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Fault Identification in Mechanical Components and Performance Analysis of PROR Hydropower Plants of Nepal Electricity Authority

By

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A THESIS

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ABSTRACT

One of the main reasons of power cuts is the outage in power plants due to various problems in electro-mechanical components along with civil structure. This report focuses on the reason of power outage due to mechanical problems in powerhouse. The frequent problems in mechanical components were identified in selected hydropower which are Kali Gandaki Hydropower Plant, Middle Marsyangdi Hydro Power Plant and Marsyangdi Hydro Power Plant and found that the desander and the water-cooling system encountered the problems more frequently. This report calculates the outage hours due to maintenance and due to unexpected problems and makes a financial evaluation of the loss occurred in the last four fiscal years along with the performance analysis. The availability of these plants ranges from 70-85% and the reliability is found to be more than 98%. The average plant factor ranges from 68-73% with MHPP at highest (72.13%). The average capacity factor ranges from 93- 110% with MMHPP at highest (109.20%). Similarly, the average performance factor of the plant ranges from 92-98% with KGAHPP at highest (97.52%). Moreover, the generation cost per unit electricity is also calculated from the collected data. The total forced outage in four fiscal years in three power plants is 1220.19 hours. The generation loss due to maintenance of the power plants over the four years' period is found to be 2,55,640.33 MWh. The total revenue loss due to the outage hours is found to be 586.88 crores.

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LIST OF SYMBOLS AND ABBREVIATION

NEA	:	Nepal Electricity Authority
IPP	:	Independent Power Producers
FY	:	Fiscal Year
MW	:	Mega Watt
kW	:	Kilo Watt
ROR	:	Run-of-River
PROR	:	Peaking Run-of-River
HPP	:	Hydropower Plant
KGAHPP	:	Kali Gandaki A Hydropower Plant
MHPP	:	Marsyangdi Hydropower Plant
MMHPP	:	Middle Marsyangdi Hydropower Plant
IDA	:	International Development Association
KFW	:	Kreditanstalt für Wiederaufbau
ADB	:	Asian Development Bank
GWh	:	Giga Watt Hour
MWh	:	Mega Watt Hour
rpm	:	Revolution Per Minute
kV	:	Kilo Volt
MVA	:	Mega Volt Ampere
Hz	:	Hertz
O & M	:	Operation & Maintenance
i.e.,	:	That is
PPA	:	Power Purchase Agreement

CHAPTER ONE: INTRODUCTION

1.1 Background

Hydropower, or hydroelectric power, is one of the oldest and largest sources of renewable energy, which uses the mechanical energy of moving water to generate electricity. Hydropower plants typically involve diverting the flow of rivers or streams to create reservoirs for storing water. When the water flows into the turbines that are connected to the generator through mechanical shaft, the mechanical energy carried by the water is converted into electrical energy, Hydropower plants are more efficient and cleaner than the traditional fossil fuel-based power plants. Since these power plants can also be started and closed quickly, we can use these as both base load plants and peak power plants.

More than 6000 river and rivulets flowing across the country along with its mountainous terrain make hydroelectricity a significant player in Nepal's energy sector. The hydropower potential of the country is at a whopping 42,000 MW which is astronomically higher than the current peak demand of just 2211.62 MW. Nepal Electricity Authority (NEA) and various Independent Power Producers (IPPs) have invested a large amount of capital in the development of hydroelectric power in the country. In the FY 2023/24, the total generation capacity has reached 3,157 MW among which 2991 MW is generated through hydropower resources. The independent power producers (IPPs) are responsible for 1915 MW of total hydropower generation capacity while NEA hydropower plant contributes 583MW and NEA Subsidiary contributes 493 MW of power. [1] In the last fiscal year, the total energy available in the system was 13,966 GWh. The energy acquired from IPPs and NEA Subsidiaries was 6,564 GWh and 2,597 GWh which is more than 65% of the total available energy. [1]

Furthermore, in addition to supply the electric power within the country, significant steps are being made to export the excess electricity which would in turn contribute significantly to Nepal’s economy. Hydroelectricity contributes significantly to Nepal's economy by reducing reliance on imported energy, creating jobs during construction and operation phases, and potentially generating revenue through electricity exports to neighboring countries like India and Bangladesh.

Nepal plans to further exploit its hydroelectric potential to meet domestic energy demands and promote economic development. The government encourages both public and private investments in the sector to achieve these goals. Currently, 137 projects with combined installed capacity of 3,906MW are being developed by IPPs after obtaining financial closure with NEA and a further 136 projects with combined installed capacity of 3,899MW are at various stages of development with financial closure yet to be done with NEA. [1] Nepal government has planned to commission electricity projects of capacity 15,000 MW within 2028. [2]

Overall, hydroelectricity remains a pivotal component of Nepal's energy strategy, offering a sustainable and reliable source of power that aligns with the country's geographical strengths.

1.2 Problem Statement

The efficient operation of hydropower plants is crucial for ensuring sustainable energy production and economic viability. However, the occurrence of mechanical problems within these facilities poses significant challenges that can directly impact revenue streams. Mechanical failures such as turbine malfunctions, generator issues, and structural degradation not only lead to unplanned downtime but also result in reduced energy output and increased maintenance costs. These operational inefficiencies not only hinder the plant's ability to meet energy demands but also diminish its overall profitability. Therefore, understanding the root causes, frequency, and economic consequences of mechanical failures in hydropower plants is essential for devising effective maintenance strategies and optimizing revenue generation in the renewable energy sector.

Nepal, endowed with abundant water resources, holds significant potential for hydropower generation. However, the development and operational efficiency of hydropower projects in Nepal are hindered by various challenges. These include but are not limited to inadequate infrastructure, geological complexities, regulatory hurdles, environmental concerns, and socio-political instability. Moreover, technical issues such as sedimentation, siltation, and hydraulic inefficiencies further exacerbate the operational difficulties of existing hydropower plants. These multifaceted challenges not only impede the optimal utilization of Nepal's hydropower potential but also undermine the sector's contribution to national energy security and economic growth. Therefore, a comprehensive understanding of these issues is essential for formulating effective strategies to enhance the sustainability and performance of hydropower projects in Nepal.

A hydropower plant often has a lifespan of 50 – 100 years with proper maintenance. For smooth running of power plant regular monitoring and maintenance of each and every parts of power plant are indispensable. Improvisation of old power plant is often less costly than developing a new power plant, often has relatively smaller environment and social impacts, and requires less time for implementation. A study on micro-hydro and medium hydro power plant was already done and found significant loss in revenue due to the problems in electro-mechanical components but a study on the problems in large hydropower of NEA was not found.

This study mainly focuses on mechanical problems on existing hydropower, their causes and their effects on total generation of energy as well as on the effects on revenue. This study focuses on the mechanical problems, their causes and their effects on large hydropower specially PROR of Nepal owned by NEA.

1.3 Objectives

1.3.1 Main Objective

To identify the frequent faults occurring on mechanical components and their impact on operation of PROR hydropower of Nepal Electricity Authority.

1.3.2 Specific Objectives

- To determine the total outage hours of the hydropower plants.
- To calculate the availability and reliability factor of hydropower plants.
- To calculate the plant factor, capacity factor and performance factor of hydropower plants.
- To calculate the generation cost per unit electricity generated of hydropower plants.
- To determine the loss of generation and revenue due to frequent problems.

1.4 Limitations

- Most of the data are collected from primary sources i.e., plant manager and engineers. Email and telephone were used for some data collection.
- Some errors in data recording such as human error and minor maintenance are being ignored.

CHAPTER TWO: LITERATURE REVIEW

The concept of energy intertwined with human civilization's progress and technological advancements. Early human relied on biomass energy in the form of wood, animal fats, and plant materials for heating, cooking, and light. [3] Fire was essential for survival and was used as a source of warmth and protection. Greeks, Romans, and Chinese developed various technologies to harness renewable energy sources like windmills and water wheels for grinding grains and pumping water. The middle ages saw the expansion of wind and water power in Europe. The discovery and exploitation of fossil fuels, namely coal and later oil, marked a significant turning point in energy history. [4] The steam engine invented in the late 18th century, revolutionized transportation, industry and agriculture. In the late 19th and early 20th centuries, concerns over environmental degradation and climate change prompted a shift towards renewable energy sources such as wind, solar, hydroelectric, and geothermal power. [5] Technological advancements and government incentives have led to rapid growth in renewable energy installations worldwide. [6]

Today, there is a growing emphasis on energy efficiency, sustainable development, and reducing greenhouse gas emissions. Because of which, hydropower became a major source of energy generation. Dams and reservoirs were constructed to harness the energy of flowing water to generate electricity on a large scale. Famous examples include the Hoover Dam in the United States and the Three Gorges Dam in China.

Hydropower is a method of generating electricity by harnessing the energy of flowing or falling water. Hydroelectric power plant converts potential energy available in flowing water to electrical energy by passing through a turbine generator system. Hydropower can be scaled from small installations, like micro-hydro systems that power a single home or small community, to large dams that generate electricity for entire regions.

2.1 Hydropower in Nepal

Hydropower plays a crucial role in Nepal's energy sector, largely due to the country's abundant water resources from the Himalayan rivers. It is the primary source of electricity in Nepal. The first hydropower plant was established at Pharping (500-KW) in 1911 AD, 29 years after the world's first plant was established, during Prime Minister Chandra Shamsher Rana's regime. Thereafter, a slow progress in hydropower is seen through small scale hydro power plants. Nepal established the Nepal Electricity

Authority (NEA) as the state-owned utility responsible for electricity generation, transmission, and distribution in 17^{th} August 1985. The 1990s marked a period of policy and regulatory reforms aimed at promoting private sector participation in hydropower development. The Hydropower Development Policy of 1992 introduced provisions for independent power producers (IPPs) and encouraged foreign investment in the sector. The ultimate breakthrough came with the construction of the Kali Gandaki-A Hydropower Plant in 2003, which marked a significant milestone. Since then, Nepal has continued to develop its hydropower sector, with ongoing projects aiming to harness its vast potential and meet domestic and export energy needs. Currently, there are total 20 hydropower plants under NEA, 2 thermal electric power plants, 3 subsidiary companies of NEA and around 161 hydropower plants as IPPs generating total 3044 MW. [1]

Types of Hydropower Plants

a) Run-of-River (ROR): These plants use the natural flow of the river with little to no storage, often with a small dam or diversion structure.
b) Peaking Run-of-River (PROR): These plants utilize a small storage facility to regulate water flow, allowing it to generate electricity during peak hours.
c) Storage: These plants rely on a large reservoir to store water and release it as needed to generate power.
d) Pumped Storage: These facilities act as a battery by storing energy. Water is pumped from a lower reservoir to a higher one during low demand and released back to generate power during high demand.

2.2 Components of Hydropower

Hydropower systems are complex and consist of several key components that work together to harness the energy from flowing water and convert it into electrical power. Here are the main components of a typical hydropower system:

a) Catchment Area:

   The catchment area of hydro plant is the whole area behind the dam, draining into a stream or river across which the dam has been built at suitable place.

b) Reservoir:

   The reservoir is the large body of water created behind the dam by impounding the river flow. It stores water that can be released as needed to generate electricity.

Reservoirs also serve other purposes such as flood control, irrigation, and recreation.

c) Dam:

A dam is a structure built across a stream or river to hold water back. The dam helps regulate the flow of water and increases the hydraulic head, which is the height difference between the water level upstream and downstream of the dam.

d) Trash Rack:

The main function of trash rack is to prevent the entry of debris which may damage the fixed blades and runner of turbine or chock up the nozzles of the impulse turbine. These are steel bars arranged in a grid-like structure. The design of trash rack affects the amount of debris that flows in the intake tunnel. Trash rack is constructed using metal bars that are evenly spaced. These track racks should be cleaned regularly to avoid blockages.

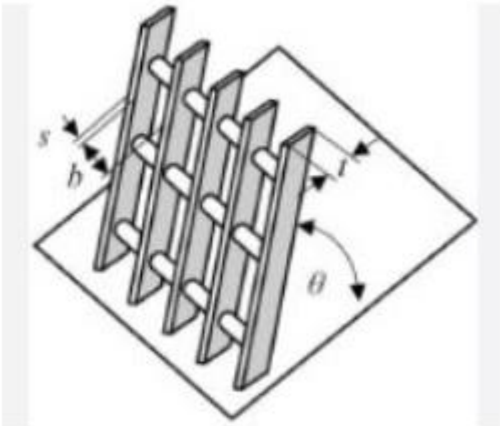

Figure 2. 1: Trash Rack [7]

e) Desander:

Desanders are especially designed to remove sediment and silt from water entering the turbine. When water is passed through the desander basin, the solid particles are removed from the water and accumulated. These accumulated solid particles have to be removed in a certain interval so that the water supply to the turbine is not affected.

f) Surge Tank:

It provides better regulation of water in the system during variable load conditions. The pressure in penstock is increased due to sudden decrease of water flow rate to turbine when load on turbine. This sudden rise of pressure in penstock above normal pressure is called water hammer. Similarly, when load on turbine is increased, the pressure in penstock reduces. Surge tank is introduced in the system between the dam and inlet of turbine.

g) Penstock:

Penstock is the crucial part in hydropower which channels the water from reservoir to the turbine at powerhouse. The primary purpose of a penstock is to direct and control the flow of water, which drives the turbine blades. The choice of material depends on factors such as the pressure, size, and environmental conditions. Penstocks are typically made from steel, concrete, or reinforced concrete. They need to be sturdy and durable because they must withstand high pressure and flow rates.

The penstock is equipped with expansion joints. As the penstock pipe is exposed to changes in temperature which can result in its expansion and contraction. This continuous expansion and contraction can cause significant effect to the penstock pipe. Hence, to eliminate these problems, expansion joints are used in penstock such that it can freely expand and contract.

Figure 2. 2: Penstock with Expansion Joint

h) Water Turbine:

A turbine is a machine that plays a key role in transforming fluid energy into usable work. A water turbine uses the potential energy resulting from the difference in elevation between an upstream water reservoir and the turbine-exit water level (the tailrace) and the kinetic energy of the flowing water. This difference in elevation is called head of water. The higher the head and greater the flow, greater the energy that can be generated. The water flowing from the penstock pipe spins the blades of a turbine which in turn spins the generator that ultimately produces electricity.

Basically, there are two types of water turbines. i.e. impulse turbine and reaction turbine based on the head of water and the flow.

1. Impulse Turbine:

   It is a type of turbine that uses kinetic energy of a high speed fluid and converts into mechanical energy. It is often used in hydropower plant having high head and low discharge. The pressure of the fluid remains constant as it passes through moving blades.

2. Reaction Turbine:

   It converts kinetic energy of high-speed fluid into mechanical energy causing pressure drop over the turbine's moving blades. It is often used in low head and high discharge.

   This study was carried out on the reaction turbine i.e. Francis Turbine. Francis turbine finds its application for the head ranging from 2m to 300m. The flow of the water into this turbine is radial while the exit from the turbine is axial i.e. parallel to rotational axis. The main components of Francis Turbine are:

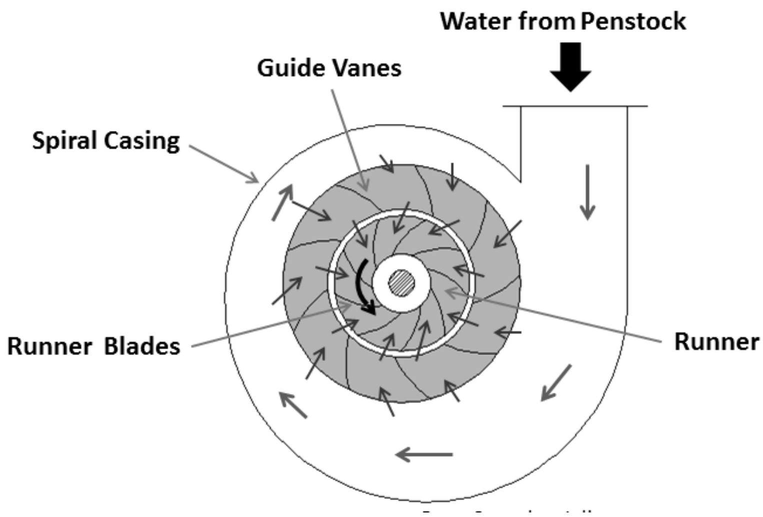

Figure 2. 3: Reaction Turbine [8]

i. Spiral Casing

   The water from penstock pipe enters the spiral casing through inlet valve. Spiral casing is designed in such a way that its cross-sectional area decreases uniformly around the circumference. This reduction in cross-sectional area ensures that the water flows towards the runner blades at a consistent velocity, resulting in a decrease in pressure as the water moves through it. By decreasing the cross-sectional area around the circumference, we achieve uniform pressure, which in turn leads to consistent momentum or velocity as the water strikes the runner blades.

ii. Fixed Vanes

Fixed vanes, also called stay vanes, help to reduce vortex in water such that water flows in a single direction.

iii. Guide Vanes

Guide vanes give direction to the water flowing in the spiral casing. According to the load demand, these guide vanes can be adjusted which controls the water flow rate.

iv. Runner Blades

These are the main parts of the turbine which uses the pressure energy of water to rotate the turbine. These blades are intricately designed to ensure smooth entry and exit of water without any shocks.

v. Draft Tube

Draft tube is the outward path for water flowing through runner blades. It connects the runner blades and tail race. Its cross-sectional area increases along its length. As the water exiting the runner blades has significantly low pressure, the increasing cross-sectional area helps to recover the pressure of water moving towards tail race.

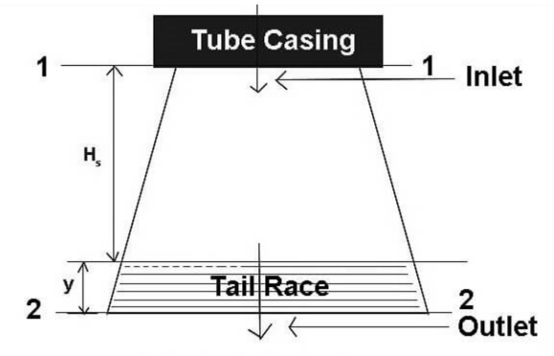

Figure 2. 4: Draft Tube [9]

i) Generator:

A generator is an electrical device that converts the mechanical energy produced into electrical energy. It is typically housed in a generator hall connected to turbine through shaft. The electricity generated is then transported via transformer into the transmission line.

j) Unit Transformer:

It steps up/down the electricity generated in required voltage and transfers to the transmission line through substation.

k) Valves

Valves are the safety elements that controls the flow of water by regulating its pressure, direction and volume. There are different kinds of valves at different position in hydropower plant. Butterfly valve, spherical valve, gate valve, check valve, pressure relief valve and control valve are some common types of valves.

Butterfly valves are mainly used for low and medium pressure application. The valve is usually opened using hydraulic pressures and closed using weight. Butterfly valves allow the flow of fluid in both directions.

Spherical valves are mainly used for high pressure application. These valves also allow the flow of fluid in both directions. The valve is operated using hydraulic pressures.

l) Bearings:

Bearings are located in various places in hydropower which helps in maintaining the efficiency and preventing wear and tear by supporting rotating machinery, reducing friction and ensuring smooth operation. They prevent excessive wear by distributing the loads evenly across the turbine shafts and generators. Bearings also prevent overheating by minimizing the friction between moving parts, thus, reducing energy losses. There are different types of bearings used in hydropower such as, radial bearings, thrust bearings, spherical bearings and fluid film bearings. These bearings are made up of bronze and brass, steel and stainless steel and composite materials. These bearings are then lubricated using high pressurized oil which acts as both lubricant as well as coolant. Turbine guide bearings, Upper and lower guide bearing in generator and thrust bearings are the major bearings used in hydropower. Bearings are often exposed to water and moisture which can lead to corrosion. These bearings are equipped with temperature and vibration sensor which is monitored and recorded in log books 24 x 7 during the operation. Any damage to the bearing will cause a raise in temperature and instability causing excess vibration. These bearing undergo wear, contamination or lubrication breakdown over time which require regular inspection and maintenance to ensure best operation.

m) Coupler

Coupler are used in hydropower plant to establish a connection between hydraulic turbine and generator. The coupler helps to transmit the rotational motion.

n) Compressor:

Air compressor provides compressed air for various operations in hydropower. Compressed air is mainly used for pneumatic braking system in hydropower. Along with this, compressed air generated by compressor helps to vent and relieve pressure during start-up and shutdown. Also compressed air is used for cooling systems and maintenance procedures. Most of the hydropower has at least one compressor in operation and the other as stand by. So, the problems in compressor does not contribute to outage hours of hydropower.

