds their forecasted annual energy generation on F/Y 2076/77, whereas Fewa HPP has the lowest performance during rainy seasons, primarily due to debris choking problems, uncontrolled outages, units and plant breakdown problems, inefficiencies of hydro mechanical and electromechanical components.

.**Availability Factor**

Availability factor as discussed in earlier topic relating with machine running hours and outage hours. Table 12 shows the machine availability whose values are all below 35% in overall observed from F/Y 2070/71 to consecutive seven years till 2076/77. These values indicates that outage hours are significant higher than running hours of the plant.

Table 12: Machine Availability Factor of Fewa HPP

F/Y	Actual Hours	Total Running Hours	Outage Hours (Planned & Forced)	Outage Hours (Plant & Unit Tripping)	Total Outage Hours	Machine Availability Factor
70/71	35136	11985.53	23062.05	88.42	23150.47	34%
71/72	35040	12409.75	21777.55	852.70	22630.25	35%
72/73	35040	9274.62	25696.03	69.35	25765.38	26%
73/74	35136	9095.00	25805.75	235.25	26041.00	26%
74/75	35040	10939.82	23980.78	119.40	24100.18	31%
75/76	35040	8506.43	26375.53	158.03	26533.57	24%
76/77	35040	8506.43	17826.60	8706.97	26533.57	24%

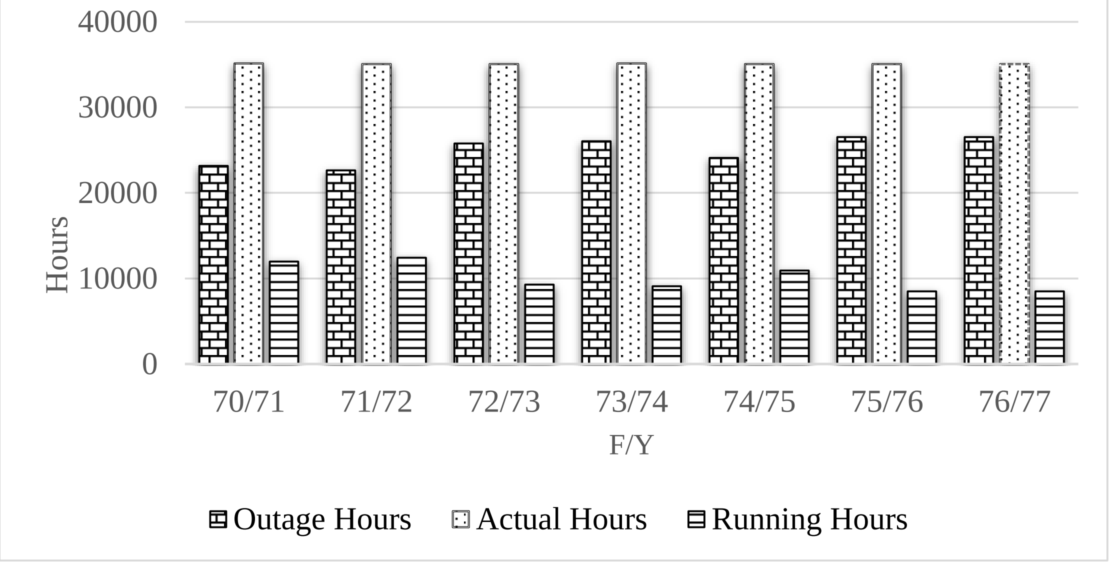


Figure 16: Graph showing running and outage hours

Annual Energy Generation per Installed Capacity

The annual energy generation of Fewa HPP in relation to the installed capacity of Fewa HPP has been examined and calculated as follows for various fiscal years.

Table 13: Determination of Energy Generation per Installed Capacity

S.No	F/Y	Energy Generation GWh	Installed Capacity MW	Annual Energy Generation per Installed Capacity GWh/MW
1	70/71	2.05	1	2.05
2	71/72	2.31	1	2.31
3	72/73	1.66	1	1.66
4	73/74	1.47	1	1.47
5	74/75	1.91	1	1.91
6	75/76	1.53	1	1.53
7	76/77	2.31	1	2.31
8	77/78	1.85	1	1.85

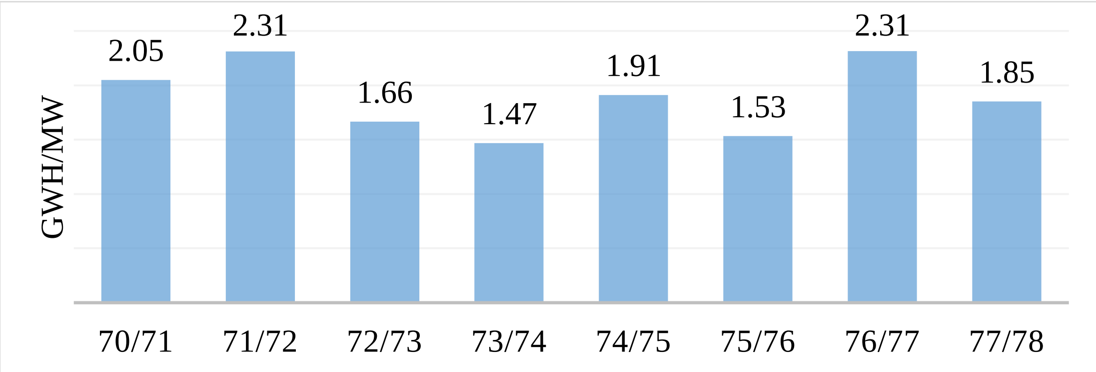


Figure 17: Graph showing actual energy generation per installed capacity

4.2 Rehabilitation and Modernization Approach

From the plant diagnosis and assessment on the need of rehabilitation, scope for this work covers repair maintenance, new replacement and installation of latest efficient technology based plant equipment's is required.

4.2.1 Civil Structures

Civil structures in Intake need maintenance for Intake slabs. The railing posts in the intake structure requires reinforcement. Also, since the intake area is exposed to the public, it is recommended to enclose it with a chain-linked fencing.

Structural maintenance is deemed necessary in canals. The earthen canal needs to be lined in some stretches. The Stone masonry lined and Reinforced lined canal need severe maintenance. The reinforcements in the canal are exposed due to scouring and need immediate maintenance because the failure can affect the stability of the canal in both banks. Forebay structure need major maintenance for spillway wall, which is damaged highly. Some of the Forebay structure is suffering from scouring which need maintenance. The Powerhouse structure should be demolished and reconstructed from Main Inlet Valve to the Draft tube according to the new dimensions of the electromechanical equipment. Considering the rusting and wearing of the Bifurcation pipe, it is recommended to replace the bifurcation pipe and the civil structure for bifurcation need to be demolished and reconstructed accordingly.

4.2.2 Hydro Mechanical Systems

Gates

In the power canal gate, there was a remarkable gap between side rubber seal and side sealing frame which contributes to water leakage. Proper design optimization shall be carried out to control this leakage.

In the forebay gates, the concrete structure should be repaired so that all the embedded steel structures remain within concrete. All the metal surfaces also require a proper mechanical cleaning followed by Zinc rich primer and epoxy base paint. Fractured pinion block should also be replaced. Welding is not recommended for repair as it is a cast iron part. Proper design optimization shall be carried out to control leakage from the seal.

Trash Rack Cleaning Mechanism

A proper trash rack cleaning mechanism should be employed to address the problem of floating debris. However, a conventional trash rack cleaning mechanism will not be effective because of the nature of the debris. An appropriate Trash Rack cleaning mechanism will be suggested.

Penstock and Draft Tube

The current painting state of penstock was observed to be inadequate. A proper mechanical cleaning following surface cleaning and surface treatment standards is required along with coating of Zinc rich primer and epoxy base paint. Also, it is highly required to replace the manifold pipes (pipes downstream of bifurcation blocks) and the draft tube.

4.2.3 Electromechanical Equipment

An overall replacement of electromechanical components is proposed with the Single Line Diagram shown in Figure 18 which have four set of three phase generator with two set of three phase transformer.

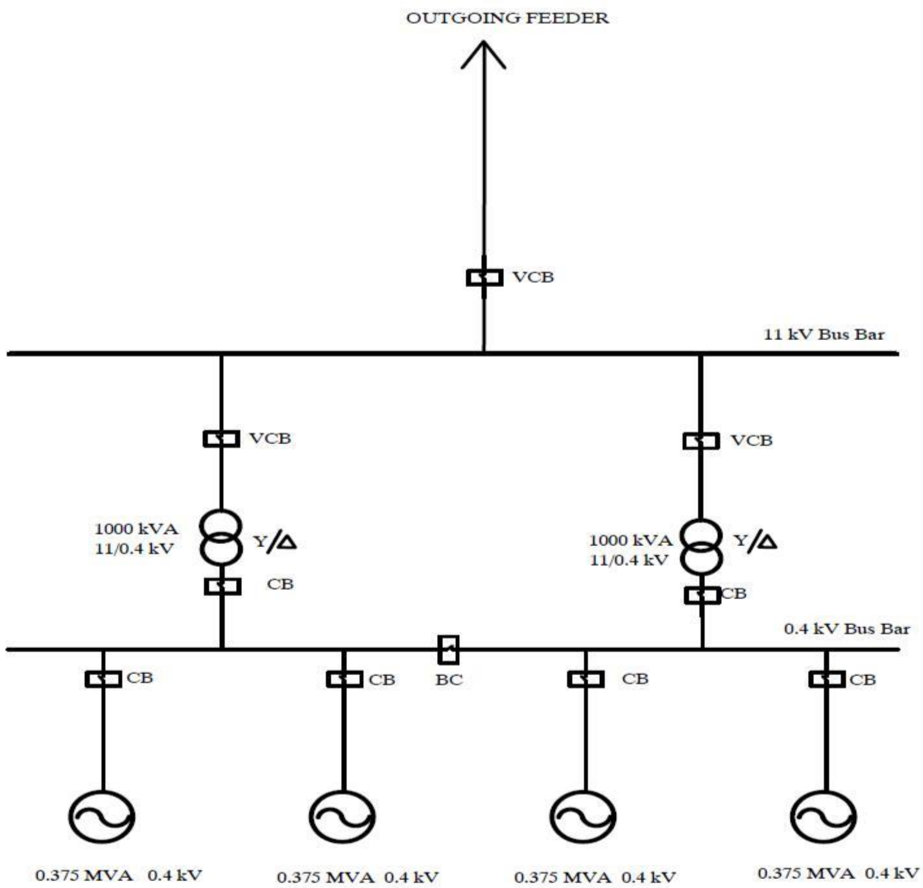


Figure 18: Single Line Diagram of Fewa HPP

4.2.4 Turbine-generator unit

For the turbine-generator units, we have specified two options based on available head and discharge which have been tabulated in Table 13. The number and capacity of turbine-generator units will be determined based on the option selected. Options 1 & 2 are all proposed for the existing head (74.7 m) and discharge (2 m^3/s). Option 1 employ four units whereas option 2 employ two units.

Table 14: Proposed Options for Turbine Generator unit

Specifications		Option 1 (4 units)	Option 2 (2 units)
Net head [H]:	m	74.7	74.7
Max discharge [Q]:	m^3/s	0.5	1
Frequency [f]:	Hz	50	50
Max Turbine Power	kW	319	640
Turbine specifications			
Turbine type:		Francis	Francis
Speed [n]:	rpm	1000	1000
Maximum Run-away speed:	rpm	1625	1686
Specific speed [ns]:		94.95	134.29
Peak Efficiency [η max]:	%	88.8	89.2
Turbine Power Max	kW	319	640
Max Electrical Power [P](sync):	kW	299	603
Flow @Run-away speed:	m^3/s	0.22	0.49
Generator specifications			
Type:		Synchronous	Synchronous
Number of poles:		6	6
Frequency [f]:	Hz	50	50
Power factor:		0.80 ~ 0.9	0.80 ~ 0.9
Speed [n]:	rpm	1000	1000
Peak efficiency:	%	92.5	92.5
Nominal power:	kVA	332	670
Annual Energy:	MWh	10512	10512

Main Inlet Valve

The existing Main inlet valves should be replaced with electric or hydraulic actuation type gate or butterfly type valve so that its operation can be automated by linking with the governor system.

Governor

The mechanical governor is not compatible with modern day turbine-generator set so it has to be replaced with Digital governor.

Main Transformer

The main transformers are in working state but it is found that there are oil leakage problems, with possibility of insulation deterioration. So, routine maintenance is recommended. However, the transformer could be replaced altogether if the scheme of Single line Diagram changes. The number and capacity of transformer will depend on the scheme selected and depends upon client's requirement.

400 V and 11 kV Switchgear Panel Excitation Control & Protection Systems

The 400 V and 11 kV Switchgear Panels, Excitation, Control and protection systems are at vulnerable state, so they are required to be replaced.

11-kV Line Bay Equipment

The 400 V and 11 kV Switchgear Panels, Excitation, Control and protection systems are also required to be replaced.

Earthing and Lightning protection system

Currently, there is lack of proper earthing system and lightning protection system visualized in Fewa HPP. So, considering the safety of both the personnel and of the equipment in the power plant, it is highly required to provide an earthing and lightning protection system in the Fewa HPP as per IEEE 80 standard and as per NEA Grid Code.

Crane & SCADA System

In regards to crane, it is required to upgrade it to an electrically operated type to improve the work efficiency of the operator. In order to communicate with LDC and control within the powerhouse, SCADA system is required.

4.3 Financial Analysis

Case I: Revenue Calculation in Existing Condition

Plant Capacity: 1000 kW

Dry Rate: Rs.8.40 & Wet Rate: Rs. 4.80 per unit

Table 15: Energy and Revenue Calculation in existing scenario

Months	Total Energy (kWh)	Net Dry Energy (kWh)	Net Wet Energy (kWh)	Revenue (NRs)		
				Dry	Wet	Total
Shrawan	186441.25		186441.25	-	894,918.00	894,918.00
Bhadra	218130.00		218130.00	-	1,047,024.00	1,047,024.00
Ashoj	262093.75		262093.75	-	1,258,050.00	1,258,050.00
Kartik	110882.50		110882.50	-	532,236.00	532,236.00
Mangsir	192470.00	192,470.00		1,616,748.00		1,616,748.00
Poush	221346.25	221,346.25		1,859,308.50	-	1,859,308.50
Magh	227415.00	227,415.00		1,910,286.00	-	1,910,286.00
Falgun	168480.00	168,480.00		1,415,232.00	-	1,415,232.00
Chaitra	94983.75	94,983.75		797,863.50	-	797,863.50
Baisakh	56043.75	56,043.75		470,767.50	-	470,767.50
Jestha	4816.25		4,816.25	-	23,118.00	23,118.00
Ashad	144686.25		144,686.25	-	694,494.00	694,494.00
Total	1,887,788.75	960,738.75	927,050.00	8,070,205.50	4,449,840.00	12,520,045.50

In the above table total energy for the various months has been taken on the basis of the average energy generated within the specified month of last eight consecutive years from F/Y 2070/71 to 2077/78.

Case II: Revenue Calculation in Modified Condition after Rehabilitation

Plant Capacity: 1000 kW

Dry Rate: Rs. 8.40 & Wet Rate: Rs. 4.80 per unit.

Plant factor 0.5 is taken for four months due to 50% water unavailability in power canal as due to consumption of water for farming by irrigation department whereby power canal receives 1 cumec water for power generation in those four months while in rest month's power canal receives full 2 cumec water.