2.3 Problems in Mechanical Components of Hydropower:

a) Trash Rack

The major problem in trash rack is accumulation of debris such as branches, logs, twigs, leaves, etc. This will lead to uneven flow of water causing head loss. The accumulation of debris can also block the entry of water when the debris are not handled well. Hence, trash rack needs to be periodically cleaned for removal of such debris mainly in rainy season. The metal bars used in trash rack undergo mechanical wear and tear such as corrosion and cracking. The trash rack can also be subjected to structural fatigue due to hydraulic vibration. Modern ways should be implemented to clean the trash rack as installing Trash Rack Cleaning Machine. Thus, trash rack requires regular maintenance and repair works to reduce the outages in plant.

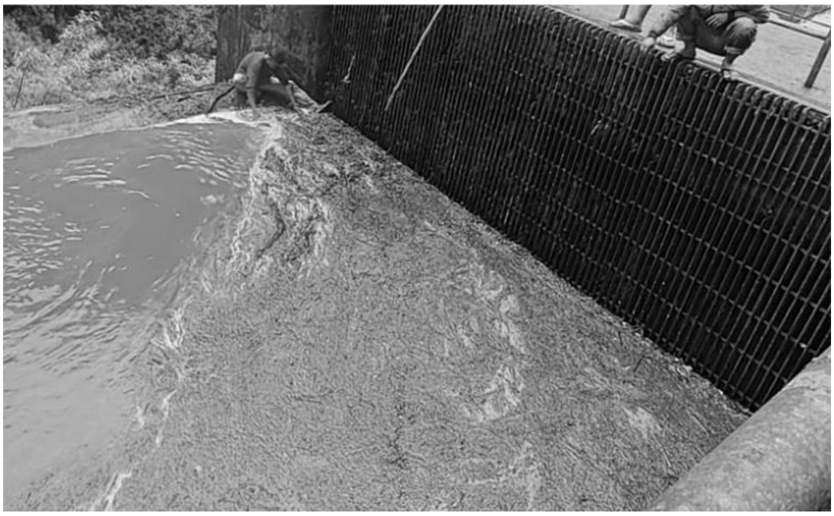

Figure 2. 5: Clogged Trash Rack

b) Penstock Pipe

The common issue that occurs in penstock pipes are cracks, corrosion and water leakage. These issues are caused due to misalignment of penstock pipe during installation, sudden jerk during opening and closing of inlet valve, landslides, soil erosion, temperature change or freezing of water inside the pipe.

The problem of expansion and contraction of penstock pipe can be minimized using expansion joints. Furthermore, the issues are less common in underground penstock pipes compared to exposed ones. Sudden jerks while starting and stopping the turbine induces the problem in penstock girder.

c) Turbine

The turbine runner is subjected to high pressure water jets along with silt which causes corrosion and cavitation in the runner blades. Cavitation takes place when water vaporizes due to low pressure near the turbine blades, resulting in bubbles that collapse forcefully, leading to damage and vibrations. Continuous stress and vibrations during operation can create fatigue cracks in turbine components, which may ultimately result in failure. Moreover, sediments suspended in the water can erode turbine components, especially in Francis turbines, where wider clearance gaps may cause cross-flow and secondary currents, worsening erosion.

Spiral casing suffers from corrosion, fatigue, cracking, rupture of casing and water leakage due to rapid changes in water flow, water hammering and silt containing in water. The turbulent flow in the spiral casing also introduces vibration which hampers the structural integrity of the casing.

In Francis Turbine, runner blades experience scoring and pitting more frequently due to the large pressure change and abrasive sediments. Runner blades also undergo erosion, cavitation and fatigue over the time of operation leading to the turbine failure.

The most common problem that fixed vanes experience is vortex-induced vibration which creates cracks and flow instabilities. The incorrect design of the stay vane can result in the creation of wakes and the shedding of significant eddies at the trailing edge, which may cause pressure variations as well as noise and vibrations during the turbine's operation.

Draft tubes exhibit complex flow patterns with a variety of flow phenomena, including secondary flow, turbulence, separation, whirling motion, and unsteadiness. The continuity and momentum equations that characterize the advanced fluid flows are usually intractable using analytical techniques.

d) Generator

Generator most commonly encounters with problems like overheating, leaks, stalling, loose bearings and with cooling system. Also, there will be wear and tear on slip rings and on carbon brushes which leads to electrical problems. Loose bearings lead to increased friction, heat and vibration damaging the generator.

e) Valves

The problem in valves occur mainly due to silt contained in water. The major problems are water leakage due wear and tear in the valve, rusting of seal used in valve, valve getting jammed due to fault in bush and bearing, etc. The damage in valve can also occur due to excessive force used during closing and opening of the valve.

The valve which experiences the most problem is Main Inlet Valve (MIV) as it is most frequently operated during machine startup and shutdown. The prevention of issue in MIV is critical as any repair work would require the whole plant to shut down.

f) Cooling System

Hydropower uses the force of moving water to spin the shaft connected to the generator, which produces massive amount of heat causing overheating and damaging the equipment. Generally, water-based cooling system is used in hydropower with closed loop and open loop system. Water from either penstock or tail race is used for cooling purpose. This water contains the silt which damages the pipeline and valves. Also, the heat exchangers used to transfer the massive heat produced in generators undergo wear and tear causing leakage of water deteriorating the cooling capacity of the exchangers.

g) Bearings/Bushes

If the vibration or the temperature is too high, then the unit must be shut down and bearing should be dissembled. Afterwards the bearing condition has to be examined and repair if required and then replace without disrupting the alignment. In most cases bearing gets damaged due to improper supply of lubrication or due to the vibration. Now the root of vibration is mainly the turbine blades which get corroded due to silt and cavitation, thus creating imbalance in rotation leading to the vibration. If the bearing is damaged and signs are pretty obvious then the plant should be shut down as soon as possible because instability created in the system can lead to severe damage to other parts as well. Lubricating system is also a cooling system for the bearings. The oil circulating through the bearings are cooled by the water. Sometimes the water tubes which are used to cooled the lubricating oil contains sand and it makes a layer in tube isolating the flow of heat energy from the oil to water, which results in increase of bearing temperature. In such cases, the unit should be shut down but if there is a backup cooling system then the cooling unit can disassemble, cleaned and repair as required. [10]

Summarizing the problems, some major mechanical problems that occur frequently are:

a) Cavitation in runner blades, guide vanes and draft tube, spiral casing etc.
b) Leakage in shaft seal
c) Cavitation in almost all component
d) Sediment buildup on runner
e) Water leakage in Valves
f) Bearing wear and tear
g) Water leakage in cooling System
h) Loose nut bolt due to vibration
i) Components fatigue due to continuous operation
j) Wear and tear due to ageing
k) Malfunctioning in governing system

These problems are mainly caused due to;

a) Poor maintenance

   Not proper preventive maintenance, poorly trained personnel and outdated system causes various problems causing huge loss in generation.

b) High sediment load in water

   Sediment erosion has been one of the greatest problems in Himalayan region. Erosion affects hydro-mechanical components like turbines and guide vanes causing serious damages [5]. Unplanned development in hilly and mountain region causes the increment of debris and sediments in the reservoir.

c) Extreme weather conditions

   Unpredictable rainfall patterns and droughts effects the water availability and flow variation in the river. Heavy rainfall followed by long drought affects the volume of water in reservoir. Also, flooding and landslide caused by heavy rainfall damages the infrastructure of hydropower plants disrupting the generation. It also increases the number of sediments in the reservoir directly affecting in the generation capacity of the plant.

d) Shaft misalignment

Shaft misalignment can be caused by various factors including wear and tear on bearings, misaligned couplings, design flaw, temperature fluctuations, foundation settlements and structural distortions. It causes major vibration in the system.

These problems can be minimized by;

a) Maintenance:

There are mainly two types of maintenance i.e., preventive maintenance and corrective maintenance.

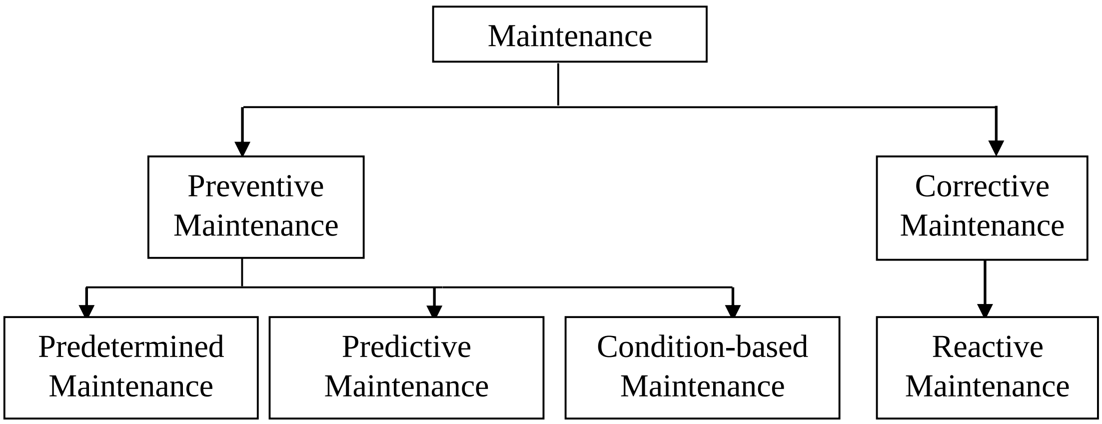

Figure 2. 6: Different Types of Maintenance

Preventive maintenance is a proactive approach for maintaining smooth operation of every equipment in the plant. This involves regular inspection, cleaning and lubricating and eliminating the minor issues which may lead to major issues. It also involves scheduled repair and replacement of the parts. Well organized and consistent monitoring and inspection increases the productive life of the product.

Predetermined maintenance, conditioned maintenance and predictive maintenance comes under preventive maintenance.

Predetermined maintenance is a scheduled maintenance created by the manufacturer of the equipment rather than the maintenance team. This is done on the recommendation by the factory. It is much easier to schedule and manage.

Conditioned-based maintenance is the maintenance that is done on the basis of observation or measurement of outcome. When any part uses more energy than usual to operate than it requires a conditioned maintenance.

Predictive maintenance is a data-driven maintenance. Data are recorded on a regular basis and these data are interpreted to forecast the problems that may arise. All of these preventive maintenances improve the product quality resulting in better efficiency at low cost reducing the catastrophic failure. It is always better to prevent the problems or find out the causes of problems that may occur and have a better solution before the complete failure of the product. However, sometimes unforeseen circumstances arise and the operation of generating equipment is disturbed. In such case, corrective maintenance has to be done to restore the operation.

Corrective maintenance also known as unplanned maintenance is done to bring the systems back to operation as soon as possible. This includes repairing of the malfunctioning units/parts or replacing the parts.

Reactive maintenance is an urgent maintenance which is carried out when the system fails or some catastrophic events occur. These includes minor repair to complete replacement of the machine.

b) Qualified Personnel:

For every work to be done every person involved should be well educated and should have acquired knowledge related to the subject. The technicians in power plant should be very familiar with the process and updated system. Qualified technicians can solve the problems with much ease and in a better way.

c) Analysis of Data:

Monitoring and analyzing day to day data helps to forecast the possible problems which can greatly help on improving the operation time and minimizing the maintenance cost.

2.4 Relevant Terminologies

Scheduled Outage Hour: Scheduled outage hour is pre-planned outage that helps to prevent unforeseen failure and larger power outages. It ensures the reliable output for longer period of time. These outage hours are necessary to carry out the planned and preventive maintenance. It includes overhauling of every electromechanical component along with civil structures. Though these outage hours result in generation loss, the preventive maintenance done in this period enhances the performance of HPP in a long run. [11]

Idle Outage Hour: Idle outage hour is the period where plants remain in stop condition though it has the potential to operate at full load. These hours are the result of system outage and of Load Dispatch Center's Order. [11]

Forced Outage Hour: Forced outage hour is the time where failure of generating equipment's occurs due to unexpected emergencies. It includes extreme weather conditions like flood and components malfunction. It lowers the plant's overall capacity to generate electricity and helps to evaluate the reliability of the plant. Some examples of forced outage hours are mechanical issues in turbine components, electrical system faults like faults in relays, limit switch, breaker, damage to the penstock pipe, flooding and sudden change in water flow. [11]

Plant Factor: Plant factor is defined as the ratio of annual actual energy generation by a plant to the maximum possible energy generation. [12]

$$\text{Plant Factor} = \frac{\text{Annual Actual Energy Generation(MWh)}}{\text{Installed Capacity (MW)x Total Hours in a year}} \text{ x } 100$$

Capacity Factor: Capacity factor is defined as the ratio of annual actual energy generation to designed annual energy generation. [12]

$$\text{Capacity Factor} = \frac{\text{Annual Actual Energy Generation}}{\text{Designed Annual Energy Generation}} \text{ x } 100$$

Performance Factor: Performance factor is defined as the ratio of annual actual energy generation to forecasted energy generation. [12]

$$\text{Performance Factor} = \frac{\text{Annual Actual Energy Generation}}{\text{Forecasted Annual Energy Generation}} \text{ x } 100$$

Availability Factor: Availability factor of hydropower is defined as the percentage of the amount of time that it is available to generate electricity over a certain period of time divide by total time that it can be available. It is the ratio of total running hour to the total machine hour. [13]

$$\text{Availability Factor} = \frac{\text{Total Running Hours}}{\text{Total Machine Hours}}$$

Reliability Factor: Reliability factor of hydropower refers to the ability of generating units to perform their intended function. Reliability factor is the probability that the plant will not be in a forced outage condition. It is the ratio of force outage time to total time. A high reliability factor is the indication of hydropower that has minimum unplanned shutdown and is highly dependable. Such hydro powers are crucial for grid stability. [13]

$$\text{Reliability factor} = 1 - \frac{\text{Total forced Outage}}{\text{Total Machine Hours}}$$

2.5 Researches on Major Issues in Hydropower Plants

P. Sapkota et all (2022) found that the major issues in most of the power plant in Nepal are due to erosion in turbine and its components like guide vanes, top cover, etc. due to cavitation and vibration in different loads. Lack in continuous monitoring and interpreting the data is also another major cause which creates unpredictable problems in power plants. [14]

A. Ojha (2017) studied about the frequent problems on mechanical components and their effects in generation loss and revenue loss of medium hydropower plant. This report analyzed the technical status of four medium hydro power having Francis Turbine and found that there was a significant loss in generation due to frequent problems such as water leakage, sediments in water, which creates cavitation, scouring, vibration, etc. [11]

R. Pandey et all (2023) identified and analyzed the issues in Chameliya Hydropower Plant. This HPP had almost half a drop in generation in dry season than in wet season due to low water flow in river. Moreover, shaft speed variation, misalignment and bearing failure were the major issues in Chameliya HPP. [15]

P. Singh et all (2025) presented a framework to achieve high level of reliability and safety on electromechanical components in HPP. To achieve the sustainable maintenance and operation programs in electricity generation system, a reliability, availability and maintainability model was presented. [16]

Pawan Bhatt and K. R. Joshi (2024) suggested that Nepal has to utilize its optimum resources in generating electricity for the socio-economic prosperity. Though almost only 4% of the potential of hydro-electricity has been utilized, Nepal is approaching towards saturation of its national demand. So, acknowledging the challenges, some better policies should be developed to build new hydropower and better plan should be executed to reduce the generation losses in existing HPP. [17]

R. Dhungana (2015) studied about the micro-hydro power plants and their challenges in achieving the designed generation. Most of the MHPP faced major problems in turbines housing, erosion in bucket and nozzle, collapse of lightning arrester, electric pole fell down, transmission wire breakdown due to landslides and storm which leads to revenue loss. It concluded that most of the MHPP are economically not feasible. [18]

S. Chitrakar and H. P. Neopane (2019) studied about the challenges for hydropower development due to river sediments. In Run-of-River type HPPs, sediments go directly in turbine components causing severe impacts. In reservoir HPPs, sediments decrease the storage capacity thus reducing the energy production. Sedimentation is thought to cause an annual loss of 0.57% of the total storage in the reservoirs that are currently in existence worldwide. The presence of hard mineral contents in the sediments further enhances the problem of erosion in turbine components. [19]

D. Sapkota et all (2014) evaluated the reliability and availability of Sunkoshi Hydro Power Plant by using Markov Model. It was found that the plant has reliability index more than 99% though it has significant number of scheduled outages. Almost all the preventive maintenance was done at this period which decreases the forced outages. [20]

B. P. Pandey (2023) evaluated reliability and availability of Kali Gandaki Hydropower Plant using Markov model. It was found that the plant has reliability index exceeding 99% and availability index ranges from 56.86% to 89.44%. It was suggested that implementing real time monitoring of sediments, optimizing the design of desander, implementing automated cleaning system helps in improving the operational capacity of the plant. [13]

M. Bashyal and L. Poudel (2021) performed a performance analysis of Fewa Hydropower Plant (1MW) and calculated the plant factor, capacity factor and performance factor of hydropower plants. The financial analysis for the rehabilitation of the power plant shows that it is economically viable. [12]

CHAPTER THREE: RESEARCH METHODOLOGY

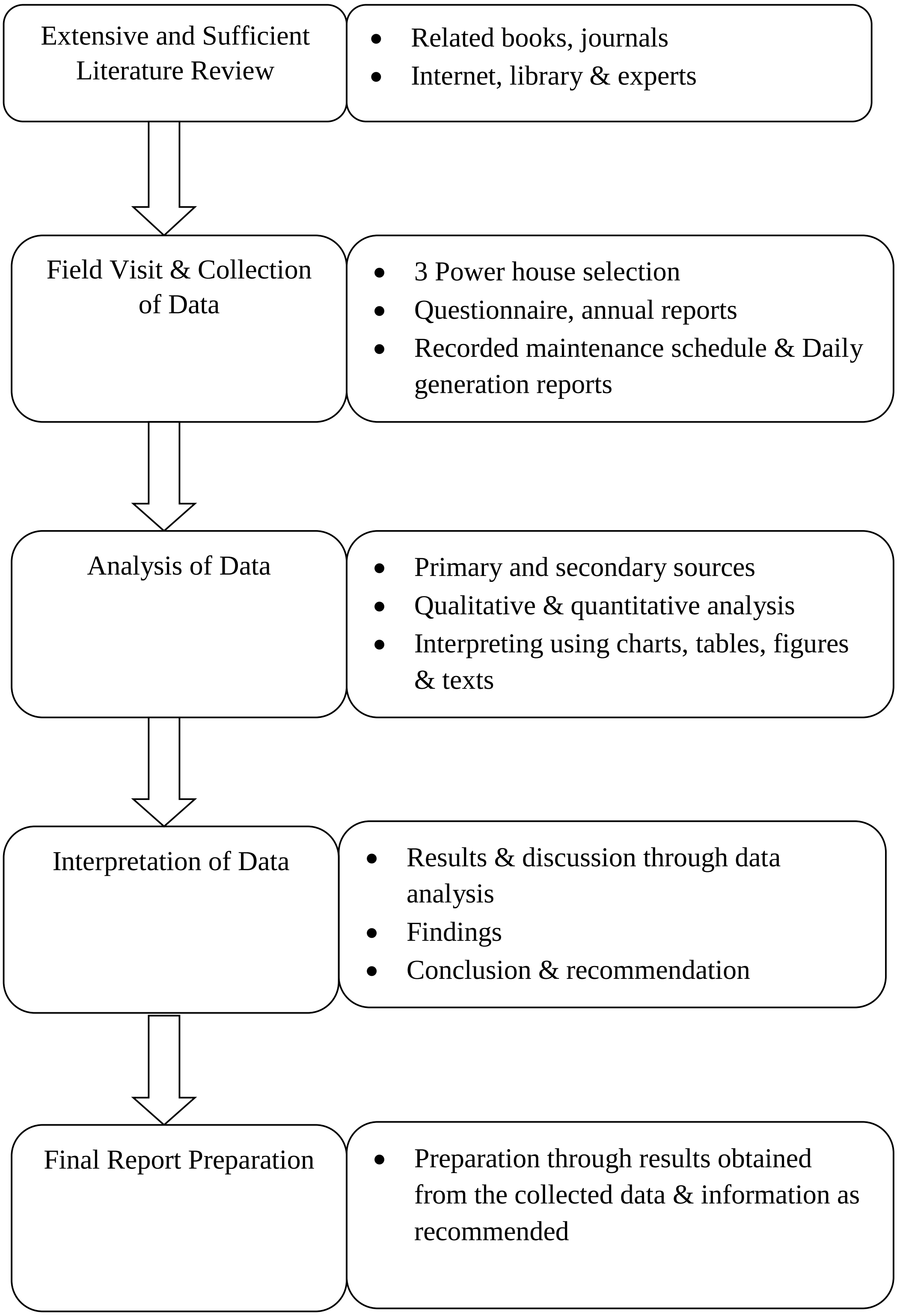

Figure 3. 1: Flowchart of Methodology

3.1 Literature Review

Various papers and researches done on different hydropower of Nepal were studied. Researches based on effects of maintenance on electricity generation and various possible problems on mechanical components were reviewed. Researches from research gate, previous researches from library of Pulchowk Campus and magazines from Nepal Electricity Authority were mostly used for research purpose.

3.2 Selection of Hydropower Plants

Nepal Electricity Authority has classified hydropower on two categories; medium hydropower generating less than 30 MW and large hydropower generating 30 MW or more than 30 MW. Selection of hydropower was done on the basis of the hydropower that has been in operation for more than 10 years and falls under large hydropower, having the same type of turbine i.e., Francis Turbine and operates on the same principle as Peaking Run-Off River (PROR). Based on these criteria, three large hydropower owned by NEA were selected which are Kali Gandaki A Hydropower Plant, Middle Marsyangdi Hydropower Plant and Marsyangdi Hydropower Plant.

3.3 Site Visit and Collection of Data

A set of questionnaires as listed in Appendix I was prepared about the conditions of mechanical components, problems that occurred on those components, their causes and solutions along with the outage hours due to those problems. With these questionnaire, all three hydropower plants were visited and asked to the engineers, operators and technicians in the power plants. Also, the data were collected from the daily recorded generation log book and maintenance log book along with the visual inspection. These data were collected for four fiscal years from 2077/078 to 2080/081. Other secondary data have been collected from annual report published by NEA during these fiscal years.

3.4 Analysis of Data & Interpretation of Data

From the data collected, the problems on mechanical components were identified for each year along with their frequency of occurrence. The causes of those problems were also recognized and the outage hours due to these individual problems were calculated. Data collected from power plants were also analyzed in Microsoft excel to find out the total outage hours due to planned outage and forced outage hours, loss of generation with respect to generation target given by NEA. Based on these data, availability and reliability factor was calculated. The plant factor, capacity factor and performance factor were also calculated along with generation cost. Moreover, the revenue loss due to generation loss was calculated and compared between these three hydropower plants. The results from calculation were interpreted. All these data were interpreted using charts, tables and figures.

3.4 Results and Discussion

The results of the findings were compared and discussed in this chapter. The potential results were the tables and graphs of frequency of occurrence of problems and their outages hours. The availability and reliability factor of the three HPPs in those four FY was discussed. The loss in generation and the loss in revenue were also discussed briefly in this chapter.

3.5 Report Writing

At last, a detailed report was prepared including all the data collected and their calculation. The results were interpreted and discussed briefly and summed up with conclusion and recommendation.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Problems in Mechanical Components in KGAHPP

Kaligandaki A Hydropower Plant (KGAHPP) is a peaking run of river type hydropower plant which uses the water from Kaligandaki river to generate 144MW of hydroelectricity. It was commission on 2002 AD and is located in Beltari, Syangja. It has a total installed capacity of 144 MW consisting of 3 units each of 48 MW. The annual designed generation is 842 GWh. The cumulative generation of the Plant has reached 17,257 GWh until the end of FY 2080/81. In FY 2080/81, it generated 841.6 GWh of energy which is 94.2 % of annual targeted generation and 99.88 % of design generation. The salient feature of Kaligandaki Hydropower plant is presented in Appendix II.

4.1.1 Problems in FY 2077/078

Table 4. 1: Problems in Mechanical Components in FY 2077/078 in KGAHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (576 hours)	Repaired/Replaced
Facing Plate	Erosion and cavitation	1	Cavitation, friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion and cavitation	1	Silt		Repaired/Replaced
Head Cover	Erosion and cavitation	1	Silt, corrosion		Repaired
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt		Repaired/Replaced
Turbine Housing	Erosion, cavitation	1	Silt		Repaired/Replaced
Draft Tube	Erosion, Cavitation	1	Silt		Repaired
Water Cooling System	Leakage/Filter chocking	8	Silt and corrosion	14.85	Cleaned, Repaired
Air Cooler	Blockage, Leakage	3	Silt, Wear and tear and ageing	7.32	Repaired/Replaced
Balancing Pipe	Leakage	1	Silt and corrosion	1.75	Repaired/Replaced
Turbine Guide	Wear and tear,	1	Problem in oil cooler	0.38	Cooler cleaned

Bearing (TGB)	Temperature Rise				
Shaft Seal	Leakage	3	Friction and water pressure	34.47	Replaced
Desander	Blockage	9	Silt and sedimentation	35.47	Flushed

Table 4. 1 shows the problems that occurred in mechanical components in FY 2077/078 along with their frequency of occurrence and their impact in running hour of the plant. Most of the problems were caused by silt present in water resulting in cavitation, erosion and corrosion of the parts. In this year, unit 2 was overhauled. Almost all components of plant were inspected and repaired/replaced resulting in total 576 hours of outage. Despite of overhauling, some issues were occurred in cooling system due to the silt buildup in cooling pipes and corrosion. In water cooling system, problem occurred 8 times resulting 14.85 hours of outage. Also, air cooler experienced leakage and blockage problems 3 times over the span of this year resulting 7.32 hours of outage. Balancing pipe caused 1.75 hours of outage because of leakage of water due to cavitation and corrosion. Unit was tripped for 0.38 hour due to temperature rise in Turbine Guide Bearing. This was because of chocking of oil filter. Shaft seal leakage was found three times with 34.47 hours of outage. This was due to water pressure and friction when the shaft is rotating. The amount of silt was so high that desander get blocked 9 times and for the flushing of desander 35.47 hours shutdown was required.

4.1.2 Problems in FY 2078/079

Table 4. 2: Problems in Mechanical Components in FY 2078/079 in KGAHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Water Cooling System	Leakage/Filter chocking	9	Silt and corrosion	16.71	Cleaned, Repaired
Air Cooler	Blockage, Leakage	3	Silt, Wear and tear and ageing	17.82	Repaired/Replaced
	Vibration	3	Water flow change, mechanical imbalances	12.98	Addressing mechanical imbalances
Penstock	Pressure Low	1	Flow Variation	1.80	Regulating the flow
Desander	Blockage	12	Silt and sedimentation	36.43	Flushed

Table 4. 2 shows the frequent problems that occurred on mechanical components in KGA in FY 2078/079. This year KGA encountered with less problem comparative to last year. There was leakage problem and filter chocking issue in water cooling system resulting in 16.71 hours of outage. The cooler pipes were cleaned and repaired. Some damaged heat exchanger plates were changed with the new ones. This year machine experienced vibration because of fluctuation in water flow, bearing wear and tear, silt corroding runner causing imbalance and leakage through guide vanes and balancing pipes. There was 12.98 hours of outage due to vibration throughout the year. Desander was flushed 12 times resulting 36.43 hours of outage in generation. These problems mainly occurred in rainy season as there was high amount of silt presence in water along with flow variation.

4.1.3 Problems in FY 2077/078

Table 4. 3: Problems in Mechanical Components in FY 2079/080 in KGAHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	2	Silt and sediments	Overhauling (432 hours)	Repaired/Replaced
Facing Plate	Erosion and cavitation	2	Cavitation, friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion and cavitation	2	Silt and corrosion		Repaired/Replaced
Head Cover	Erosion and cavitation	2	Silt and corrosion		Repaired
Bottom Ring/Wearing Ring	Erosion, cavitation	2	Silt and corrosion		Repaired/Replaced
Turbine Housing	Erosion, cavitation	2	Silt		Repaired/Replaced
MIV	Cavitation, Leakage	2	Silt, friction		Repaired
Draft Tube	Erosion, Cavitation	2	Silt and water pressure variation		Repaired
Water Cooling System	Leakage/Filter chocking	2	Silt and corrosion	5.18	Cleaned, Repaired
Air Cooler	Blockage, Leakage	3	Silt, Wear and tear and ageing	6.02	Repaired/Replaced
Spiral Casing	Leakage	1	Silt and corrosion	6.05	Repaired/Replaced

Set- ring of MIV	Wear and tear, leakage	3	Silt and corrosion	360	Replaced
Desander	Blockage	11	Silt and sedimentation	19.73	Flushed

Table 4. 3 shows the frequency of problems occurred on mechanical components in FY 2079/080. In last FY there was no overhauling, so, this year overhauling was done on unit 1 and unit 3. Unit 1 was overhauled in Kartik and unit 3 was overhauled in Chaitra. In overhauling almost all components were inspected and repaired. Some components that were severely damaged were replaced. There was leakage from Main Inlet Valve (MIV) in all units. The repair and maintenance of set ring of these MIVs took 360 hours of outage. Similarly, leakage from spiral casing was seen in this year. This was due to the cavitation and corrosion and it was repaired by using r-metal and corrosion resistant paint which takes 6.05 hours. As previous year, there was leakage in water cooler and air cooler mainly in rainy season. These leakages were fixed by repairing cooling pipes, tightening loose nut bolts and flushing the pipes as sediments build up in pipes. These issues gave the outage hour of 11.20 hour throughout the year. Comparing to last two fiscal years, desander was flushed less as there was less silt and less flood.

4.1.4 Problems in FY 2080/081

Table 4. 4: Problems in Mechanical Components in FY 2080/081 in KGAHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (384 hours)	Repaired/Replaced
Facing Plate	Erosion and cavitation	1	Cavitation, friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion and cavitation	1	Silt		Repaired/Replaced
Head Cover	Erosion and cavitation	1	Leakage		Repaired
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt		Repaired/Replaced
Turbine Housing	Erosion, cavitation	1	Silt		Repaired/Replaced
MIV	Cavitation	1	Leakage		Repaired
Draft Tube	Erosion, Cavitation	1	Silt		Repaired

Water Cooling System	Leakage/Filter chocking	6	Silt and corrosion	13.13	Cleaned, Repaired
Air Cooler	Blockage, Leakage	2	Silt, Wear and tear and ageing	4.68	Repaired/Replaced
Balancing Pipe	Leakage	1	Silt and corrosion	9.55	Repaired/Replaced
	Vibration	1	Mechanical Imbalances	2.12	Adjusting the mechanical imbalances
Trash rack	Blockage	10	Problem in oil cooler	135.47	Cleaned
Penstock	Pressure Low	3	Flow Variation	2.17	Regulating the flow
Desander	Blockage	24	Silt and sedimentation	142.02	Flushed

Table 4. 4 shows the frequency of problems in mechanical components in FY 2080/081 in Kali Gandaki A hydropower plant. In this fiscal year unit 2 was overhauled. Overhauling of unit includes repair and maintenance of runner blades, turbine housing, guide vanes, spiral casing, fixed vanes, facing plates, bottom ring, balancing pipes, governor, cooling system, generator, bearings, bushes, compressor, pumps, etc. Despite the overhauling, cooling system experienced leakage and blockage problems in rainy season with 17.81 hours of blockage. This year the machine stopped for 2.12 hours because of vibration. In rainy season, there was high flood which resulted flow variation and high debris because of which trash rack was cleaned for 10 times with total of 135.47 hours of outage. Also, desander was flushed 24 times resulting 142.02 hours of outage.

4.2 Problems in Mechanical Components in MMHPP

Middle-Marsyangdi Hydropower Plant (MMHPP) is a peaking run of river type hydropower plant which uses the water from Marsyangdi river to generate 70 MW. It was commissioned on 2008 AD with the aid of Government of Germany, Nepal, NEA and KFW. It took almost 8 years to complete with total cost of NRs. 27.6 Billion. It has the installed capacity of 70 MW consisting of 2 units each of 35 MW. It has the annual design generation of 398 GWh. The cumulative generation of the Plant has reached 6,663.2 GWh until the end of FY 2080/81. In FY 2080/81, it generated 441.1 GWh of energy which is 97.2 % of annual targeted generation and 110.95% of design generation. The salient feature of Middle Marsyangdi Hydropower plant is presented in Appendix II.

4.2.1 Problems in FY 2077/078

Table 4. 5: Problems in Mechanical Components in FY 2077/078 in MMHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (360 hours)	Repaired/Replaced
Facing Plate	Erosion, wear and tear	1	Cavitation, friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/Replaced
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt, friction due to vibration		Repaired/Replaced
Turbine Housing	Leakage	1	Erosion, cavitation		Repaired/Replaced
Head Cover	Leakage	1	Erosion, cavitation		Repaired/Replaced
Draft Tube	Corrosion and cavitation	1	Erosion, cavitation		Repaired/Replaced
Balancing Pipe	Leakage	1	Silt and corrosion	1.75	Repaired/Replaced
Guide Vanes	Leakage	1		0.85	Repaired
Water Cooling System	Leakage/Filter chocking, damaged insulation in pipes	8	Silt and corrosion	14.85	Repaired
Turbine Guide Bearing (TGB)	Temperature Rise	1	Problem in oil cooler	0.73	Repaired
Shaft Seal	Leakage	2	Friction and water pressure	1.17	Repaired/Replaced
Head Cover	Leakage	1	Corrosion and cavitation	6.00	Repaired
Desander	Blockage	5	Silt and sedimentation	77.64	Flushed

Table 4. 5 shows the problems in mechanical components along with their frequency and their effect in operating hours of the plant in FY 2077/078. In MMHPP, each unit gets overhauled in alternate year. Unit 1 was overhauled in this year. The overhauling of unit includes repair and maintenance of almost all components including runner blades, turbine housing, draft tube, head cover, shaft seal, balancing pipe, bottom ring, water cooling system, air coolers, generator, governor, bushes, etc. This overhauling was carried on for 15 days. Mainly these components experienced cavitation and corrosion due to the presence of silt in water. Despite of overhauling, there were some problems on these components resulting in outage. The most frequent problem was leakage in pipes, valves and fouling in heat exchanger plates of water-cooling system. This mostly occurred in rainy season due to silt which causes cavitation of pipes, valves and filter chocking. Similarly, shaft seal leakage occurred 2 times resulting in 1.17 hour of outage. Moreover, turbine guide bearing temperature rose once and head cover was repaired once resulting more of 6.37 hour of outage. Turbine guide bearing temperature rose due to problem in oil cooling system. Problem with head cover was erosion and corrosion.

4.2.2 Problems in FY 2078/079

Table 4. 6: Problems in Mechanical Components in FY 2078/079 in MMHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (288 hours)	Repaired/Replaced
Facing Plate	Erosion, wear and tear	1	Cavitation, friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/Replaced
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt, friction due to vibration		Repaired/Replaced
Turbine Housing	Leakage	1	Erosion, cavitation		Repaired/Replaced
Draft Tube	Corrosion and cavitation	1	Erosion, cavitation		Repaired/Replaced
Head Cover	Leakage	1	Silt and corrosion	7.95	Repaired
Guide Vanes	Leakage	2		11.75	Repaired

Water Cooling System	Leakage/Filter chocking, damaged insulation in pipes	3	Silt and corrosion	3.82	Repaired
Air Cooler	Leakage	4	Silt, Wear and tear	11.67	Repaired
Turbine Guide Bearing (TGB)	Oil Level low	2	Oil Leakage	6.28	Oil Top up
Desander	Blockage	3	Silt and sedimentation	65.00	Flushed

In FY 2078/079, unit 2 was overhauled which took 288 hours to complete. Regardless of overhauling, some problems occurred in head cover, guide vanes, water and air-cooling system and TGB leading to total 41.47 hours of outage. The frequently occurring problem was in air cooler and water cooler which was caused by silt. Problem in water cooling system occurred three times resulting 3.82 hours of outage. Similarly, air cooling issues occurred four times contributing total loss of 11.67 hours in total running hours of the plant throughout the year. Moreover, TGB temperature was high because of low oil level which created 6.28 hours of outage. In rainy season, desander was flushed 3 times which took 65 hours to complete. During the overhauling, the gates in desander basin were also repaired.

4.2.3 Problems in FY 2079/080

Table 4. 7: Problems in Mechanical Components in FY 2079/080 in MMHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (480 hours)	Repaired/Replaced
Facing Plate	Erosion, wear and tear	1	Silt and friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/Replaced
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt and friction due to vibration		Repaired/Replaced
Turbine Housing	Leakage	1	Erosion and cavitation		Repaired

Head Cover	Leakage	1	Silt and corrosion		Repaired/ Replaced
Draft Tube	Corrosion and cavitation	1	Erosion and cavitation		Repaired
Guide Vanes	Leakage	2	Silt and vibration	11.75	Repaired
Water Cooling System	Leakage/Filter chocking	3	Silt and corrosion	44.47	Cleaned
Governor	Oil Level Low	2	Leakage	1.20	Top up oil
Air Compressor	Overheating	1	Low oil level	1.18	Top up oil
Desander	Blockage	4	Silt and sedimentation	68.82	Flushed

Table 4. 7 depicts the problems occurred in fiscal year 2079/078 in mechanical components along with their outage hours. Overhauling of unit 2 was done which took 480 hours to complete. In spite of regular maintenance, some problems are inevitable which lead to certain outage hours in operation of the plant. Guide vanes were repaired twice which cost 11.75 hours of outage. There was leakage through guide vanes which was resolved through arranging the alignment and tightening loose nut bolts. Governor system regulates turbine speed by adjusting guide vanes. Problems in governor leads to unstable power output, increased wear on mechanical components and potential shutdowns. Governor oil level decreased twice due to worn seals causing 1.20 hours of outage. Oil level in air compressor was also low once which tripped the machine for 1.18 hours. This was solved by topping up the oil. In rainy season, desander was flushed 4 times resulting 68.82 hours of outage.

4.2.4 Problems in FY 2080/081

Table 4. 8: Problems in Mechanical Components in FY 2080/081 in MMHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (384 hours)	Repaired/Replaced
Facing Plate	Erosion, wear and tear	1	Silt and friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/Replaced

Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt and friction due to vibration		Repaired/Replaced
Turbine Housing	Leakage	1	Erosion and cavitation		Repaired
Draft Tube	Corrosion and cavitation	1	Erosion and cavitation		Repaired
Head Cover	Leakage	1	Silt and corrosion		Repaired/Replaced
Guide Vanes	Leakage	2	Silt and vibration	11.75	Repaired
Water Cooling System	Leakage/Filter chocking	1	Silt and corrosion	0.38	Cleaned
Governor	Oil Pressure Low	2	Low oil level	1.47	Top up oil
	Vibration	2	Mechanical imbalances, water flow variation	2.53	Adjusting mechanical imbalances
Desander	Blockage	8	Silt and sedimentation	124.50	Flushed

Table 4. 8 depicts the frequency of problems that occurred in mechanical components in FY 2080/081 along with their outage hours in MMHPP. Unit 1 was overhauled and almost all components such as runner, spiral casing, guide vanes, balancing pipes, bearings, bushes, oil sump tank, governor, generator, etc. were inspected and repaired, if required also replaced. However, some inevitable problems occurred in water cooling system and governor resulting in 1.85 hours of outage. This year there was no problem in air cooling and oil cooling pipes and valves. Even so, the machine tripped twice due to vibration leading to 2.53 hours of outage. Heavy rainfall occurred with huge amount of debris from upstream accumulated in intake which required desander flushing 8 times with total 124.50 hours of outage.