Outage hours is limited to 4% after rehabilitation for maintenance purpose, outages, plant and unit tripping conditions, etc.

Total energy after rehabilitation is calculated as:

Total energy = No. of days in a month * 24* Plant factor *Outage (4%)* Plant Capacity (1000 kW).

[No. of days of the months has been considered as of F/Y 2076/77 for analysis.]

Table 16: Energy & Revenue Calculation in modified scenario

Months	No of Days	Plant Factor	Total Energy (kWh)	Net Dry Energy (kWh)	Net Wet Energy (kWh)	Revenue (NRs)		
						Dry	Wet	Total
Shrawan	32	0.5	383,450.00		383,450.00		1,840,560	1,840,560.00
Bhadra	31	0.5	372,000.00		372,000.00		1,785,600	1,785,600.00
Ashoj	30	1	720,000.00		720,000.00		3,456,000	3,456,000.00
Kartik	30	1	720,000.00		720,000.00		3,456,000	3,456,000.00
Mangsir	30	1	720,000.00	720,000.00		6,048,000.00		6,048,000.00
Poush	29	1	696,000.00	696,000.00		5,846,400.00		5,846,400.00
Magh	29	1	696,000.00	696,000.00		5,846,400.00		5,846,400.00
Falgun	30	1	720,000.00	720,000.00		6,048,000.00		6,048,000.00
Chaitra	30	0.5	360,000.00	360,000.00		3,024,000.00		3,024,000.00
Baisakh	31	0.5	372,000.00	372,000.00		3,124,800.00		3,124,800.00
Jestha	32	1	768,000.00		768,000.00		3,686,400.00	3,686,400.00
Ashad	31	1	744,000.00		744,000.00		3,571,200.00	3,571,200.00
Total	365		7,271,450.00	3,564,000.00	3,707,450.00	29,937,600.00	17,795,760.00	47,733,360.00

Table 17: Energy & Revenue differences (existing vs. rehabilitated plant)

Months	Energy from Existing Plant (MWh)	Energy from Rehabilitated Plant (MWh)	Energy Difference (MWh)	Revenue from Existing Plant (NRs)	Revenue from Rehabilitated Plant (NRs)	Revenue Difference (NRs)
Shrawan	186.44	383.45	197.01	894,918.00	1,840,560.00	945,642.00
Bhadra	218.13	372.00	153.87	1,047,024.00	1,785,600.00	738,576.00
Ashoj	262.09	720.00	457.91	1,258,050.00	3,456,000.00	2,197,950.00
Kartik	110.88	720.00	609.12	532,236.00	3,456,000.00	2,923,764.00
Mangsir	192.47	720.00	527.53	1,616,748.00	6,048,000.00	4,431,252.00
Poush	221.35	696.00	474.65	1,859,308.50	5,846,400.00	3,987,091.50
Magh	227.42	696.00	468.59	1,910,286.00	5,846,400.00	3,936,114.00
Falgun	168.48	720.00	551.52	1,415,232.00	6,048,000.00	4,632,768.00
Chaitra	94.98	360.00	265.02	797,863.50	3,024,000.00	2,226,136.50
Baisakh	56.04	372.00	315.96	470,767.50	3,124,800.00	2,654,032.50
Jestha	4.82	768.00	763.18	23,118.00	3,686,400.00	3,663,282.00
Ashad	144.69	744.00	599.31	694,494.00	3,571,200.00	2,876,706.00
Total	**1,887.79**	**7,271.45**	**5,383.66**	**12,520,045.50**	**47,733,360.00**	**35,213,314.50**