4.3 Problems in Mechanical Components in MHPP

Marsyangdi Hydropower Plant is located at Aabookhaireni, Tanahun which is four-hour daily peaking run-of-river type power Plant commissioned on 1989 AD with aid of IDA, KFW, KFED, SFD, ADB and Nepal Government. It took only 3 years to complete the project with total cost of ASD 221.57 million. It has the installed capacity of 69 MW consisting of 3 units each of 23 MW. It has the annual design generation of 467.45 GWh. The cumulative generation of the Plant has reached 14,595 GWh until the end of FY 2080/81. In FY 2080/81, it generated 446.1 GWh of energy which is 95% of annual targeted generation and 95.43 % of design generation. The salient feature of Marsyangdi Hydropower plant is presented in Appendix II.

4.3.1. Problems in FY 2077/078

Table 4. 9: Problems in Mechanical Components in FY 2077/078 in MHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (389 hours)	Repaired/Replaced
Facing Plate	Erosion, wear and tear	1	Silt and friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/Replaced
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt and friction due to vibration		Repaired/Replaced
Turbine Housing	Leakage	1	Erosion and cavitation		Repaired
Draft Tube	Corrosion and cavitation	1	Erosion and cavitation		Repaired
Head Cover	Leakage	1	Silt and corrosion		Repaired/Replaced
Air Cooler	Leakage	5	Silt, corrosion, wear and tear	5.10	Cleaned
Guide Vanes	Leakage	4	Silt and corrosion	105.53	Repaired
Turbine Guide Bearing (TGB)	Wear and tear, Temperature Rise	1	Problem in oil cooler	12.54	Oil sump tank cleaned and oil replaced
Lower Guide Bearing (LGB)	Temperature high	1	Oil get contaminated	11.40	Sump tank cleaned and oil replaced
Shaft Seal	Leakage	11	Friction and water pressure	141.35	Replaced
	Vibration	4	Mechanical Imbalances	31.73	Adjusting Mechanical Imbalances
Desander	Blockage	16	Silt and sedimentation	273.12	Flushed

Table 4. 9 shows the frequency of problems in mechanical components in FY 2077/078 in MHPP. Unit 1 was overhauled in this fiscal year which took 384 hours of outage. All electro-mechanical components were inspected and if problem found, repaired else replaced the component that could not be repaired. Though the overhauling of unit 1 was done, some issues were occurred in other two units throughout the year. The leakage in air cooler occurred four times resulting the outage hour of 5.10. Guide vanes were repaired four times which required total of 105.53 outage hours. Due to the problem in oil cooler, temperature of TGB and LGB was high once which tripped the machine. The oil sump tank was emptied and cleaned and filled with new oil which required 23.94 hours. MHPP encountered with the shaft seal problems more frequently than other two power plants mentioned above. In this fiscal year, shaft seal issues were recorded eleven times resulting in outage hour of 141.35 hours. Similarly, to minimize the faults and damage to the components desander was flushed sixteen times in rainy season resulting 273.12 outage hours.

4.3.2 Problems in FY 2078/079

Table 4. 10: Problems in Mechanical Components in FY 2078/079 in MHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (264.6 hours)	Repaired/Replaced
Facing Plate	Erosion, wear and tear	1	Silt and friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/Replaced
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt and friction due to vibration		Repaired/Replaced
Turbine Housing	Leakage	1	Erosion and cavitation		Repaired
Draft Tube	Corrosion and cavitation	1	Erosion and cavitation		Repaired
Head Cover	Leakage	1	Silt and corrosion		Repaired/Replaced
Water Cooling System	Leakage/Filter chocking	1	Silt and corrosion	0.43	Cleaned
Air Cooler	Leakage, Blockage	3	Silt, Wear and tear and ageing	5.68	Cleaned

MIV	Leakage	1	Silt and corrosion, seal damaged	283.1	Repaired
Turbine Guide Bearing (TGB)	Wear and tear, Temperature Rise	4	Problem in oil cooler	7.93	Cleaned
Shaft Seal	Leakage	8	Friction and water pressure	96.37	Repaired/Replaced
Desander	Blockage	13	Silt and sedimentation	214.32	Flushed

Table 4. 10 depicts the frequency of problems in mechanical components in MHPP and their effects in operating hours of the plants in FY 2078/079. Unit 2 was overhauled in this year resulting in 264.6 hours of outage. MIV leakage were repaired before overhauling the units. It took 283.1 running hours to repair MIV. MIV has only been repaired 3 times in 34 years of operation. It was done in 2057, 2068 and 2078 which is a ten-year gap between each repair. This year also air cooler experienced the problem of leakage three times which cost 5.68 hours of outage. TGB temperature was high three times because of sludgy and contaminated oil. The oil sump tank was cleaned and filled with new oil which solved the problem. Frequent problems occurred in shaft seal mostly in rainy season due to silt and friction due to vibration effecting in the efficiency of the plant. Most of the time the shaft seal was replaced with new ones while some time the problem was solved with minor repair. To prevent the plant from adverse effect of flood, desander was flushed thirteen times throughout the year, mainly in rainy season.

4.3.3 Problems in FY 2079/080

Table 4. 11: Problems in Mechanical Components in FY 2079/080 in MHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (415.27 hours)	Repaired/Replaced
Facing Plate	Erosion, wear and tear	1	Silt and friction due to vibration		Repaired/Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/Replaced
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt and friction due to vibration		Repaired/Replaced

Turbine Housing	Leakage	1	Erosion and cavitation		Repaired
Draft Tube	Corrosion and cavitation	1	Erosion and cavitation		Repaired
Head Cover	Leakage	1	Silt and corrosion		Repaired/R eplaced
Water Cooling System	Leakage/Filt er chocking	4	Silt and corrosion	4.12	Cleaned
Air Cooler	Leakage	3	Silt, Wear and tear and ageing	6.33	Cleaned
Turbine Guide Bearing (TGB)	Temperature Rise	3	Problem in oil cooler	7.45	Oil sump tank cleaned
Upper Guide Bearing (UGB)	Temperature Rise	2	Problem in oil cooler	1.63	Cooling pipes cleaned
Shaft Seal	Leakage	8	Friction and water pressure	143.20	Replaced
Desander	Blockage	15	Silt and sedimentation	243.63	Flushed

Table 4. 11 depicts the frequent problems that occurred in MHPP in FY 2079/080 along with outage hour due to respective problems. Unit 3 was overhauled in this year which took 415.27 hours to complete. Runner, guide vanes, facing plate and bottom ring were replaced with spare while head cover, draft tube and turbine housing were repaired through welding and other appropriate methods. The most frequent cause of outage was desander blockage which occurred for 15 times resulting in outage hour of 243.63 hours. Another significant cause for outage was shaft seal leakage which the plant experienced for 8 times resulting in total outage hours of 143.20 hours. This was the time taken to replace the faulty shaft seal. Other mechanical problems were leakage and filter chocking in water cooling system, leakage in air cooler, temperature rise in turbine guide bearing and upper guide bearing which were all resolved by cleaning and adding additional lubricants.

4.3.4 Problems in FY 2080/081

Table 4. 12: Problems in Mechanical Components in FY 2080/081 in MHPP

Components	Problems	Frequency	Causes	Outage Hour	Solution
Runner	Scoring and pitting	1	Silt and sediments	Overhauling (305.32 hours)	Repaired/ Replaced
Facing Plate	Erosion, wear and tear	1	Silt and friction due to vibration		Repaired/ Replaced
Guide Vanes	Erosion, cavitation	1	Silt		Repaired/ Replaced
Bottom Ring/Wearing Ring	Erosion, cavitation	1	Silt and friction due to vibration		Repaired/ Replaced
Turbine Housing	Leakage	1	Erosion and cavitation		Repaired
Draft Tube	Corrosion and cavitation	1	Erosion and cavitation		Repaired
Head Cover	Leakage	1	Silt and corrosion		Repaired/ Replaced
Air Cooler	Leakage/Blockage	4	Silt, Wear and tear and ageing	8.93	Cleaned and repaired
Lower Guide Bearing (LGB)	Temperature Rise	2	Problem in oil cooler, friction	34.33	Cleaned
Shaft Seal	Leakage	1	Friction and water pressure	21.13	Replaced
Desander	Blockage	21	Silt and sedimentation	199.27	Flushed

Table 4. 12 shows the frequent problems that occurred in mechanical components in FY 2080/081 and their effect in operating hours of the plant. This year MHPP faced less problems in comparison to last three fiscal years. Overhauling of unit 1 was done which includes the replacing of runner, facing plates, bottom ring and guide vanes along with repair of turbine housing, head cover and draft tube. This overhauling took 305.32 hours to complete. Problem in oil cooler resulted in temperature rise of lower guide bearing which accounted for outage hours of 34.33 hours. Shaft seal was replaced just once in contrast to the previous years and this resulted in outage hours reducing up to just 21.13 hours. Another mechanical component to experience fault was air cooler which had a total fault count of 4 resulting in outage hours of 8.93 hours. Desander

flushing was carried out 21 times resulting in outage hours of 199.27 hours in FY 2080/081.

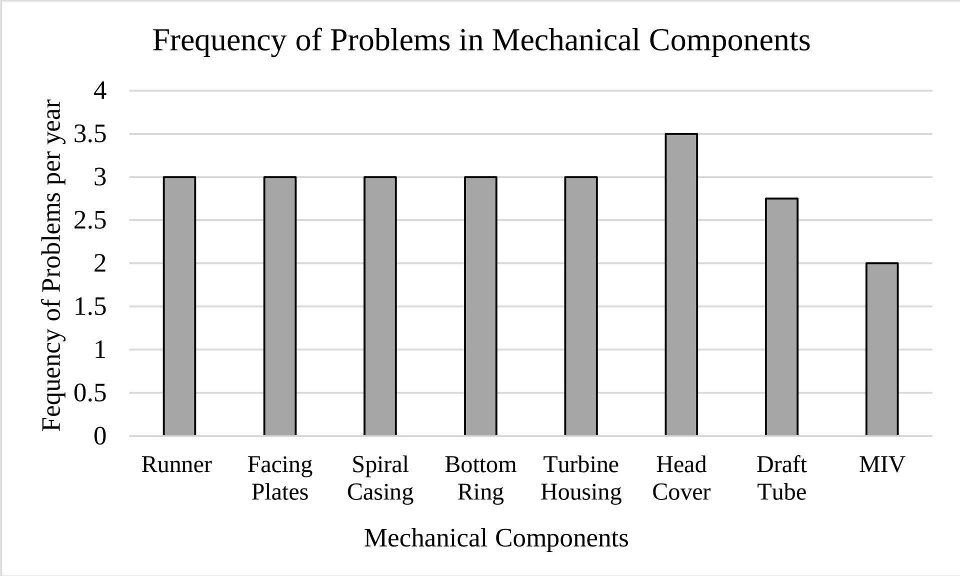

Figure 4. 1: Frequency of Problems in Mechanical Components Per Year

The most frequent problems that occur on Francis Turbine are cavitation on runner blades, turbine housing, guide vanes, leakage of water in turbine housing, MIV, cooler pipes, valves, etc. These problems are mostly caused due to silt and sediment particles in water. These problems lead to reduced efficiency, increased vibration and potential damage to the turbine. In all three power plants, almost similar type of problems was observed with the slight difference in frequency of occurrence.

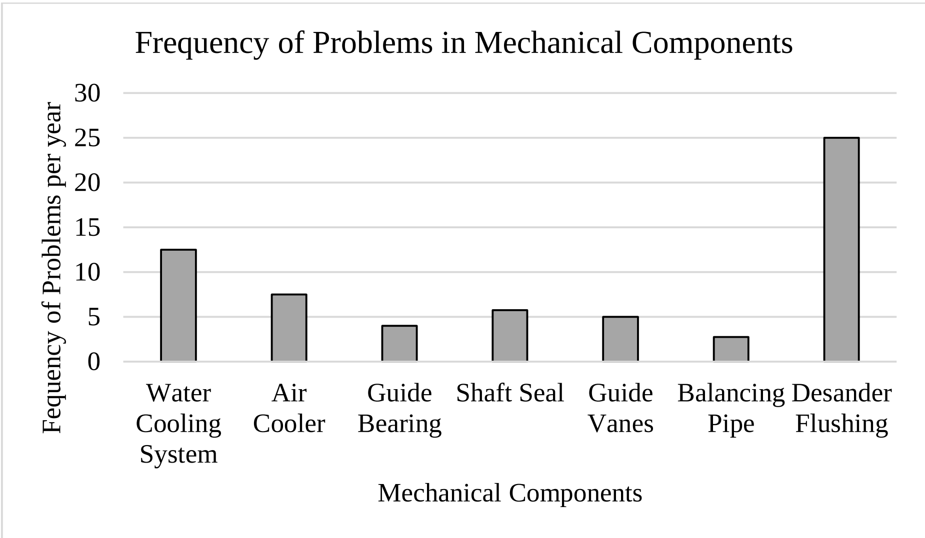

Figure 4. 2: Frequency of Problems in Mechanical Components Per Year

It was found that KGAHPP had more occurrence of problems than MMHPP and MHPP. There was more erosion and cavitation in turbine components in Kali Gandaki

HPP. Figure 4. 1 and Figure 4. 2 shows that except desander flushing, the most frequently occurred problem was leakage and filter chocking in cooling pipeline. Less occurrence of forced mechanical problems means these power plants have better preventive maintenance. It seems that these power plants follow “Prevention is better than cure” principle very well.

4.4 Outage Hour

4.4.1 Kali Gandaki A Hydropower Plant

Figure 4. 3 shows the monthly running and outage hours of Kali Gandaki A HPP in FY 2077/078. The pattern of total outage hour says that the outage hour went on increasing as the dry season progressed due to insufficient water in the river causing the idle hours of the plant. This year KGA experienced 7390.22 hours of forced outage because of various problems in electro-mechanical components. The main reason of these problem was silt in water and variation in flow during floods in rainy season. Total scheduled outage hour of the year was 913.57 hours where scheduled outage in Jestha and Ashadh was high as overhauling was done in these months.

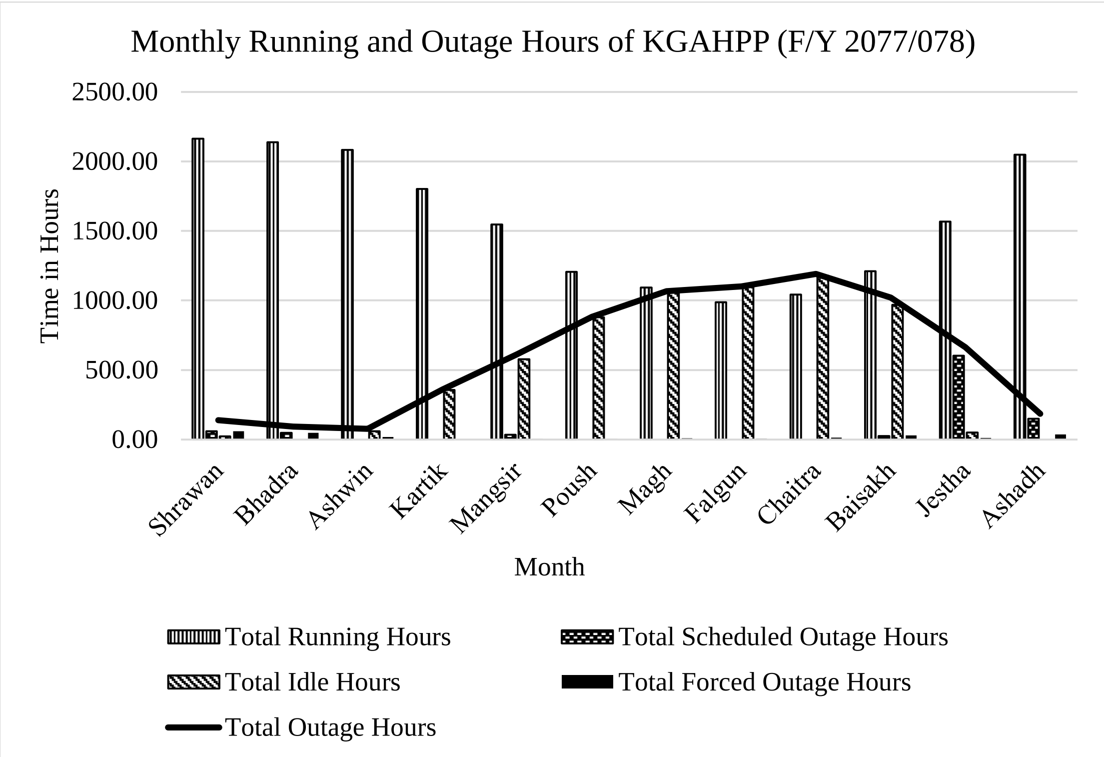

Figure 4. 3: Monthly Running and Outage Hours of KGAHPP (F/Y 2077/078)

From Figure 4. 4, it can be explained that in FY 2078/079 there was less outage hour compared to last fiscal year but the forced outage hour throughout the year increased to 322.68 hours. Scheduled outage was less in this year as there was no overhauling of any unit. The forced outage hour was high in rainy season because of the huge amount of silt and debris in water. The idle hour was maximum in Falgun as it peaked the dry season.

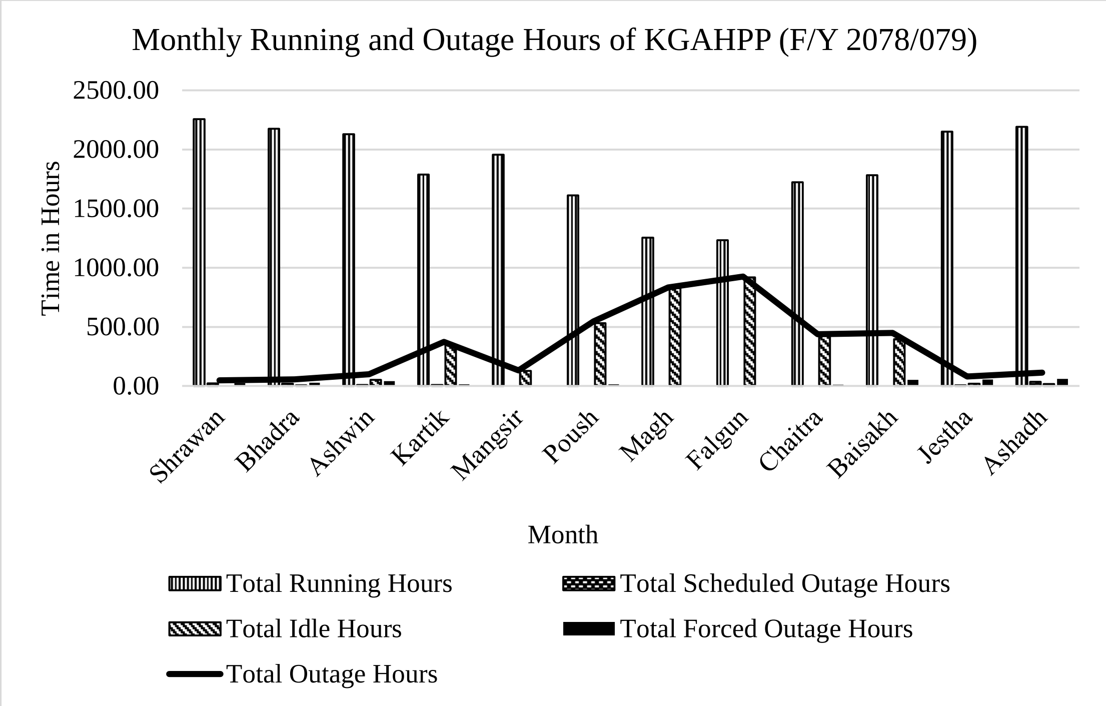

Figure 4. 4: Monthly Running and Outage Hours of KGAHPP (F/Y 2078/079)

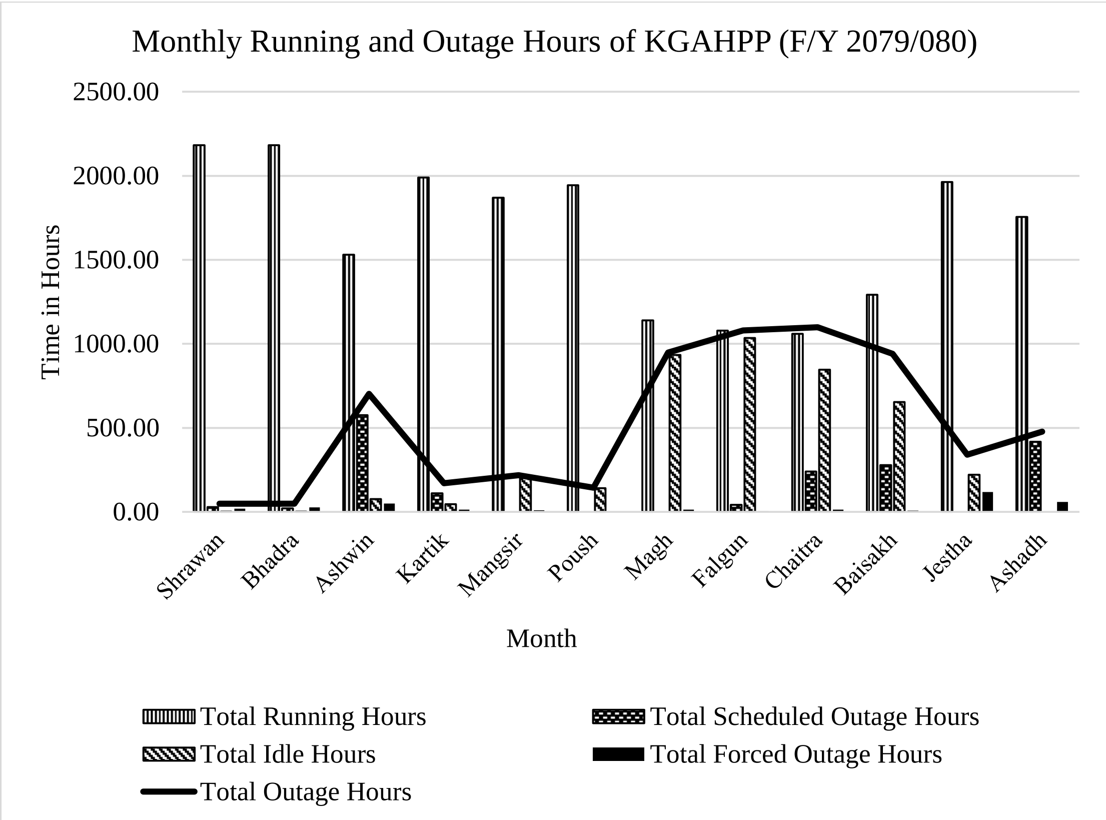

Figure 4. 5: Monthly Running and Outage Hours of KGAHPP (F/Y 2079/080)

Figure 4. 5 shows that in FY 2079/080, more preventive maintenance were done on the plant. There were scheduled outage in Ashwin, Chaitra, Baisakh and Ashadh of 575.53 hours, 239.48 hours, 279.15 hours and 418.13 hours respectively. Total running hour was high in Shrawan with 2183.27 hours. The maximum forced outage was in Jestha with 119.17 hours.

In FY 2080/081, the total running hour of the plant was 19847.66 hours with maximum running hour in Shrawan i.e. 2196.45 hours. Scheduled outage was high in Kartik as overhauling was done in this month. As the dry season started, idle hour went on increasing and forced outage hour and scheduled outage hour was in decreasing order. From this it can be concluded that the problem in the plant is due to high amount of silt and flood in rainy season.

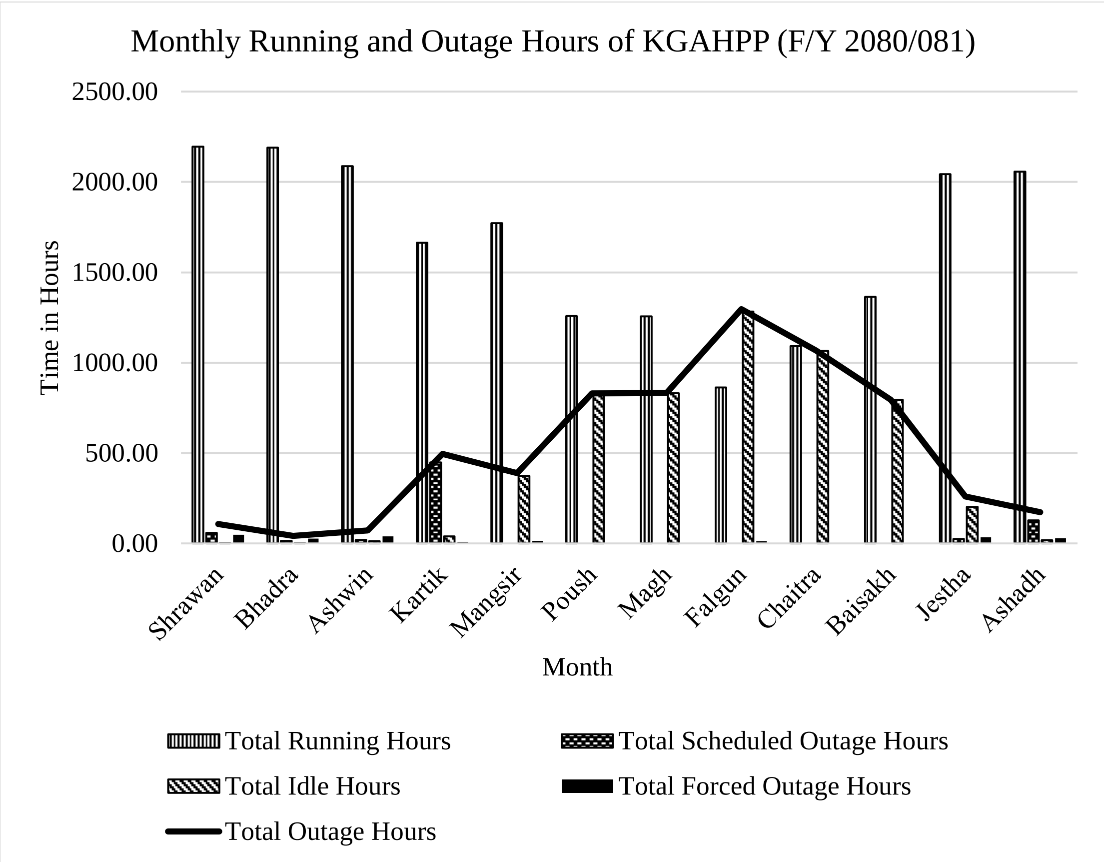

Figure 4. 6: Monthly Running and Outage Hours of KGAHPP (F/Y 2080/081)

4.4.2 Middle Marsyangdi Hydropower Plant

Figure 4. 7 shows that in FY 2077/078, MMHPP had maximum running hours in Shrawan i.e., 1463.20 hours with the total running hours of the year reaching 12613.40 hours. There was a maximum total scheduled outage in Chaitra i.e., 781.13 hours and maximum idle hours in Ashadh i.e., 817.62 hours. Though the water level was high in

Ashadh, the plant remained idle for long because of the high flood in river. From figure, it also can be interpreted from that there was an overhauling of the plant in Chaitra. There was very less forced outage hour throughout the year i.e., 6.17 hours.

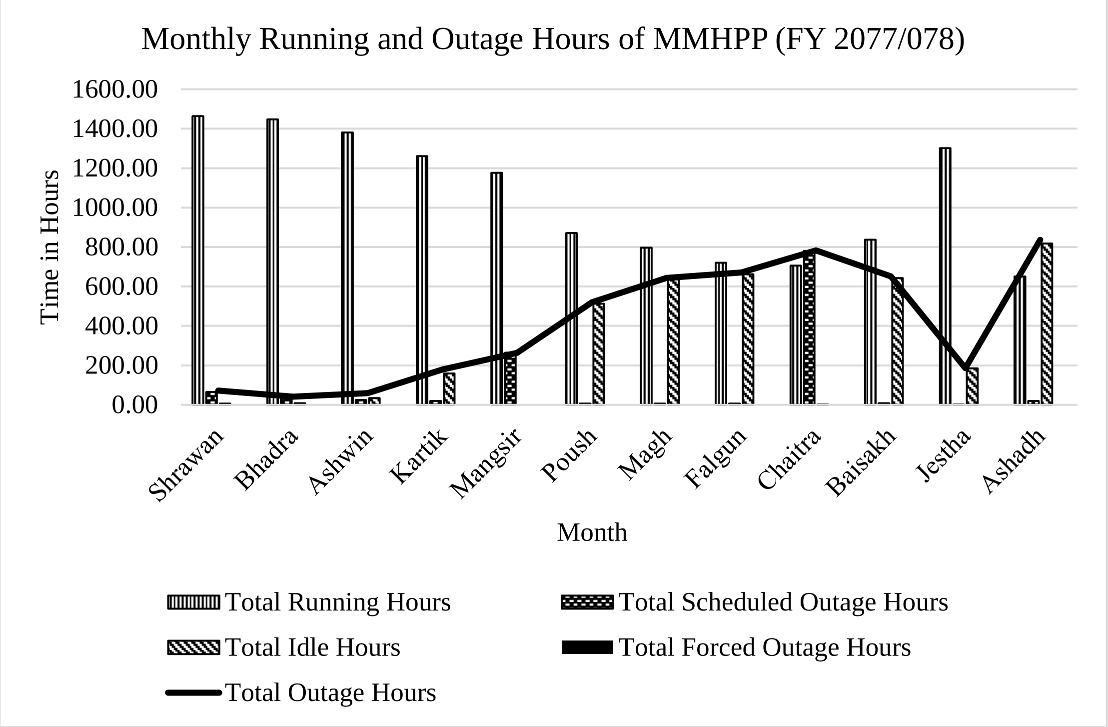

Figure 4. 7: Monthly Running and Outage Hours of MMHPP (F/Y 2077/078)

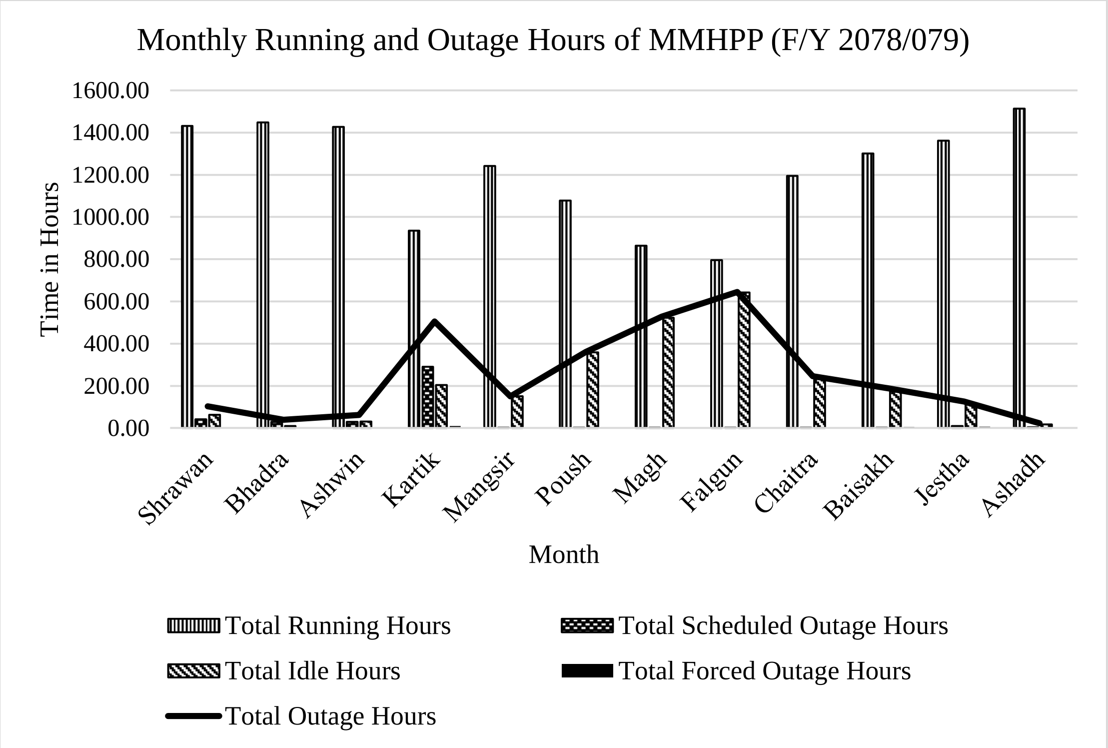

Figure 4. 8: Monthly Running and Outage Hours of MMHPP (F/Y 2078/079)

In FY 2078/079, there was certain increment in total hours resulting to total hours of 14590.94. With the increment in total running hours of 86%, compared to previous FY, forced outage also increased to 30.34 hours which is 20% more than FY 2077/078. From the Figure 4. 8, it can be interpreted that Kartik had total of 289.77 hours of total scheduled outage. Also, maximum idle outage was recorded in Falgun i.e. 642.68 hours.

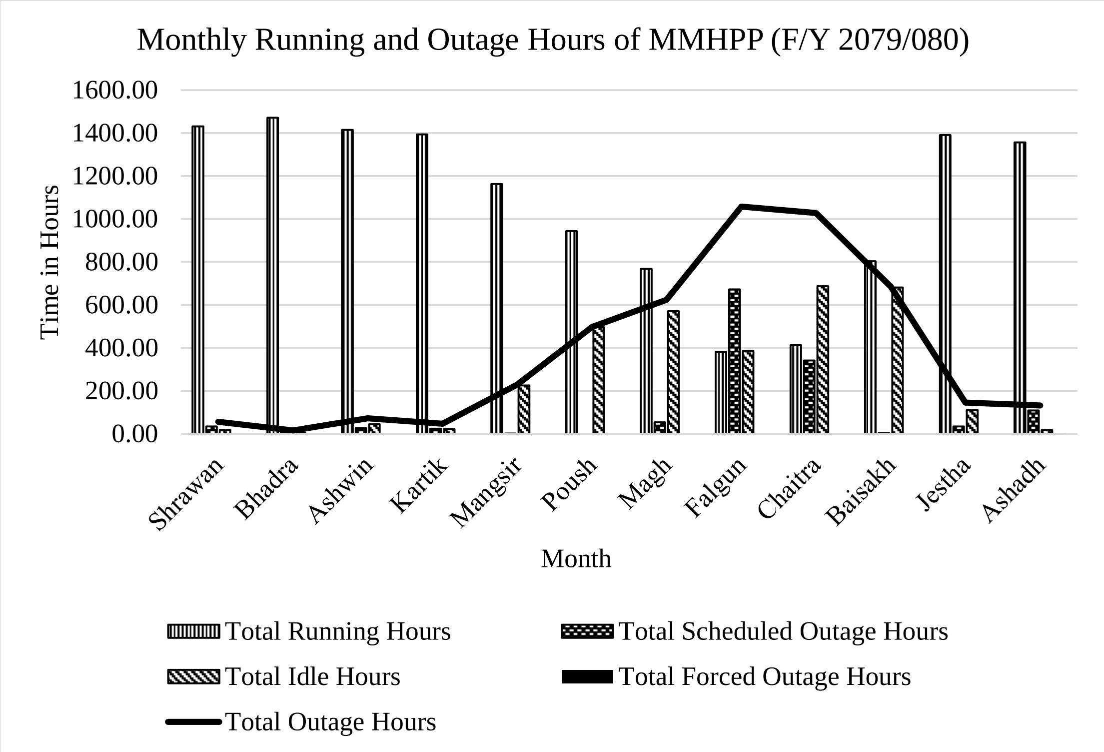

Figure 4. 9: Monthly Running and Outage Hours of MMHPP (F/Y 2079/080)

Figure 4. 9 shows that there was a preventive maintenance in Falgun because the scheduled outage was recorded to 672 hours. Total forced outage, compared to last year, decreased to only 11.80 hours throughout the year. Total outage hour was on peak on Falgun because of both scheduled outage and idle outage. Scheduled outage was high in Falgun and Chaitra which is the result of overhauling.

Figure 4. 10 shows the monthly running and outage hours in FY 2080/081 of MMHPP. Similar to last year, this year also recorded very less amount of forced outage i.e., 8.85 hours throughout the year. This amount of forced outage is unpreventable. This was due to lower guide bearing overheat and some issues in the air cooling pipes. This year total running hour escalated to 14069 hours which was 1136.37 hours more than last fiscal year. Scheduled outage was high in Falgun with 332.43 hours as preventive maintenance of almost all components in powerhouse and gate were repaired and maintained.

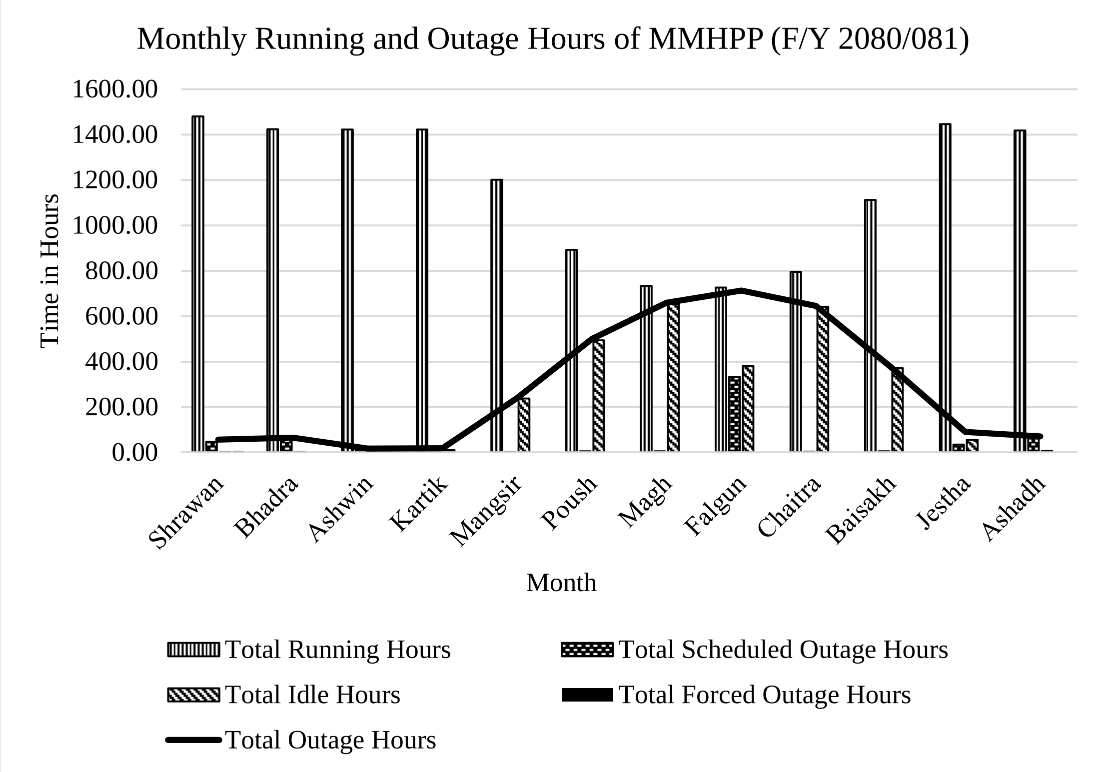

Figure 4. 10: Monthly Running and Outage Hours of MMHPP (F/Y 2080/081)