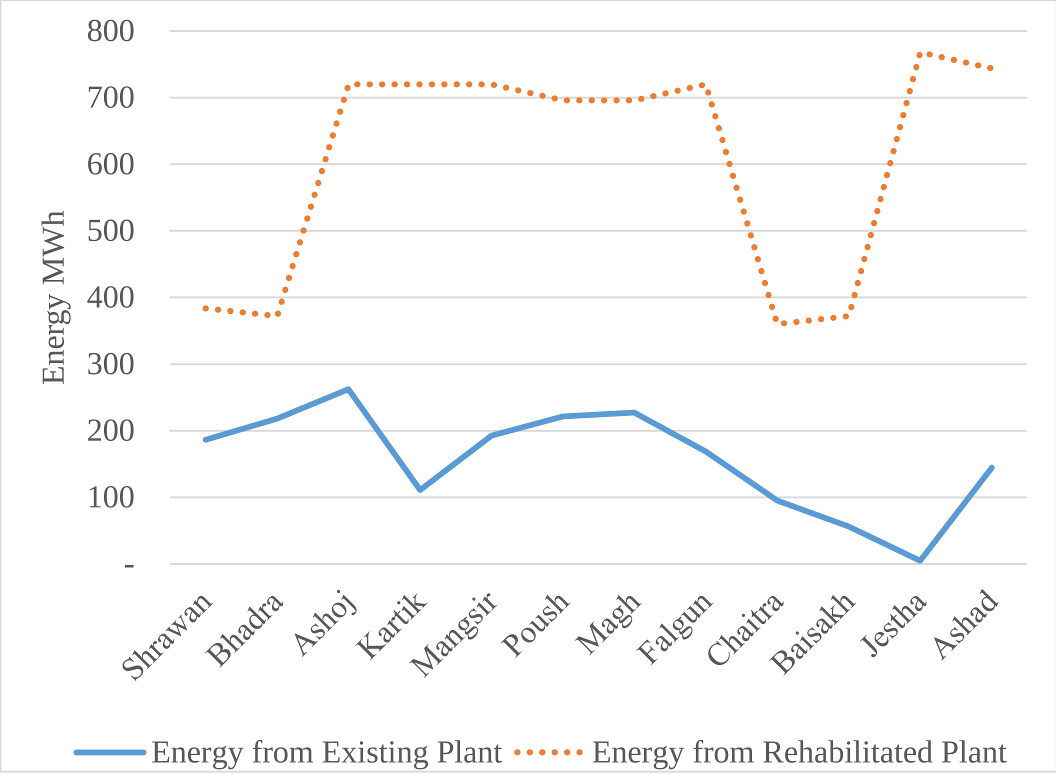


Figure 19: Energy from existing vs. rehabilitated plant

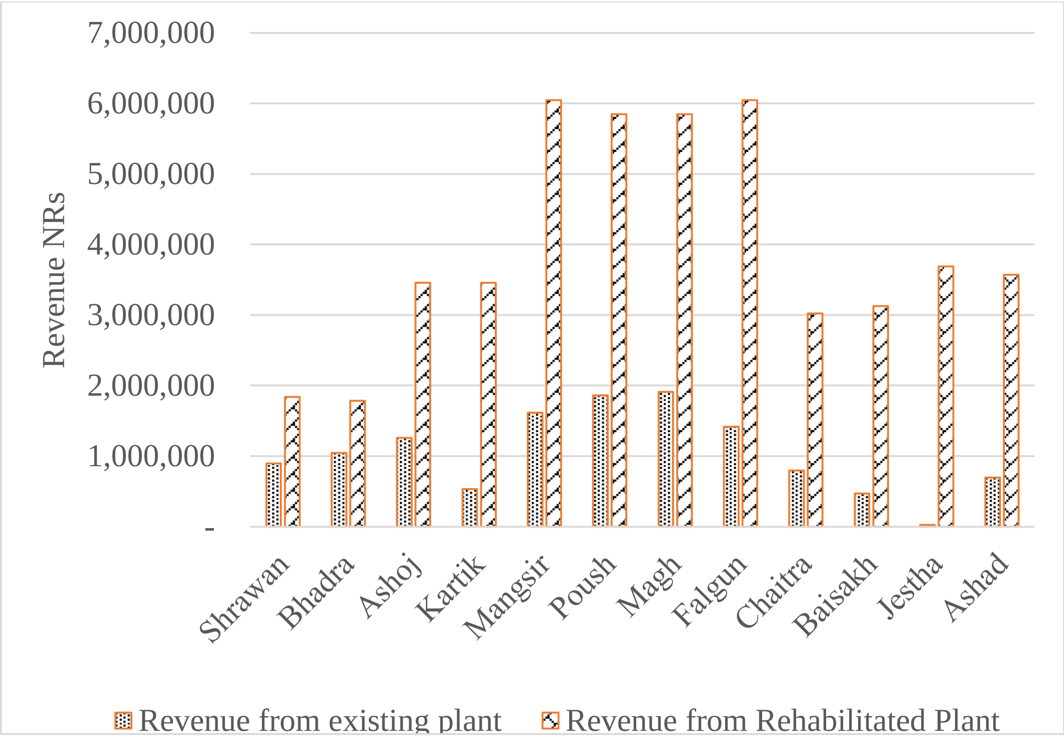


Figure 20: Revenue from existing vs. rehabilitated plant

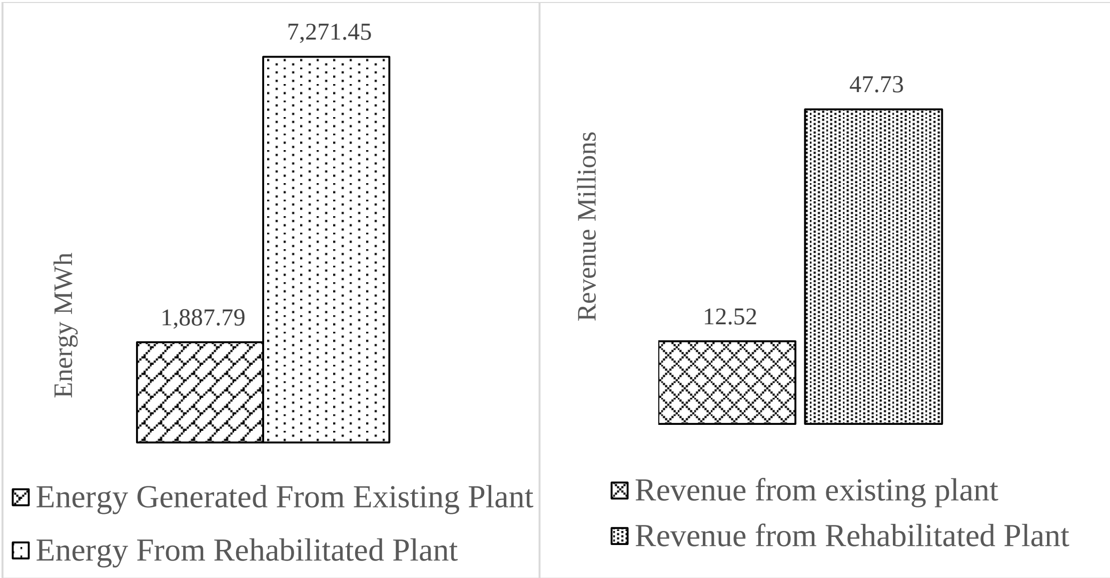


Figure 21: Annual Energy & Revenue from existing vs. rehabilitated plant

Rehabilitation Prospective

Fewa HPP rehabilitation prospective in existing facility restoring to its initial/original performance status with civil structure maintenances works, replacement and new installation of hydro mechanical components and complete electromechanical components of power house is computed. Major works for rehabilitation are:

SN	Description of Works
	Civil Works
1	Concrete Lining works of Main Canal (730 m)
2	Forebay Civil Maintenance Works
3	Powerhouse Civil Maintenance Works
	Hydro-Mechanical & Electromechanical Works
1	Canal Inlet Gate body, embedded parts, Seal plate, track plate, rubber seals, manual screw spindle hoist complete set
2	Penstock Inlet Gate body, embedded parts, Seal plate, track plate, rubber seals, manual screw spindle hoist complete set
3	Spare parts for Gates and Stop logs
4	Intake fine trash rack body with its embedded parts complete set
5	Trash Rack Cleaning Machine, electrical and manual operation type along with its control and protection system and required spare parts
6	Penstock Manifolds
7	Hydraulic Turbine and Auxiliaries: horizontal- shaft, Francis-type hydraulic turbine with all auxiliary equipment and accessories all complete comprising turbine runner, shaft seal, turbine guide bearing, covers, labyrinth seal rings, spiral casing with stay ring, wicket gates and operating mechanism, servomotors. draft tube, turbine inlet pipe assembly, control, instrumentation and safety

	devices, piping and drainage system, air supply against cavitation, foundation and anchor bolts, electrical materials, governor system, pressure oil system, cooling water system, compressed air system, tool/ devices for assembly and maintenance, spare parts.
8	Turbine Main Inlet Valve (MIV) and bypass system along with its control and protection system complete
9	EOT crane hoist capacity 5 tons, Single girder type with complete accessories
10	Alternating current, salient pole type, three phase synchronous generators each of 375 KVA, 0.4 kV, 0.80 pf & Mandatory Spare Parts
11	Governor Control System along its spare parts
12	Main Transformer 11/0.4kV 1 MVA, Station Transformer 11/0.4 kV 100 kVA
13	Brushless Excitation Control System and spare parts associated
14	Generator, Power Transformer &11kV Transmission Line Protection System
15	Switchgear System
16	Automation and Control System
17	Auxiliary System and Cables

Rehabilitation Cost:

Rehabilitation of Fewa HPP, comprises civil repair and maintenance works i.e. of main canal, forebay and powerhouse along with electromechanical and hydro mechanical works which consists new installation of equipment's so as to renovate and modernize with latest efficient technology. Detail rehabilitation costs is obtained from the quotations from the vendors and suppliers. Civil costs for concrete lining works of main canal is estimated on the basis of Kaski district Rates. Forebay & Power house Maintenances Civil costs along with hydro mechanical costs is obtained from MSIPL, Nepal. Electromechanical Costs including Turbine and auxiliaries as provided by European Manufacturer/ Vendor in European Currency which had been converted to Nepali Rupees as conversion rate of 1 Euro equivalent to NRs. 142.37. (Nepal Rastra bank, 2021). Contingency charges of 10 % is considered for Civil, Hydro Mechanical works and 5% electromechanical components including Turbine and Auxiliaries respectively. Total costs thus obtained is as listed in table 18.

Table 18: Rehabilitation Costs

S.N	Particulars	Amount (NRs)	Contingency	Total (NRs)
1	Civil Works	38,573,399.17	3,857,339.92	42,430,739.09
2	Electromechanical works	75,040,000.00	3,752,000.00	78,792,000.00
3	Hydro mechanical Works	7,769,957.42	388,497.87	8,158,455.29
4	Sub Total	121,383,356.59		129,381,194.38
5	VAT (13%) on item no 1			5,515,996.08
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			**138,896,911.41**

(Source: MSIPL and ZECO)

Financial Analysis Indicators

After cash flow analysis considering the plant rehabilitation and its outcomes in terms of energy and revenue, then determining all sort of rehabilitation costs as well as other costs associated, present worth of net benefit is calculated. Thus from detail analysis and calculations BC ratio, NPV, IRR and Payback Period found is shown in table 19.

Table 19: Results of Financial Analysis

Cash flow (NRs)	Cost	Revenue
	138,896,911.41	223,403,979.52
B/C	1.61	
NPV	84,507,068.11	
IRR	19.91 %	
Discounted Payback Period (Yrs.)	8.08	

Thus obtained financial analysis result suggest the projects feasibility as:

- B/C > 1
- IRR > 12%
- NPV > 0
- Payback Period is less than 10 years

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

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

- Operational performance analysis of Fewa HPP 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 plant's performance.
- Financial analysis computed with rehab costs and revenue benefits resulted with BC ratio: 1.61, IRR: 19.91%, NPV: 84.5 million NRs and Payback period: 8 years, which indicates project feasibility.