4.4.3 Marsyangdi Hydropower Plant

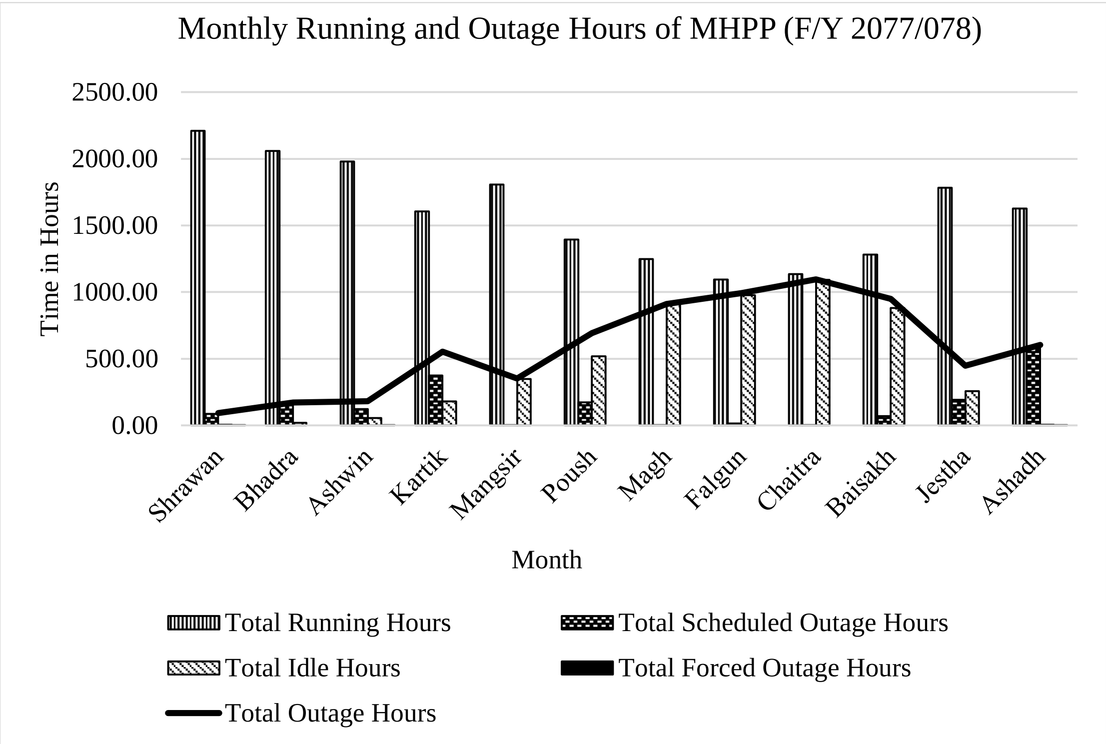

Figure 4. 11: Monthly Running and Outage Hours of MHPP (F/Y 2077/078)

Figure 4. 11 shows that MHPP had the total running hour of 19229.44 hours with most outage hours in Chaitra in FY 2077/078. This outage hour was the contribution of

scheduled outage, idle outage and forced outage. However, forced outage hour was minimum almost equals to zero throughout the year having maximum forced outage in Asadh i.e., 4 hours. The total forced outage hour throughout the year is only 4.77 hour but total idle hour is 5255 hours. Total scheduled outage was higher in Kartik and Ashadh i.e., major preventive maintenance like overhauling were carried in these months. Total idle hour goes on increasing order from Mangsir to Chaitra which means the plant's potential is not fully utilized in these months.

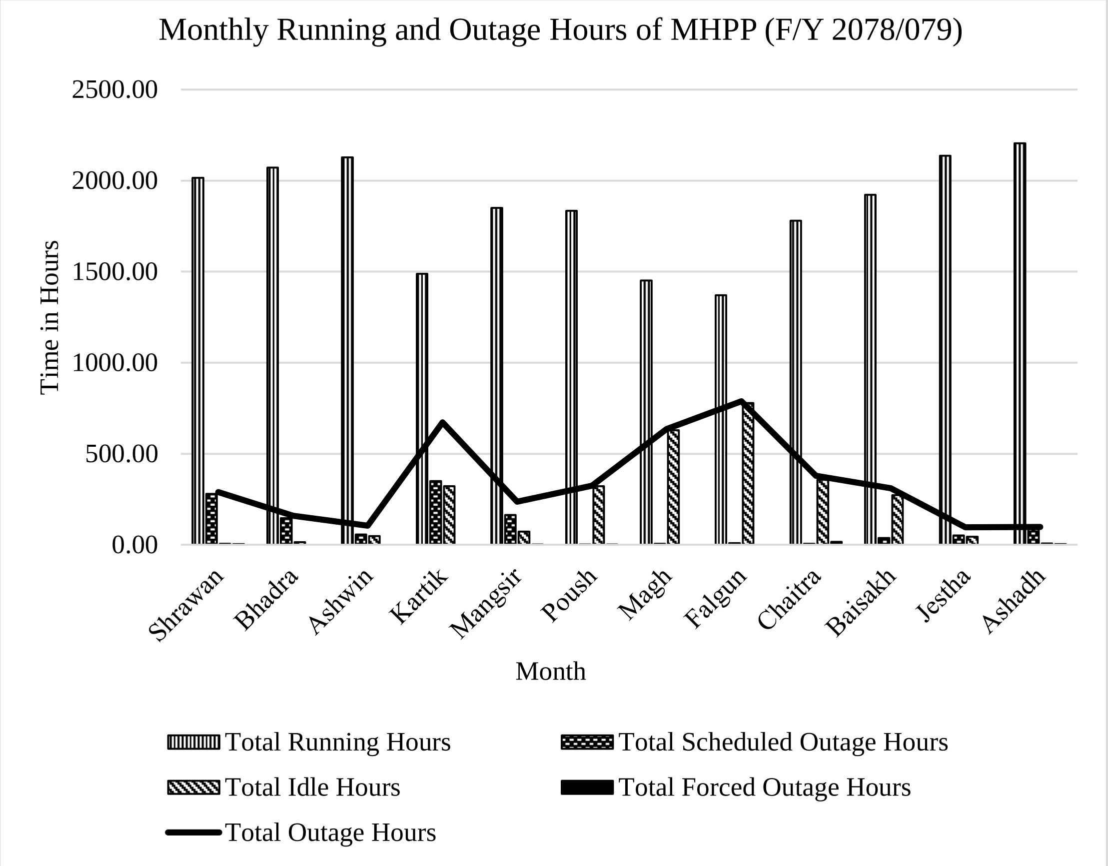

Figure 4. 12: Monthly Running and Outage Hours of MHPP (F/Y 2078/079)

In FY 2078/079, MHPP had the total running hour of 22254.77 hours with maximum total outage hour in Falgun which is 788.57 hour. Compare to last FY this year's forced outage hour increased to 26.98 hours. The idle hours also decreased to almost half than last FY 2077/078 which leads to more generation this year. The scheduled maintenance was done on Kartik which took 350.80 hours to complete.

From Figure 4. 13, in FY 2079/080, MHPP had total running hours of 20946.48 hours which is slightly less than last FY 2078/079. This year forced outage hour remained 13.01 hours. Forced outage hour was higher in the month of Ashadh and Ashwin which were created by heavy rainfall and floods. The total outage hour is maximum in the month of Chaitra with the value of 991 hours because of the maximum idle hour i.e., 965.25 hours. The scheduled outage during this fiscal year amounted to 970.75 hours with overhauling of Unit 3 being carried out in the month of Ashoj and Karthik. Other significant scheduled outages occurred in the monsoon season in the month of Shrawan and Ashadh.

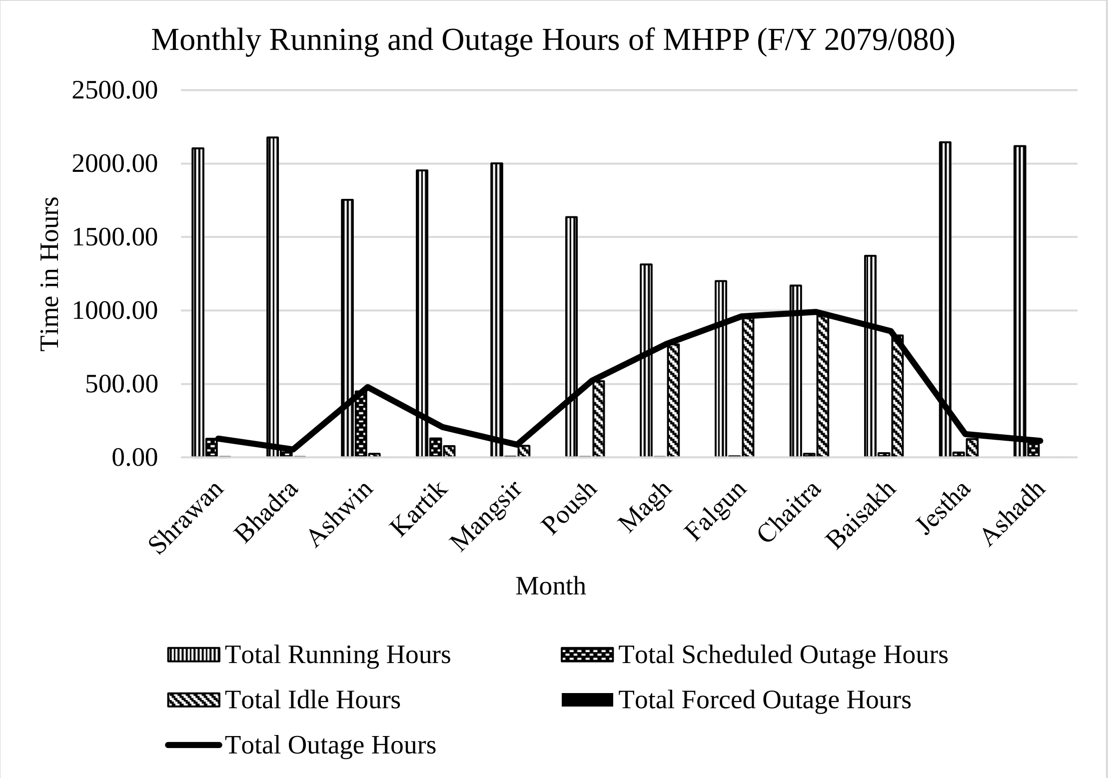

Figure 4. 13: Monthly Running and Outage Hours of MHPP (F/Y 2079/080)

Figure 4.14 shows the monthly running and outage hour of MHPP for the FY 2080/081. The total scheduled outage hour for the year was 628.12 hours which almost two-thirds from the previous fiscal year. Highest scheduled outage was observed in the month of Kartik which is 312.70 hours. Overhauling of unit 1 was completed during this month. The powerhouse remained idle during most of the dry season with total idle hours of 4286.04 hours during the whole year. The total forced outage during the year was 3.66 hours which is significantly less than the previous fiscal year. Overall, the machines at MHPP had a total running of 21290.18 hours and total outage hours of 4917.82 hours.

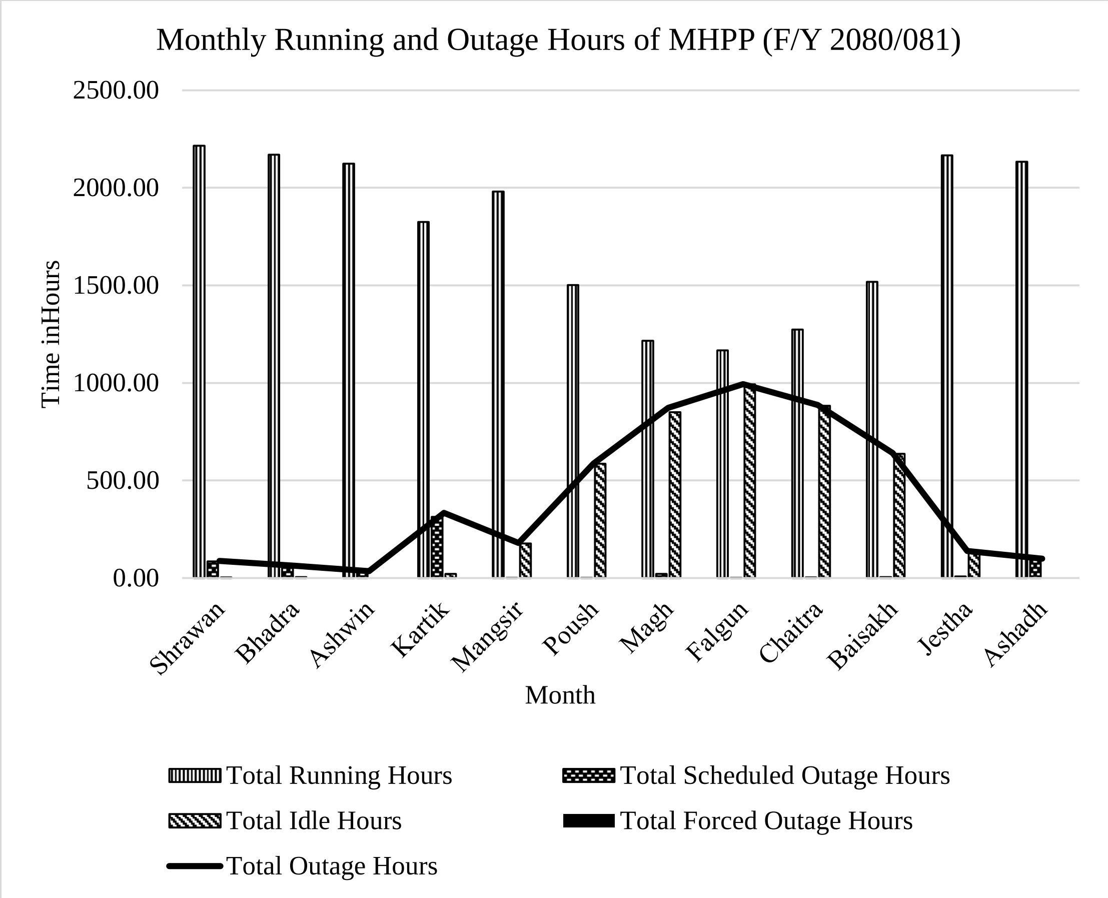

Figure 4. 14: Monthly Running and Outage Hours of MHPP (F/Y 2080/081)

4.5 Plant Factor

The Plant factor of the selected hydropower plants over the last four fiscal years is calculated below.

Table 4. 13: Plant Factor in FY 2077/078

Name of HPP	Installed Capacity (MW)	Annual Actual Generation (MWh)	Plant Factor
Kaligandaki A	144	817712.86	64.82%
Middle Marsyangdi	70	398846.30	65.04%
Marsyangdi	69	398920.10	66.00%

From Table 4. 13, it can be interpreted as, though KGA had generated the most energy, its plant factor is the lowest among the three power plants (64.82 %) which means that it was operated at less than two-thirds of its potential capacity over the year. Among MMHPP and MHPP, MHPP had slightly higher plant factor indicating that MHPP had utilized its capacity slightly more than MMHPP. This table shows that these power plants were not operated at full capacity all the time and MHPP was operated most efficiently in this fiscal year with the plant factor 66%.

Table 4. 14: Plant Factor in FY 2078/079

Name of HPP	Installed Capacity (MW)	Annual Actual Generation (MWh)	Plant Factor
Kaligandaki A	144	974831.97	77.28%
Middle Marsyangdi	70	468270.00	76.36%
Marsyangdi	69	464271.50	76.81%

In the FY 2078/079, KGAHPP had the highest plant factor among the three plants unlike previous year which shows the significant improvement in efficiency. MMHPP and MHPP also increased their efficiency showing better performances. Among MMHPP and MHPP, as these have similar generation capacity, MHPP had slightly higher plant factor than MMHPP which was 76.81%. A plant factor of around 76-77 % is relatively high which suggests that in FY 2078/079, these plants were operated efficiently.

Table 4. 15: Plant Factor in FY 2079/080

Name of HPP	Installed Capacity (MW)	Annual Actual Generation (MWh)	Plant Factor
Kaligandaki A	144	832678.79	66.01%
Middle Marsyangdi	70	428402.10	69.86%
Marsyangdi	69	434558.80	71.89%

Table 4.15 shows that the plant factor of KGAHPP dropped again to 66.01% which indicates that the reduction in plant's efficiency with the higher scheduled outage and idle outage. MMHPP and MHPP both plants reduced their plant's factor compared to last year. MHPP had highest among the three plants i.e., 71.89% which is slightly higher than MMHPP's 69.86%.

Table 4. 16: Plant Factor in FY 2080/081

Name of HPP	Installed Capacity (MW)	Annual Actual Generation (MWh)	Plant Factor
Kaligandaki A	144	841596.00	66.72%
Middle Marsyangdi	70	441127.00	71.94%
Marsyangdi	69	446082.00	73.80%

Table 4.16 shows that the plant factor of KGAHPP remained at 66.72%. The plant factor of MMHPP and MHPP increased by around 2% to reach 71.94% and 73.80% respectively. MHPP had the best plant factor in comparison to other power plants followed by MMHPP and KGAHPP respectively.

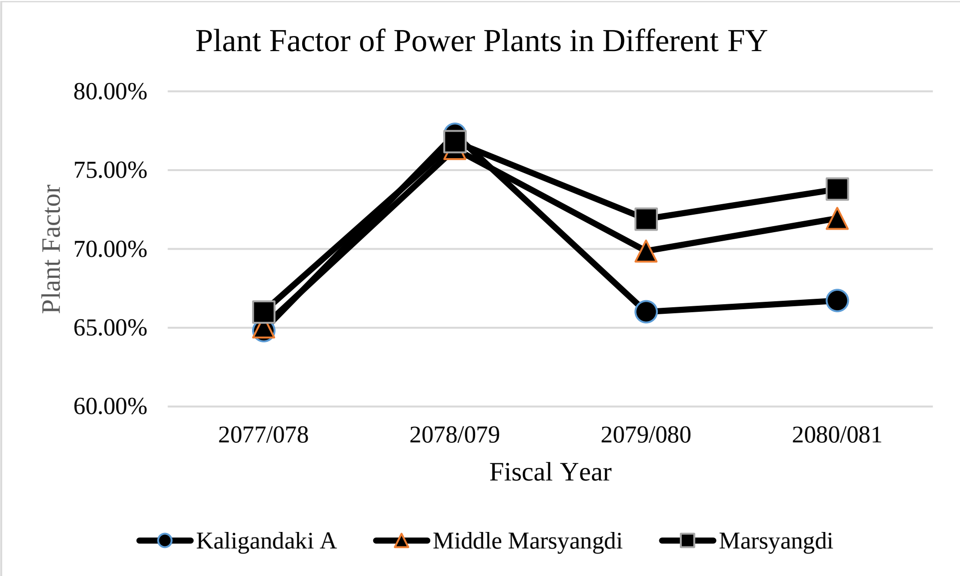

Figure 4. 15: Plant Factor of Power Plants in Different FY

The above Figure 4. 15 shows the quick summary report of plant factor in selected 3 power plants during the research period. It can be seen that the plant factor of three power plants where fairly in the similar range during the first two fiscal years. However, during the latter years, KGAHPP had a significantly less plant factor than the other two power plants. The plant factor of all the power plants is maximum during FY 2078/079. After decreasing by a considerable margin in 2079/080, the plant factor has remained somewhat steady in the following fiscal year 2080/081.

4.6 Capacity Factor

Table 4. 17: Capacity Factor in FY 2077/078

Name of HPP	Installed Capacity (MW)	Annual Design Generation (MWh)	Annual Actual Generation (MWh)	Capacity Factor
Kaligandaki A	144	842572	817712.86	97.05%
Middle Marsyangdi	70	397590	398846.30	100.32%
Marsyangdi	69	467450	398920.10	85.34%

From Table 4.17, it can be seen that KGAHPP had the capacity factor of 97.05% in the FY 2077/078. MMHPP had the highest capacity factor at 100.32% while MHPP had the lowest capacity factor for the year at 85.34%. The capacity factor of above 100% signifies that the MMHPP plant has performed better than expected. This can be attributed to higher water availability and operational efficiencies. The reason for low capacity factor of MHPP can be attributed to operational inefficiencies.