Thus, investigations have shown that Fewa HPP holds great scope for rehabilitation, renovation and modernization.

5.2. Recommendations

Performance analysis, conditional assessment helps analysts and decision makers to ensure the existing operational fleet of hydropower plant. 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 refurbishment.

An approach on life extension or restoration to initial/original designed performance of Fewa HPP with refurbishment of efficient turbo generator sets and auxiliaries has been endeavored. An optimal capacity up gradation with determination of optimized number of generating units is highly recommended.

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Appendices

Appendix 1: Detail Cash Flow Analysis

S.N	Year	Total Revenue (Existing Plant)	O&M Cost	Insurance	Net Revenue (Existing Plant)	Total Revenue (Modified Plant)	O&M Cost	Insurance	Net Revenue (Modified Plant)	Additional Revenue	Cost for All the Royalties and Taxes	Investment	Total Cash flow	Present worth of Net Benefit
		(1)	(2)=0.08*(1)	(3) =0.05*(11)	(4)=(1)-(2)-(3)	(5)	(6)=0.03*(5)	(7)=0.05*(11)	(8)=(5)-(6)-(7)	(9)=(8)-(4)	(10)=0.2*(9)	(11)	(12)	(13)
-1	2021											138,896,911.41	-138,896,911.41	
1	2021	12,520,045.50	1,001,603.64	694,484.56	10,823,957.30	47,733,360.00	1,432,000.80	694,484.56	45,606,874.64	34,782,917.34	6,956,583.47		27,826,333.87	24,844,940.96
2	2022	12,520,045.50	1,031,651.75	694,484.56	10,793,909.19	47,733,360.00	1,474,960.82	694,484.56	45,563,914.62	34,770,005.43	6,954,001.09		27,816,004.34	22,174,748.36
3	2023	12,520,045.50	1,062,601.30	694,484.56	10,762,959.64	47,733,360.00	1,519,209.65	694,484.56	45,519,665.79	34,756,706.15	6,951,341.23		27,805,364.92	19,791,309.53
4	2024	12,520,045.50	1,094,479.34	694,484.56	10,731,081.60	47,733,360.00	1,564,785.94	694,484.56	45,474,089.50	34,743,007.90	6,948,601.58		27,794,406.32	17,663,847.70
5	2025	12,520,045.50	1,127,313.72	694,484.56	10,698,247.22	47,733,360.00	1,611,729.52	694,484.56	45,427,145.93	34,728,898.70	6,945,779.74		27,783,118.96	15,764,887.84
6	2026	12,520,045.50	1,161,133.13	694,484.56	10,664,427.81	47,733,360.00	1,660,081.40	694,484.56	45,378,794.04	34,714,366.23	6,942,873.25		27,771,492.98	14,069,902.63
7	2027	12,520,045.50	1,195,967.13	694,484.56	10,629,593.82	47,733,360.00	1,709,883.84	694,484.56	45,328,991.60	34,699,397.78	6,939,879.56		27,759,518.23	12,556,996.29
8	2028	12,520,045.50	1,231,846.14	694,484.56	10,593,714.80	47,733,360.00	1,761,180.36	694,484.56	45,277,695.08	34,683,980.28	6,936,796.06		27,747,184.22	11,206,622.33
9	2029	12,520,045.50	1,268,801.52	694,484.56	10,556,759.42	47,733,360.00	1,814,015.77	694,484.56	45,224,859.67	34,668,100.25	6,933,620.05		27,734,480.20	10,001,331.60
10	2030	12,520,045.50	1,306,865.57	694,484.56	10,518,695.37	47,733,360.00	1,868,436.24	694,484.56	45,170,439.20	34,651,743.83	6,930,348.77		27,721,395.06	8,925,547.29
11	2031	12,520,045.50	1,346,071.54	694,484.56	10,479,489.41	47,733,360.00	1,924,489.33	694,484.56	45,114,386.11	34,634,896.71	6,926,979.34		27,707,917.37	7,965,364.14
12	2032	12,520,045.50	1,386,453.68	694,484.56	10,439,107.26	47,733,360.00	1,982,224.01	694,484.56	45,056,651.43	34,617,544.17	6,923,508.83		27,694,035.34	7,108,369.09
13	2033	12,520,045.50	1,428,047.29	694,484.56	10,397,513.65	47,733,360.00	2,041,690.73	694,484.56	44,997,184.71	34,599,671.06	6,919,934.21		27,679,736.85	6,343,481.28
14	2034	12,520,045.50	1,470,888.71	694,484.56	10,354,672.23	47,733,360.00	2,102,941.45	694,484.56	44,935,933.99	34,581,261.76	6,916,252.35		27,665,009.41	5,660,809.04
15	2035	12,520,045.50	1,515,015.37	694,484.56	10,310,545.57	47,733,360.00	2,166,029.70	694,484.56	44,872,845.75	34,562,300.18	6,912,460.04		27,649,840.14	5,051,522.42
16	2036	12,520,045.50	1,560,465.84	694,484.56	10,265,095.11	47,733,360.00	2,231,010.59	694,484.56	44,807,864.86	34,542,769.75	6,908,553.95		27,634,215.80	4,507,739.20
17	2037	12,520,045.50	1,607,279.81	694,484.56	10,218,281.13	47,733,360.00	2,297,940.90	694,484.56	44,740,934.54	34,522,653.41	6,904,530.68		27,618,122.72	4,022,423.28
18	2038	12,520,045.50	1,655,498.20	694,484.56	10,170,062.74	47,733,360.00	2,366,879.13	694,484.56	44,671,996.31	34,501,933.57	6,900,386.71		27,601,546.86	3,589,293.84
19	2039	12,520,045.50	1,705,163.15	694,484.56	10,120,397.79	47,733,360.00	2,437,885.51	694,484.56	44,600,989.94	34,480,592.15	6,896,118.43		27,584,473.72	3,202,744.34
20	2040	12,520,045.50	1,756,318.05	694,484.56	10,069,242.90	47,733,360.00	2,511,022.07	694,484.56	44,527,853.37	34,458,610.47	6,891,722.09		27,566,888.38	2,857,770.14
21	2041	12,520,045.50	1,809,007.59	694,484.56	10,016,553.36	47,733,360.00	2,586,352.73	694,484.56	44,452,522.71	34,435,969.35	6,887,193.87		27,548,775.48	2,549,903.96
22	2042	12,520,045.50	1,863,277.81	694,484.56	9,962,283.13	47,733,360.00	2,663,943.31	694,484.56	44,374,932.13	34,412,649.00	6,882,529.80		27,530,119.20	2,275,158.16
23	2043	12,520,045.50	1,919,176.15	694,484.56	9,906,384.79	47,733,360.00	2,743,861.61	694,484.56	44,295,013.83	34,388,629.03	6,877,725.81		27,510,903.23	2,029,973.31
24	2044	12,520,045.50	1,976,751.43	694,484.56	9,848,809.51	47,733,360.00	2,826,177.46	694,484.56	44,212,697.98	34,363,888.47	6,872,777.69		27,491,110.78	1,811,172.20
25	2045	12,520,045.50	2,036,053.98	694,484.56	9,789,506.97	47,733,360.00	2,910,962.79	694,484.56	44,127,912.66	34,338,405.69	6,867,681.14		27,470,724.55	1,615,918.85
26	2046	12,520,045.50	2,097,135.60	694,484.56	9,728,425.35	47,733,360.00	2,998,291.67	694,484.56	44,040,583.77	34,312,158.43	6,862,431.69		27,449,726.74	1,441,681.87
27	2047	12,520,045.50	2,160,049.66	694,484.56	9,665,511.28	47,733,360.00	3,088,240.42	694,484.56	43,950,635.02	34,285,123.74	6,857,024.75		27,428,098.99	1,286,201.75
28	2048	12,520,045.50	2,224,851.15	694,484.56	9,600,709.79	47,733,360.00	3,180,887.63	694,484.56	43,857,987.81	34,257,278.02	6,851,455.60		27,405,822.42	1,147,461.72
29	2049	12,520,045.50	2,291,596.69	694,484.56	9,533,964.25	47,733,360.00	3,276,314.26	694,484.56	43,762,561.18	34,228,596.93	6,845,719.39		27,382,877.54	1,023,661.63
30	2050	12,520,045.50	2,360,344.59	694,484.56	9,465,216.35	47,733,360.00	3,374,603.69	694,484.56	43,664,271.75	34,199,055.40	6,839,811.08		27,359,244.32	913,194.77