Table 4. 18: Capacity Factor in FY 2078/079

Name of HPP	Installed Capacity (MW)	Annual Design Generation (MWh)	Annual Actual Generation (MWh)	Capacity Factor
Kaligandaki A	144	842572	974831.97	115.70%
Middle Marsyangdi	70	397590	468270.00	117.78%
Marsyangdi	69	467450	464271.50	99.32%

From table 4.18, it is still evident that MMHPP has the highest capacity factor of 117.78% closely followed by KGAHPP at 115.70%. MHPP still has the lowest capacity factor but it has increased significantly to come close to 100%. The fact that the capacity factor of all three power plant is more than or almost equal to 100% signifies that during the period there was higher water availability and operational efficiency.

Table 4. 19: Capacity Factor in FY 2079/080

Name of HPP	Installed Capacity (MW)	Annual Design Generation (MWh)	Annual Actual Generation (MWh)	Capacity Factor
Kaligandaki A	144	842572	832678.79	98.83%
Middle Marsyangdi	70	397590	428402.10	107.75%
Marsyangdi	69	467450	434558.80	92.96%

From Table 4.19, the trend of MMHPP having higher capacity followed by KGAHPP and MHPP continues. The capacity factor of MMHPP, KGAHPP and MHPP are 107.75%, 98.83% and 92.96% respectively. Except MMHPP, other two power plants could not achieve their design generation which can be attributed to decrease in water availability and in operational efficiencies.

From Table 4.20, the trend of MMHPP having higher capacity followed by KGAHPP and MHPP continues. The capacity factor of MMHPP, KGAHPP and MHPP are 110.95%, 99.88% and 95.43% respectively.

Table 4. 20: Capacity Factor in FY 2080/081

Name of HPP	Installed Capacity (MW)	Annual Design Generation (MWh)	Annual Actual Generation (MWh)	Capacity Factor
Kaligandaki A	144	842572	841596.00	99.88%
Middle Marsyangdi	70	397590	441127.00	110.95%
Marsyangdi	69	467450	446082.00	95.43%

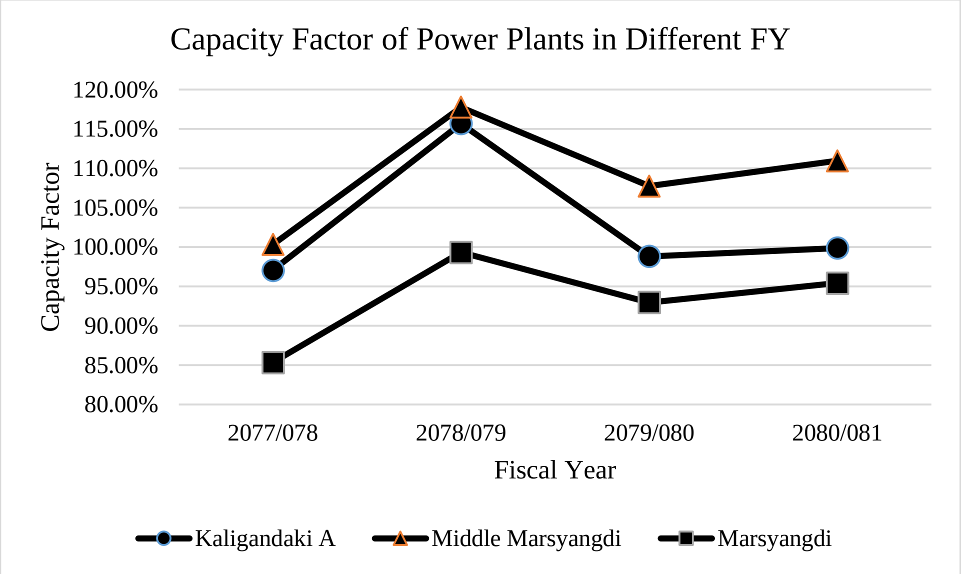

Figure 4. 16: Capacity Factor of Power Plants in Different FY

Figure 4.16 shows the capacity factor of power plants in different fiscal years. It can be seen that MMHPP has capacity factor of more than 100% during all the year. Hence, it can be concluded that MMHPP has good operational efficiency. The capacity factor of all the power plants is lowest during 2077/078 before jumping to the highest one in 2078/079. This signifies higher water availability. The factor for MMHPP and MHPP has decreased in similar ratio while for the KGAHPP, it has decreased more dramatically during the FY 2079/080 which signifies operational inefficiency at the plant. The capacity factor has increased slightly for all the power plants in the fiscal year 2080/081.

4.7 Performance Factor

Performance factor compares the annual actual generation with the targeted generation which is revised every year by NEA. The targeted generation is the updated generation that a plant could achieve based on the recent environmental effects and the present condition of the plants.

Table 4. 21: Performance Factor in FY 2077/078

Name of HPP	Installed Capacity (MW)	Annual Generation Target (MWh)	Annual Actual Generation (MWh)	Performance Factor
Kaligandaki A	144	884508.07	817712.86	92.45%
Middle Marsyangdi	70	456789.01	398846.30	87.32%
Marsyangdi	69	468429.08	398920.10	85.16%

Table 4.21 shows the performance factor of three hydro power plants in FY 2077/078. Performance factor of KGAHPP was the highest among the three plants with the value of 92.45 %. MMHPP and MHPP had the performance factor of 87.32% and 85.16% respectively. Though these two plants had almost equal actual generation, the performance factor differs by more than 2%. The performance efficiency of KGAHPP was found fair enough.

Table 4. 22: Performance Factor in FY 2078/079

Name of HPP	Installed Capacity (MW)	Annual Generation Target (MWh)	Annual Actual Generation (MWh)	Performance Factor
Kaligandaki A	144	896479.27	974831.97	108.74%
Middle Marsyangdi	70	452301.10	468270.00	103.53%
Marsyangdi	69	465220.39	464271.50	99.80%

Table 4.22 shows that the performance factor of KGAHPP and MMHPP was outstanding surpassing the generation target. MHPP also had almost equal to 100 %. The performance factor for KGAHPP, MMHPP and MHPP for the fiscal year 2078/079 was 108.74%, 103.53% and 99.80% respectively. This can be accounted by the high water availability and operational efficiency.

Table 4. 23: Performance Factor in FY 2079/080

Name of HPP	Installed Capacity (MW)	Annual Generation Target (MWh)	Annual Actual Generation (MWh)	Performance Factor
Kaligandaki A	144	879661.86	832678.79	94.66%
Middle Marsyangdi	70	435779.50	428402.10	98.31%
Marsyangdi	69	459695.11	434558.80	94.53%

Table 4.23 shows that the performance factor of MMHPP is the highest at 98.31% while MHPP is lowest at 94.53%. The performance factor of KGAHPP has decreased to 94.66%. Neither of the power plants were able to achieve their respective generation target which can be attributed to low water availability and operational inefficiencies.

Table 4. 24: Performance Factor in FY 2080/081

Name of HPP	Installed Capacity (MW)	Annual Generation Target (MWh)	Annual Actual Generation (MWh)	Performance Factor
Kaligandaki A	144	893071.00	841596.00	94.24%
Middle Marsyangdi	70	453638.00	441127.00	97.24%
Marsyangdi	69	469378.00	446082.00	95.04%

Table 4.24 presents the performance factor of respective power plants in fiscal year 2080/081. The performance factor of KGAHPP, MMHPP and MHPP was found to be 94.24%, 97.24% and 95.04% respectively. Neither of the plants were able to achieve their generation target for the second year running.

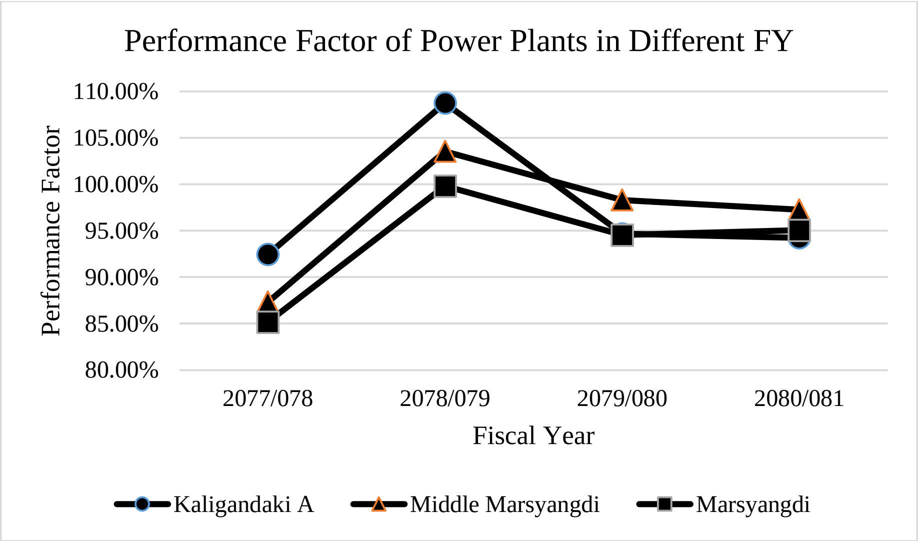

Figure 4. 17: Performance Factor of Power Plants in Different FY

Figure 4.17 shows the comparison of performance factor of different power plants during the study period. The performance factor is also found to be lowest in FY 2077/078 which a huge jump seen during the FY 2078/079 which is the highest. The performance factor decreased during the year 2079/080 and remained steady for the next year for all the powerhouses. The pattern for each of the three powerhouse is similar for performance factor.

4.8 Availability and Reliability

Availability of the hydropower refers to the total hours the powerhouse was in operation from the total available hours and reliability of the hydropower refers to the total hours the powerhouse could be started on the direction of system operator from the available hours. In general, the availability and reliability of hydropower plant should be more than 90% and 99% respectively. [11] The availability and reliability factor of three power plants during the different fiscal year are calculated and explained below.

Table 4. 25: Availability & Reliability Factor in FY 2077/078

Name of Power Plant	Installed Capacity (MW)	Total Machine Hours	Total Running Hours	Total Forced Outage Hours	Total Planned Outage Hours	Availability Factor (%)	Reliability Factor (%)
Kali Gandaki A	144	26280	18889.78	237.48	7152.73	71.88%	99.10%
Middle-Marsyangdi	70	17520	12613.40	6.17	4900.43	71.99%	99.96%
Marsyangdi	69	26280	19229.44	4.77	7043.97	73.17%	99.97%

Table 4. 25 calculates the availability and reliability factor of the three selected HPPs in FY 2077/078. Among the three HPPs, Marsyangdi HPP had fairly good availability factor in the fiscal year 2077/078, as they had the lowest forced outage hours. Kali Gandaki A had more outage hours causing the generation loss which decreased the availability factor to 71.88 %. Reliability is an important indicator to determine the performance quality of the plant. It is calculated using total forced outage hours and total machine hours. From table 4.13, in FY 2077/078, all HPPs had very good reliability factor.

Table 4. 26: Availability & Reliability Factor in FY 2078/079

Name of Power Plant	Installed Capacity (MW)	Total Machine Hours	Total Running Hours	Total Forced Outage Hours	Total Planned Outage Hours	Availability Factor (%)	Reliability Factor (%)
Kali Gandaki A	144	26352	22252.75	322.68	3776.57	84.44%	98.78%
Middle-Marsyangdi	70	17568	14590.94	30.34	2946.72	83.05%	99.83%
Marsyangdi	69	26352	22254.77	26.98	4070.16	84.45%	99.90%

In FY 2078/079, all three plants had increased their availability factor from last year and had almost same percentage. Though the forced outage of KGAHPP inflated than other two HPPs, it managed to be available for 84.44 % of time. Marsyangdi HPP and KGA HPP had same availability factor as running hours throughout the year was almost same. The reliability factor of all three HPPs was fairly high. Higher the reliability better the efficiency.

Table 4. 27: Availability & Reliability Factor in FY 2079/080

Name of Power Plant	Installed Capacity (MW)	Total Machine Hours	Total Running Hours	Total Forced Outage Hours	Total Planned Outage Hours	Availability Factor (%)	Reliability Factor (%)
Kali Gandaki A	144	26208	19990.13	339.19	5878.68	76.27%	98.71%
Middle-Marsyangdi	70	17472	12883.63	11.80	4587.37	73.74%	99.99%
Marsyangdi	69	26280	20946.48	13.01	5317.34	79.71%	99.94%

In FY 2079/080, the availability of all the three plants slightly decreased than the previous year as the total running hours throughout the year decreased. Though the forced outage of MMHPP and MHPP decreased, planned outage was high which lead to 73.74 % and 79.71 % of availability factor respectively. However, these plants were very trustworthy with the reliability factor more than 98%.

Table 4. 28: Availability & Reliability Factor in FY 2080/081

Name of Power Plant	Installed Capacity (MW)	Total Machine Hours	Total Running Hours	Total Forced Outage Hours	Total Planned Outage Hours	Availability Factor (%)	Reliability Factor (%)
Kali Gandaki A	144	26208	19847.66	215.25	6145.09	75.73%	99.18%
Middle-Marsyangdi	70	17520	14069.00	8.85	3442.15	80.30%	99.95%
Marsyangdi	69	26280	21290.18	3.66	4914.16	81.01%	99.71%

Table 4. 28 shows the availability and reliability factor of all three HPPs in FY 2080/081. KGAHPP decreased the forced outage hour from previous year to 215.25 hours being 99.18 % reliable. MHPP had again decreased its forced outage hours to only 8.85 hours which resulted 99.95 % reliability of the plant. Similarly, MHPP was 81.01 % available with only 3.66 hours of forced outage throughout the year.

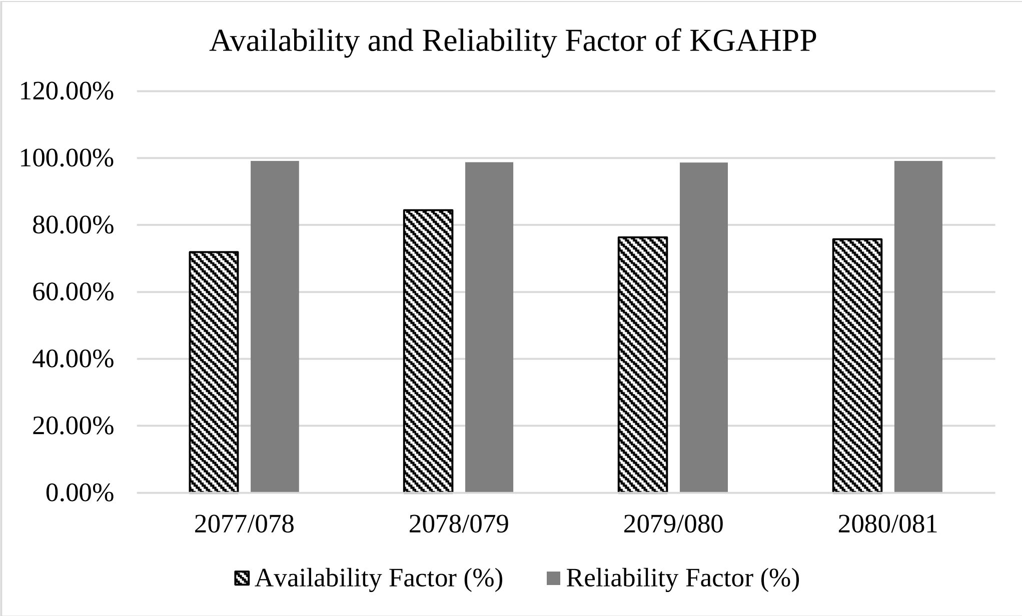

Figure 4. 18: Availability and Reliability Factor of KGAHPP

In KGA HPP, due to high planned outage and forced outage, the availability of the plant remained only 71.88 % in FY 2077/078. However, in FY 2078/079, KGA HPP improved its performance and increased the availability factor to 84.44 %. In FY 2079/080, availability factor of KGAHPP again decreased to 76.27 % with slightly increased in forced outage hour to 339.19 hours and drastic increase in planned outage hours. The reliability factor was similar to last year i.e., 98.71 %. In FY 2080/081, the plant was available for fairly good hours generating consistent energy. KGAHPP had more availability factor in all fiscal year than its design factor which is 66.75 %.

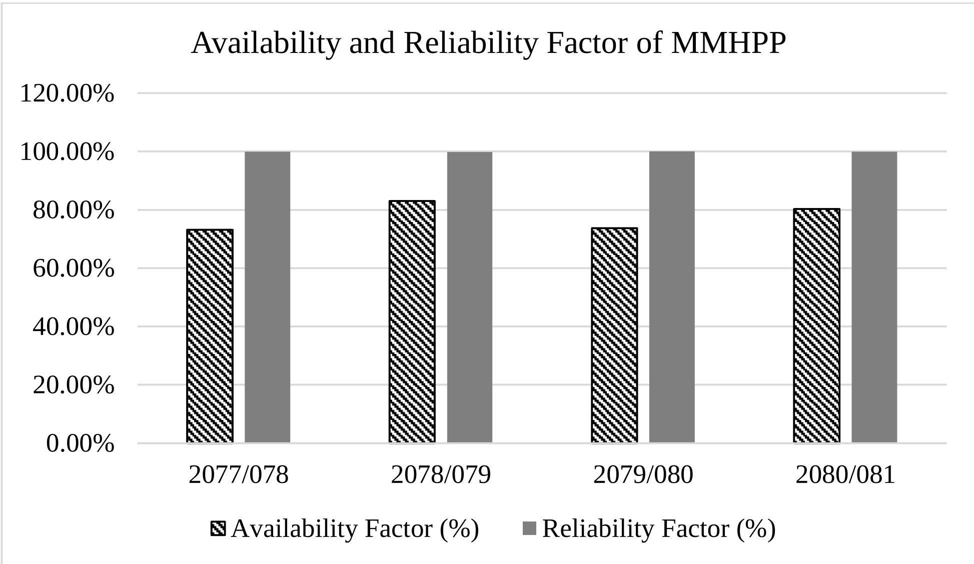

Figure 4. 19: Availability and Reliability Factor of MMHPP

Figure 4. 19 compares the availability and reliability factor of MMHPP in the four fiscal year. MMHPP improved its performance in FY 2078/079 and had highest availability among the four fiscal year. However, the reliability factor remained consistent being trustworthy and dependable source of energy. Middle Marsyangdi HPP had high availability factor in all FY in contrast with design factor of MMHPP which is 64.84%. Like MHPP, MMHPP also had higher availability factor in FY 2078/079.

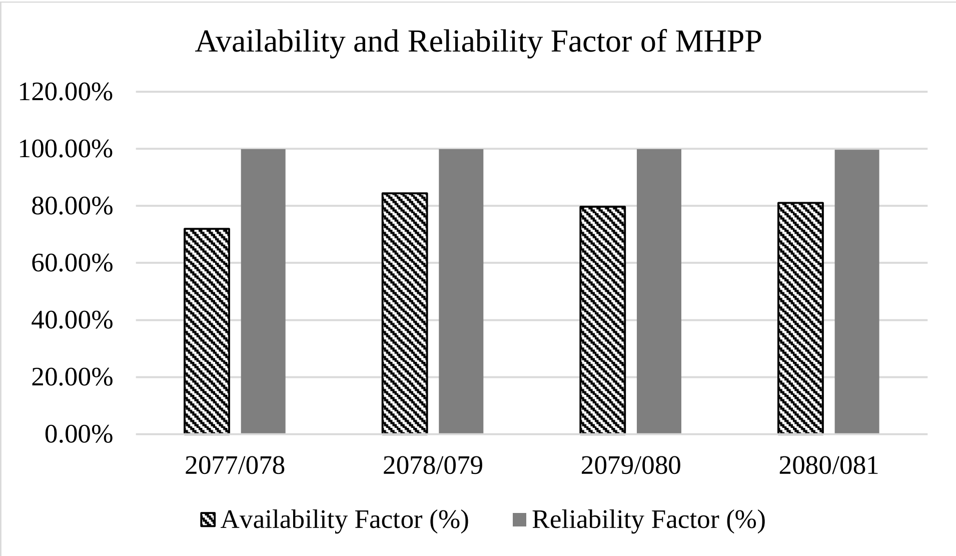

Figure 4. 20: Availability and Reliability Factor in MHPP

There was a significant increase in the availability factor in FY 2078/079 from 2077/078, a jump of 12.46 % in MHPP. But again, due to some maintenance issues in the plant the availability factor decreased to 79.71 % in FY 2079/080. The availability rises again in FY 2080/081 showing a slight recovery in losses. Despite of some outage hours the plant was very consistent throughout all years. Figure 4. 20 shows that the availability of Marsyangdi HPP was highest in FY 2078/079 which was 84.45 % and lowest was in FY 2077/078 i.e., 73.17%. Marsyangdi HPP has design factor of 77.34%. This means that MHPP had better availability factor than design factor.