Appendix 2: Calculation of Payback Period

Cost of Capital			12%	Amount in 000	
			1.12		
Year	Cash	Cum Cash.	DF	Discounted	Cum.
0	-138,896,911.41	-138,896,911.41	1	-138,896,911.41	-138,896,911.41
1	27826333.87	-111,070,578	0.8929	24,844,940.96	-114,051,970.45
2	27816004.34	-83,254,573	0.7972	22,174,748.36	-91,877,222.09
3	27805364.92	-55,449,208	0.7118	19,791,309.53	-72,085,912.56
4	27794406.32	-27,654,802	0.6355	17,663,847.70	-54,422,064.86
5	27783118.96	128,317	0.5674	15,764,887.84	-38,657,177.03
6	27771492.98	27,899,810	0.5066	14,069,902.63	-24,587,274.40
7	27759518.23	55,659,328	0.4523	12,556,996.29	-12,030,278.11
8	27747184.22	83,406,512	0.4039	11,206,622.33	-823,655.78
9	27734480.20	111,140,993	0.3606	10,001,331.60	9,177,675.82
10	27721395.06	138,862,388	0.3220	8,925,547.29	18,103,223.11
11	27707917.37	166,570,305	0.2875	7,965,364.14	26,068,587.25
12	27694035.34	194,264,340	0.2567	7,108,369.09	33,176,956.34
13	27679736.85	221,944,077	0.2292	6,343,481.28	39,520,437.62
14	27665009.41	249,609,087	0.2046	5,660,809.04	45,181,246.66
15	27649840.14	277,258,927	0.1827	5,051,522.42	50,232,769.08
16	27634215.80	304,893,143	0.1631	4,507,739.20	54,740,508.28
17	27618122.72	332,511,265	0.1456	4,022,423.28	58,762,931.56
18	27601546.86	360,112,812	0.1300	3,589,293.84	62,352,225.40
19	27584473.72	387,697,286	0.1161	3,202,744.34	65,554,969.74
20	27566888.38	415,264,174	0.1037	2,857,770.14	68,412,739.88
21	27548775.48	442,812,950	0.0926	2,549,903.96	70,962,643.84
22	27530119.20	470,343,069	0.0826	2,275,158.16	73,237,802.00
23	27510903.23	497,853,972	0.0738	2,029,973.31	75,267,775.31
24	27491110.78	525,345,083	0.0659	1,811,172.20	77,078,947.52
25	27470724.55	552,815,808	0.0588	1,615,918.85	78,694,866.37
26	27449726.74	580,265,534	0.0525	1,441,681.87	80,136,548.23
27	27428098.99	607,693,633	0.0469	1,286,201.75	81,422,749.98
28	27405822.42	635,099,456	0.0419	1,147,461.72	82,570,211.70
29	27382877.54	662,482,333	0.0374	1,023,661.63	83,593,873.33
30	27359244.32	689,841,578	0.0334	913,194.77	84,507,068.11
Simple Payback Period (Years)					**5.00**
Discounted Payback Period (Years)					**8.08**

Appendix 3: Actual Energy Generation of Fewa HPP since Commissioning

S.No	F/Y	Annual Energy Generation (MWh)	S.No	F/Y	Annual Energy Generation (MWh)
1	2025/26	326.66	28	2052/53	2404.1
2	2026/27	615.16	29	2053/54	2867.73
3	2027/28	819.72	30	2054/55	2226.43
4	2028/29	1013.17	31	2055/56	2458.9
5	2029/30	1254.45	32	2056/57	2230.5
6	2030/31	1738.81	33	2057/58	1101.43
7	2031/32	1488.87	34	2058/59	1249.18
8	2032/33	2961.13	35	2059/60	1744.91
9	2033/34	3410.38	36	2060/61	527.27
10	2034/35	3919.47	37	2061/62	1352.41
11	2035/36	3761.97	38	2062/63	2373.47
12	2036/37	2884.24	39	2063/64	2405.25
13	2037/38	2247.54	40	2064/65	1216.11
14	2038/39	1371.48	41	2065/66	2179.81
15	2039/40	3433.32	42	2066/67	1425.18
16	2040/41	1682.71	43	2067/68	1913.49
17	2041/42	1035.21	44	2068/69	1872.21
18	2042/43	1579.49	45	2069/70	2081.96
19	2043/44	2061.91	46	2070/71	2050.14
20	2044/45	1599.45	47	2071/72	2310.74
21	2045/46	2532.68	48	2072/73	1664.77
22	2046/47	1986.69	49	2073/74	1467.69
23	2047/48	843.56	50	2074/75	1911.68
24	2048/49	489.16	51	2075/76	1531.68
25	2049/50	2104.02	52	2076/77	2314.63
26	2050/51	1849.52	53	2077/78	1850.94
27	2051/52	2012.91	**Total (MWh)**		**99756.29**

Appendix 4: Quantity Measurement Sheet (Concrete Lining Works of Main Canal)

S. N	Description	Unit	Nos	Length	Breadth	Height	Quantity	Remarks
1	Site Clearance works.	Sqm	2.00	730.00	2.50		**3650.00**	**Sqm**
2	Earthwork excavation for deposited debris inside canal.	Cum						
	Main Canal		1.00	730.00	2.50	0.30	547.50	
						Total	**547.50**	**Cum**
3	M20 Grade (1:1.5:3) PCC work.	Cum						
	Main Canal							
	Floor		1.00	730.00	2.50	0.15	273.75	
	Wall		2.00	730.00	2.50	0.15	547.50	
						Total	**821.25**	**Cum**
4	Reinforcement work (Fe 500)	Tonne	No.	Length	unit wt.		Weight	
	12 mm dia bar @ 12" c/c							
	Main Canal							
	Floor		17	730.00	0.89		11044.90	
	Wall		9734	2.50	0.89		21658.15	
						Total	**32703.05**	**Kg**
						Total	**32.70**	**Tonne**
5	Formwork with waterproof 18mm thick ply	Sqm						
	Main Canal							
	Wall		2.00	730.00		2.50	3650.00	
						Total	**3650.00**	**Sqm**

Abstract of Cost for Concrete Lining Works of Main Canal

SN	Description	Unit	Quantity	Unit Rate (NRs.)	Total Amount (NRs.)	Remarks
1	Site Clearance works.	Sqm	3650.00	15.00	54750.00	
2	Earthwork excavation for deposited debris inside canal.	Cum	547.50	500.00	273750.00	
3	M20 Grade (1:1.5:3) PCC work.	Cum	821.25	13500.00	11086875.00	
4	Reinforcement work (Fe 500)	Tonne	32.70	125000.00	4087500.00	
5	Formwork with waterproof 18mm thick ply	Sqm	3650.00	650.00	2372500.00	
				Sub-Total	**17,875,375.00**	
				VAT @13%	2,323,798.75	
				Total Amount (NRs.)	**20,199,173.75**	

Mahavir Shree International P. Ltd

Baburam Acharya Sadak, Sinamangal, G.P.O.Box: 410, Kathmandu, Nepal.
Phone: 4110860, Fax: 4110855, Email: info@msi.com.np Web: www.msi.com.np

QUOTATION

CUSTOMER			REFERENCE		
	Name:	Mr. Mahesh Bashyal		No:	12072021-1012
	Address:	Kathmandu		Date:	12th July, 2021
	Tel:	9841017097		Page:	1 of 1
	email:	bashyalmahesh63@gmail.com		Our Ref No:	20780328
	Attn:				

Quotation for Various Works as per your request letter

S.N.	Description of Item	Unit	Qty	Unit Rate	Total Amount
A. Gates and Stoplogs					
1	Canal Inlet Gate body, embedded parts, Seal plate, track plate, rubber seals, manual screw spindle hoist complete set	Set	1	555,144.00	555,144.00
2	Penstock Inlet Gate body, embedded parts, Seal plate, track plate, rubber seals, manual screw spindle hoist complete set	Set	2	591,379.50	1,182,759.00
3	Spare parts for Gates and Stoplogs (shall be sufficient for at least one set of panel)	Lot	1	108,919.73	108,919.73
					1,846,822.73
B. Trashrack and Trash Cleaning Machine					
1	Intake fine trashrack body with its embedded parts complete set	Set	2	212,500.00	425,000.00
2	Trash Rack Cleaning Machine, electrical and manual operation type along with its control and protection system (rope drum type raking system with net capacity of 0.5 tonne)	Set	1	4,500,000.0	4,500,000.00
3	Spare parts for Trash Rack cleaning Machine (shall be sufficient for at least one set)	Lot	1	153,000.00	153,000.00
					5,078,000.00
C. Penstock Accessories					
1	Penstock Manifold of ID= 450 mm	Kg	3596.318	235.00	**845,134.73**
				Sub Total	**7,769,957.46**
				VAT@13%	**1,010,094.47**
				Grand Total	**8,780,051.93**

* **Payment Terms & Conditions:**

Currency	NPR
VAT:	Including 13% VAT
Payment :	To be Mutually Agreed
Validity:	1 Year
Delivery:	2-4 Weeks

Note: Quotation provided herein represents lumpsum job on the basis of site visit/conditional status as briefed.

MAHAVIR SHREE INTERNATIONAL PVT. LTD.

For, Mahavir Shree International Pvt. Ltd.

Mahavir Shree International P. Ltd

Baburam Acharya Sadak, Sinamangal, G.P.O.Box: 410, Kathmandu, Nepal.
Phone: 4110860, Fax: 4110855, Email: info@msi.com.np Web: www.msi.com.np

QUOTATION

CUSTOMER			REFERENCE		
	Name:	Mr. Mahesh Bashyal		No:	12072021-1030
	Address:	Kathmandu		Date:	12th July, 2021
	Tel:	9841017097		Page:	1 of 1
	email:	bashyalmahesh63@gmail.com		Our Ref No:	20780328
	Attn:				

Quotation for Fewa Plant Maintenance Works as per your request letter

S.N.	Description of Item	Unit	Qty	Unit Rate	Total Amount
1	Forebay Maintenance Works of Fewa (Dismantling existing structures, Site clearance, Excavation, Base Preparation, M15 blinding concrete, M25 Concrete, Form works, rebar, backfilling levelling and fencing works on forebay)	Job	1	6,378,484.29	6,378,484.29
2	Powerhouse area maintenances works of Fewa (Site Clearance Excavation Dismantling and Removal works, Base Preparation in manifold area, Base Preparation in manifold area M15 blinding concrete, Formworks, M25 Concrete, Rebar, Backfilling and levelling, Hardened Concrete Floor 38mm thick IPS Floor Finish with Floor Hardner (per 10 sq.m.), Anti slip Paint, Painting works and other required works for rehabilitation)	Job	1	7,945,741.14	7,945,741.14
3	Office (control room) Construction of Fewa	Job	1	4,050,000.00	4,050,000.00
				Sub Total	**18,374,225.43**
				VAT@13%	**2,388,649.31**
				Grand Total	**20,762,874.74**

* **Payment Terms & Conditions:**

Currency	NPR
VAT:	Including 13% VAT
Payment :	To be Mutually Agreed
Validity:	1 Year
Delivery:	2-4 Weeks

Note: Quotation provided herein represents lumpsum job on the basis of site visit/conditional status as briefed.

MAHAVIR SHREE INTERNATIONAL PVT. LTD.

For, Mahavir Shree International Pvt. Ltd.

Date: 15-06-2021

Mr. Mahesh Bashyal
Kathmandu, Nepal Tel. +977-9841017097
Email: bashyalmahesh63@gmail.com

Item no.	Particulars	Qty (A)	Unit	Unit Price in (EURO) (B)	Total Price in (EURO) (C=A x B)	Remarks
A. Hydraulic Turbine and Accessories						
1	Hydraulic Turbine and Auxiliaries : 300/325 KW, single-runner, horizontal- shaft, Francis-type hydraulic turbine with all auxiliary equipment and accessories all complete comprising turbine runner, shaft seal, turbine guide bearing, covers, labyrinth seal rings, spiral casing with stay ring, wicket gates and operating mechanism, servomotors. draft tube, turbine inlet pipe assembly, control, instrumentation and safety devices, piping and drainage system, air supply against cavitation, foundation and anchor bolts, electrical materials;governor system, pressure oil system; cooling water system; compressed air system; tools and devices for assembly and maintenance; spare parts; assembly and tests in the workshop tests at site as specified in the particular technical and general technical specifications.	4	Set	17,559.88	70,239.52	
2	Mandatory Spare Parts (shall appropriate price breakdown)	1	Lot	7,023.95	7,023.95	
3	Turbine Main Inlet Valve (MIV) and bypass system along with its control and protection system complete	4	Set	15,101.50	60,405.98	
4	EOT crane of hoist capacity 5 tonne, Single girder type with complete accessories	1	Set	21,071.86	21,071.86	
				Sub-total (A)	158,741.31	
B. Alternating Current Generator						
1	Alternating current, salient pole type, three phase synchronous generators each of 375 KVA, 0.4 kV, 0.80 pf all complete as specified in the Specification	4	Set	22,476.65	89,906.58	
2	Mandatory Spare Parts(shall appropriate price breakdown)	1	Lot	8,990.66	8,990.66	
				Sub-total (B)	***14,080,000.00***	
C. Governor System						
1	Governor Control System (all complete as specified in the Specification)	4	Set	17,208.68	68,834.73	
2	Mandatory Spare Parts (shall appropriate price breakdown)	1	Lot	6,883.47	6,883.47	
				Sub-total (C)	75,718.20	
D.Transformer						
1	Main Transformer 11/0.4kV kV 1 MVA YNd11 (specified in the Specification)	2	Set	12,994.31	25,988.62	
2	Station Transformer 11/0.4 kV 100 kVA	1	Set	4,916.77	4,916.77	
3	Mandatory Spare Parts (shall appropriate price breakdown)	1	Set	2598.86212	2,598.86	
				Sub-total (D)	***33,504.25***	
E. Excitation System						
1	Brushless Excitation Control System	4	Set	2,809.58	11,238.32	
2	Mandatory Spare Parts(shall appropriate price breakdown)	1	Lot	1,123.83	1,123.83	
				Sub-total (E)	12,362.15	
F. Control and Protection System						
1	Generator Protection System	4	Set	-	42,143.71	
2	Power Transformers Protection System	2	Set	-		
3	11kV Transmission Line Protection System	2	Set	-		
4	Mandatory Spare Parts (shall appropriate price breakdown)	1	Lot	-		
				-		

Item no.	Particulars	Qty (A)	Unit	Unit Price in (EURO) (B)	Total Price in (EURO) (C=A x B)	Remarks
G. Switchgear System						
1	0.4kV, LT Panel encloser of Generator Circuit Breakers, Bus Coupler, MCCB and metering unit	7	Set	3,511.98	24,583.83	
2	11kV,630A, VCB with all assesories included	3	Set	7,726.35	23,179.04	
3	Mandatory Spare Parts (shall appropriate price breakdown)	1	Lot	772.63	772.63	
4	LA and Grounding	1	Lot	3,511.98	3,511.98	
				Sub-total (G)	***52,047.48***	
H. Automation and Control System						
1	PLC based Control System	1	Set	17,559.88	17,559.88	
2	Mandatory Spare Parts (shall appropriate price breakdown)	1	Set	1,755.99	1,755.99	
				Sub-total (H)	***19,315.87***	
I. Auxillary System						
1	Battery and Charger	1	Set	16,155.09	16,155.09	
2	Illumination system	1	Lot	1,404.79	1,404.79	
3	Fire Fighting	1	Lot	351.20	351.20	
4	UPS	1	set	421.44	421.44	
5	Telephone PBX	1	set	561.92	561.92	
				Sub-total (I)	***18,894.43***	
J. Cables						
1	11kV power cable	1	Lot	4,916.77	4,916.77	
2	LV cover cable (copper)	1	Lot	7,726.35	7,726.35	
3	LV power cable	1	Lot	2,809.58	2,809.58	
				Sub-total (J)	15,452.69	
				Grand Totals (EURO) (A+B+C+D+E+F+G+H+I+J)	**527,077.33**	

Note:

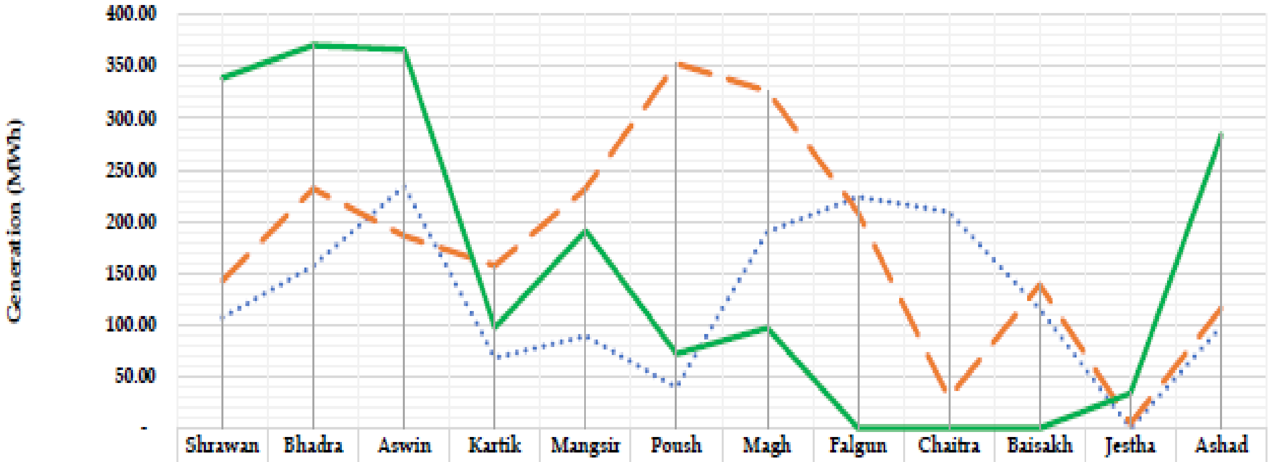
Turbine type:		Francis
Speed [n]:	rpm	1000
Maximum Run-away speed:	rpm	1625
Specific speed [ns]:		94.95
Peak Efficiency [η max]:	%	88.8
Flow @Run-away speed:	m^3/s	0.22
Generator Type:		Synchronous
Number of poles:		6
Frequency [f]:	Hz	50
Power factor:		0.80 ~ 0.9
Speed [n]:	rpm	1000
Peak efficiency:	%	92.5
Nominal power:	kVA	332

Signed: [Apolloni]

Name: [Vittorio Apolloni]
Title: **[Sales Director]**

ZECO DI ZERBARO E COSTA E C. SRL
via Astico, 52/C 36030 Fara Vicentino (VI) Italia - Tel.+39.0445.873456 – Fax +39.0445.873988
C.F. e P. IVA n. 02342150246 - Iscr.Reg. Imprese di Vicenza n. 02342150246 -
R.E.A. di Vicenza n. 0224485
Capitale sociale € 1.000.000 i.v.

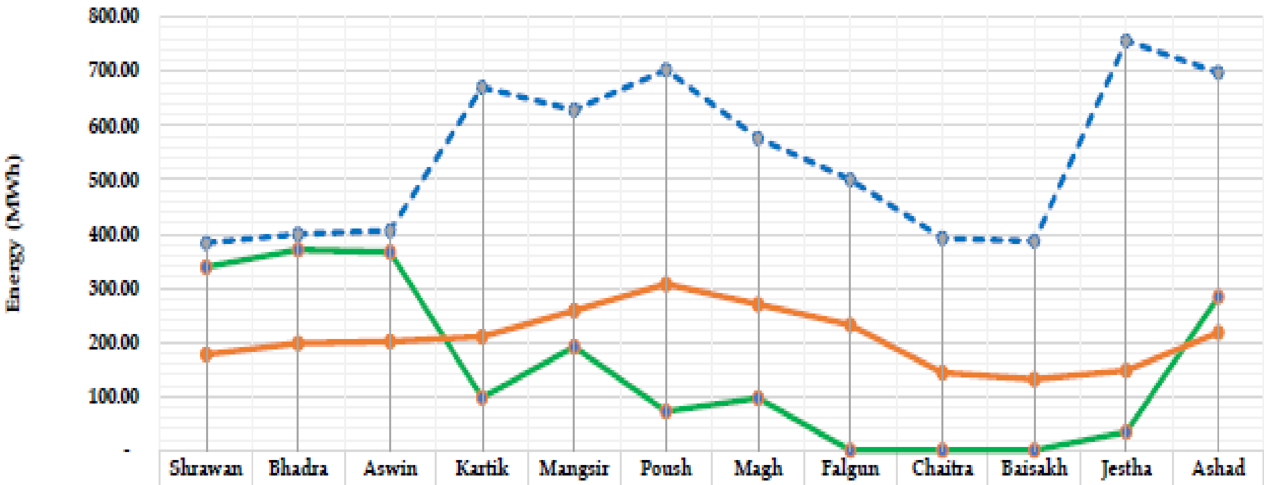
Monthly Energy Generation Trend of Last 3 Years



	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad
FY 2075/076	107.05	157.01	234.24	67.96	89.09	39.28	190.00	223.80	209.30	115.53	-	98.42
FY 2076/077	142.60	231.90	186.14	157.25	231.96	353.00	326.46	208.67	29.19	138.76	4.64	115.97
FY 2077/078	338.81	370.64	366.26	97.29	191.48	72.09	96.69	-	-	-	33.89	283.79

Month

Actual Generation comparison with Target and Designed Generation



	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad
Actual	338.81	370.64	366.26	97.29	191.48	72.09	96.69	-	-	-	33.89	283.79
Target	177.59	197.65	201.52	209.79	258.03	307.12	269.89	231.82	143.61	131.32	147.32	217.85
Designed	383.45	399.43	405.75	670.69	628.55	702.81	576.45	500.01	391.67	386.66	756.89	697.65

Month of 2077/078

Appendix: Site Photographs

Photo 1: Main Intake Gate

Photo 2: Structural damages at Main Canal

Photo 3: Forebay and Gates

Photo 4: Penstock

Photo 5: Trash rack

Photo 6: Fewa Powerhouse

Photo 7: Existing Condition of the Turbine Runner

Photo 8: 11 kV Switchgear Panels