4.9 Comparison of Performance Indices

Table 4. 29: Average Performance Index of Power Plants

Name of HPP	Plant Factor	Capacity Factor	Performance Factor	Availability	Reliability
Kaligandaki A	68.71%	102.86%	97.52%	77.08%	98.94%
Middle Marsyangdi	70.80%	109.20%	96.60%	77.27%	99.93%
Marsyangdi	72.13%	93.26%	93.63%	79.59%	99.88%

Table 4.29 depicts the performance indices of the selected hydro power plants over the period of FY 2077/078 to FY 2080/081. Plant factor is the measure of energy generated by the respective power plant with respect to its maximum possible energy generation. We can see that MHPP has the highest plant factor of 72.13% followed by MMHPP at 70.80% while KGAHPP has the lowest plant factor of 68.71%.

Capacity factor refers to the energy generated by the respective power plant with respect to its design generation. Here, we can see that MMHPP leads the way with 109.20% and KGAHPP claims the second spot with capacity factor of 102.86%. The performance factor for MHPP is the lowest at 93.26%. Hence, we can conclude that MHPP is expected to generate energy at its highest capacity for a longer period of time.

Performance factor is the measure of energy generated by the respective power plant with respect to the generation target given by NEA. The performance factor is maximum for KGAHPP at 97.52% followed by MMHPP at 96.60% and the lowest performance factor was found for MHPP at 93.63%. However, it can be noted that performance factor lies at a close range for all the power plants.

Availability of a power plant refers to time the power plant was operational out of the total possible duration. It is the measure of time while plant factor is the measure of energy. MHPP has the highest availability of 79.59% while KGAHPP has the lowest availability of 77.08. The availability of MMHPP is 77.27%. It can be concluded that all the three powerhouse have similar availability.

Reliability of a power plant refers to time the power plant was ready to be called into operation or in operation out of the total possible duration. It is the measure of forced outage of a power plant. The lesser the forced outage, the better is the reliability of the power plant. The reliability of all the power plants are in the range of 99% which is exceptional.

4.10 Generation Cost

The generation cost for the power plant over the four-year period was calculated. The value of fixed asset and annual generation was taken from generation magazine published by NEA. The rate of electricity is taken as weighted average of wet season and dry season PPA rates of NEA. The O & M cost is estimated to be 8% of total revenue and 5% depreciation of fixed asset is considered. [12] The royalty is calculated in accordance to Hydropower Development Policy.

For the FY 2077/078, the generation cost per unit of electricity for Kaligandaki A, Middle Marsyangdi and Marsyangdi Power Plant is found to be Rs. 2.74, Rs. 4.26 and Rs. 1.97 respectively. The generation cost per unit of electricity during the FY 2078/079 decreased and reached Rs 2.42, 3.57 and 1.82 respectively. For the FY 2079/080, the generation cost per unit of electricity is calculated to be Rs. 2.56, Rs. 3.68 and Rs. 1.83 for KGAHPP, MMHPP and MHPP respectively. The generation cost per unit of electricity for the FY 2080/81 decreased slightly to Rs. 2.48, Rs. 3.45 and Rs. 1.79 for KGAHPP, MMHPP and MHPP respectively. The detailed calculation of generation cost can be found in appendix IV.

The Figure 4. 21 shows the average cost of generation for respective powerhouse over the four-year period. It can be seen that MHPP has the lowest generation cost while MMHPP has the highest generation cost. The generation cost of KGAHPP is found to be Rs. 2.55 per unit of electricity generated.

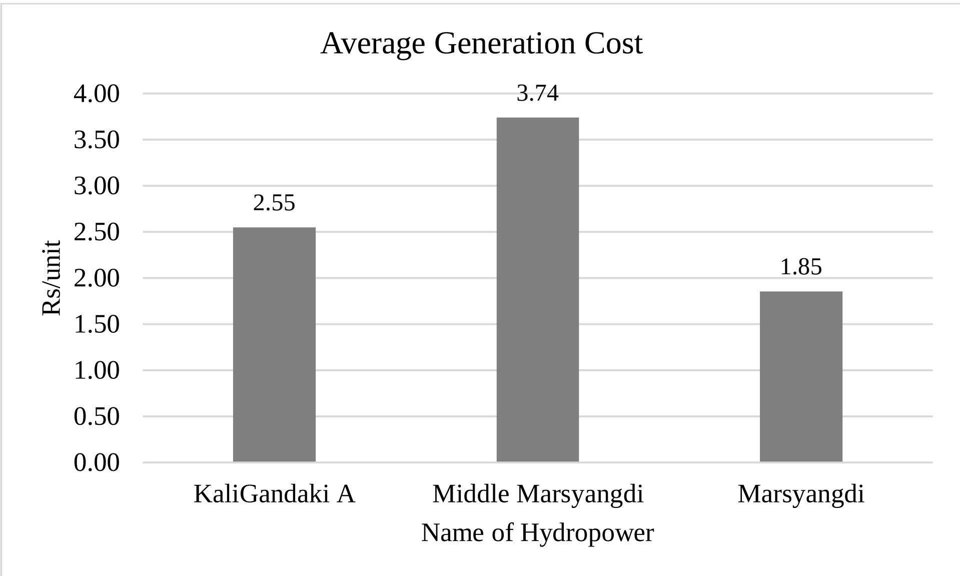

Figure 4. 21: Average Generation Cost

4.11 Annual Generation Loss

Generation loss was calculated with respect to generation target given by NEA. Every year NEA revises the generation target of all the hydropower that it owns on the basis of previous year record, weather forecast and the updated system on the plant. This is the best way to calculate the generation loss as it compares the actual generation with the most precise generation expectancy.

Table 4. 30 shows that in FY 2077/078, KGA HPP generated 8,17,712.86 MWh energy which is 66,795.21 MWh less than the generation target given by NEA. This loss is due to the planned outage, idle outage and forced outage at the plant due too various reasons discussed above. But the loss due to repair and maintenance works accounted for 55,250.40 MWh. Among which forced outage contributed the loss of 11,399.20 MWh. Though the preventive maintenance is mandatory, forced outage can be minimized and the loss in generation can be recovered by 82.72%. MMHPP had lost 143.97 MWh energy due to forced outage among the total generation loss of 57,942.71 MWh. The loss due to these outages had the recovery factor of 75.02 %. Similarly, MHPP had 59.35 % of loss recovery factor in FY 2077/078 with 69,508.98 MWh energy loss due to the outages. The data can be summarized in Figure 4. 22 below.

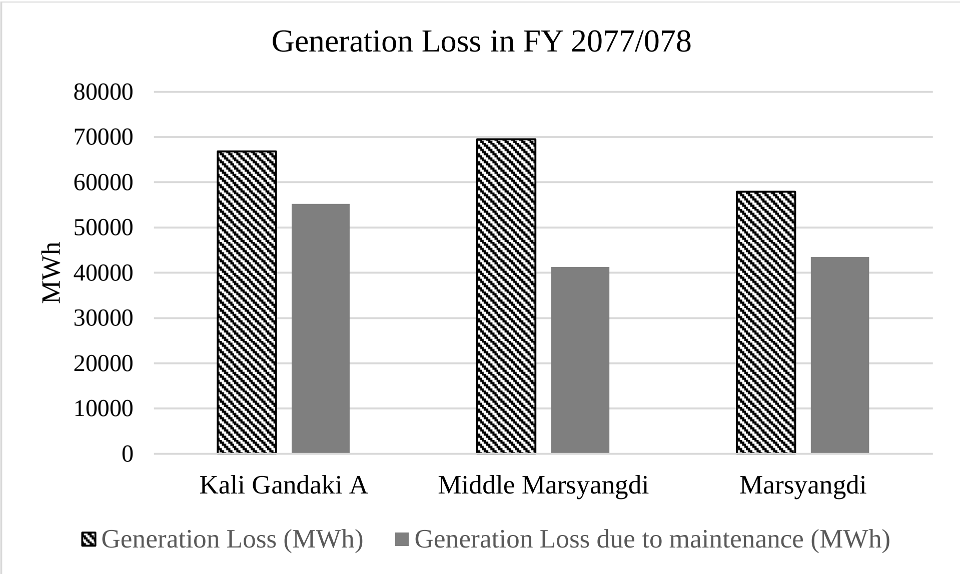

Figure 4. 22: Generation Loss w.r.to Generation Target in FY 2077/078

Table 4. 31 shows the generation loss with respect to generation target in FY 2078/079 of all the three selected HPPs. KGAHPP and MMHPP met the generation target though there was certain forced outage. This means that these powerhouses upgrade their system and improved their performances. Though the generation target was met, there were some outages due to forced outages. If those problems could be prevented, the generation would have increased further. However, MHPP could not met the generation target by 948.89 MWh. This loss was due to unforeseen and unexpected issues in shaft seal. 65.58 % loss from total generation loss could be recovered if these problems were not occurred. The data can be summarized in Figure 4. 23 below.

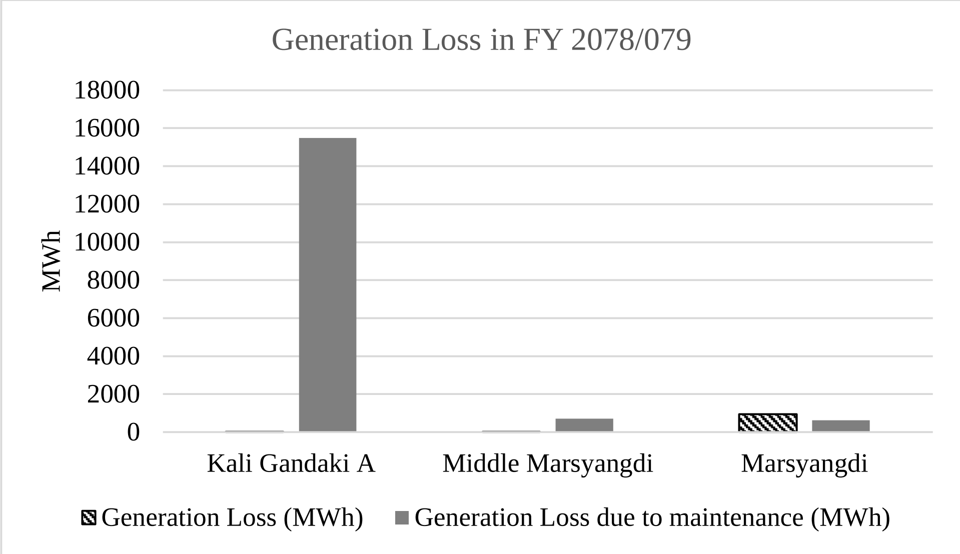

Figure 4. 23: Generation Loss w.r.to Generation Target in FY 2078/079

Table 4. 32 shows the calculation for loss in generation due to outage hours in FY 2079/080. This year KGA HPP could not meet its target due to the loss in generation by 46983.07 MWh energy. This energy loss was due to idle hours, planned outages and forced outages. If the loss due to forced outage could be prevented, then 34.65 % of total loss could be recovered. In this FY MMHPP had very less loss of generation i.e., 7377.40 MWh energy. The loss due to forced outage was only 275.33 MWh throughout the year. 96.27 % loss couldn't be recovered as this was due to idle hours. Moreover, MHPP lost 25,136.31 MWh energy. Out of this loss, 90.02 % could be recovered if the plant was well maintained and prevented the outage hours. The data can be summarized in Figure 4. 24 below.

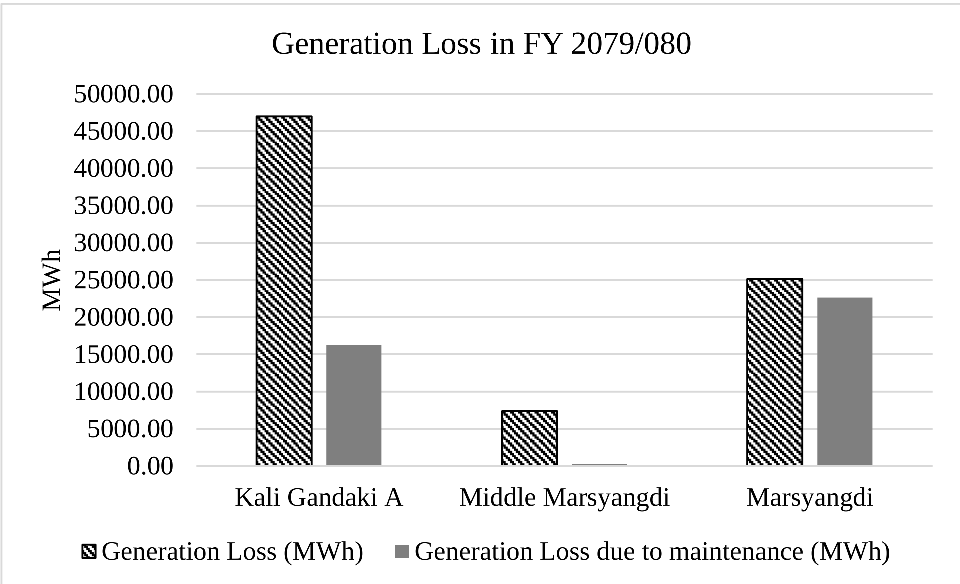

Figure 4. 24: Generation Loss w.r.to. Generation Target in FY 2079/080

Table 4. 30: Generation Loss due to Maintenance in FY 2077/078

Name of HPP	Installed Capacity (MW)	Max Annual Capacity (MWh)	Annual Generation Target by NEA	Annual Actual generation (MWh)	Total Outage Hours	Total Outage in Days	Per Day Generation (MWh)	Generation Loss (MWh)	Generation Loss due to outage hour (MWh)	Loss Recovery Factor (%)	Loss unable to recover due to maintenance (%)
Kali Gandaki A	144	1261440	884508.07	817712.86	1151.05	47.96	3456.00	66795.21	55250.40	82.72%	17.28%
Middle Marsyangdi	70	613200	456789.01	398846.30	1242.04	51.75	1680.00	57942.71	43471.40	75.02%	24.98%
Marsyangdi	69	604440	468429.08	398920.10	1793.74	74.74	1656.00	69508.98	41256.02	59.35%	40.65%

Table 4. 31: Generation Loss due to Maintenance in FY 2078/079

Name of HPP	Installed Capacity (MW)	Max Annual Capacity (MWh)	Annual Generation Target by NEA	Annual Actual generation (MWh)	Total Outage Hours	Total Outage in Days	Per Day Generation (MWh)	Generation Loss (MWh)	Generation Loss due to outage hour (MWh)	Loss Recovery Factor (%)	Loss unable to recover due to maintenance (%)
Kali Gandaki A	144	1261440	896479.27	974831.97	424.02	17.67	3456.00	0.00	15488.80	100.00 %	0.00%
Middle Marsyangdi	70	614880	452301.10	468270.00	441.24	18.39	1684.60	0.00	709.87	100.00 %	0.00%
Marsyangdi	69	606096	465220.39	464271.50	1224.45	51.02	1660.54	948.89	622.24	65.58 %	34.42 %

Table 4. 32: Generation Loss due to Maintenance in FY 2079/080

Name of HPP	Installed Capacity (MW)	Max Annual Capacity (MWh)	Annual Generation Target by NEA (MWh)	Annual Actual generation (MWh)	Total Outage Hours	Total Outage in Days	Per Day Generation (MWh)	Generation Loss (MWh)	Generation Loss due to outage hour (MWh)	Loss Recovery Factor (%)	Loss unable to recover due to maintenance (%)
Kali Gandaki A	144	1261440	879661.86	832678.79	2055.11	85.63	3456.00	46983.07	16281.28	34.65 %	65.35 %
Middle Marsyangdi	70	613200	435,779.50	428402.10	1320.91	55.04	1680.00	7377.40	275.33	3.73 %	96.27 %
Marsyangdi	69	604440	459,695.11	434558.80	983.76	40.99	1656.00	25136.31	22626.48	90.02 %	9.98 %

Table 4. 33: Generation Loss due to Maintenance in FY 2080/081

Name of HPP	Installed Capacity (MW)	Max Annual Capacity (MWh)	Annual Generation Target by NEA	Annual Actual generation (MWh)	Total Outage Hours	Total Outage in Days	Per Day Generation (MWh)	Generation Loss (MWh)	Generation Loss due to outage hour (MWh)	Loss Recovery Factor (%)	Loss unable to recover due to maintenance (%)
Kali Gandaki A	144	1261440	893071.00	841596	908.12	37.84	3456.00	51475.00	43589.76	84.68 %	15.32%
Middle Marsyangdi	70	613200	453,638.00	441127.00	592.00	24.67	1680.00	12511.00	1537.81	12.29 %	87.71%
Marsyangdi	69	604440	469,378.00	446082.00	631.78	26.32	1656.00	23296.00	14530.94	62.38 %	37.62 %

Table 4. 33 shows the generation loss due to outage hours in FY 2080/081. KGAHPP could not meet the target by 51,475 MWh energy. The generation loss due to planned outage and force outage was 43,589.76 MWh energy. This loss has a recovery factor of 84.68 %. Because of the idle hours, 15.32 % energy could not be recovered. Similarly, MMHPP could not meet the target by 12,511 MWh energy. 12.29 % of this loss could be recovered if the plant hadn't encountered any forced outages. Moreover, MHPP couldn't meet the target by 23,296 MWh energy. This loss consisted loss of 14,530.94 MWh energy due to repair and maintenance works. The data can be summarized in Figure 4. 25 below.

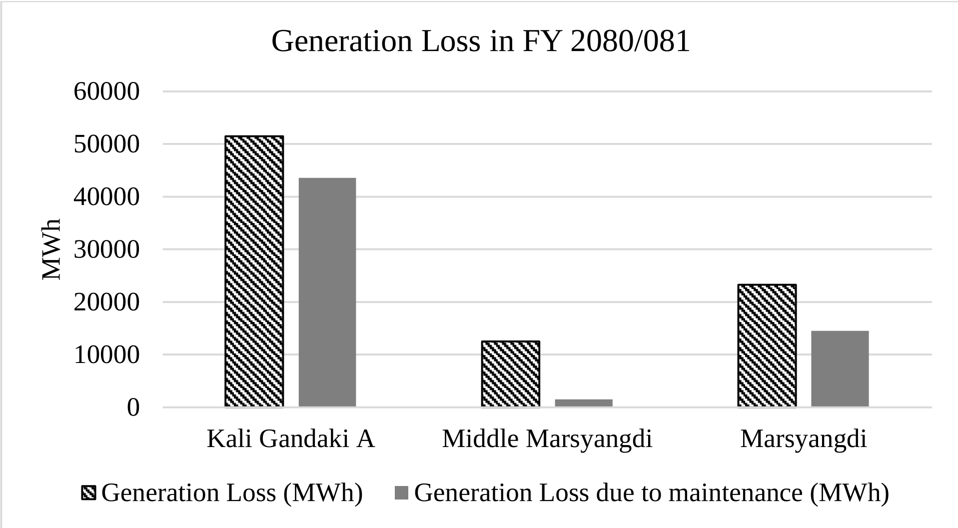

Figure 4. 25: Generation Loss w.r.to Generation Target in FY 2080/081

4.12 Revenue Loss

The loss in generation directly effects the generation of revenue of the plant. The revenue loss is calculated by multiplying the loss in generation with the prevailing electricity prices. Here, the price of per unit electricity was taken as the average of wet season PPA rate and dry season PPA rate of Nepal Electricity Authority. The price per unit electricity is calculated to be NRs. 6.6 per unit.

The Table 4. 34 shows the revenue loss in FY 2077/078 in the three selected HPPS due to planned outage and forced outage. The loss in generation due to planned outage created the loss of 60.88 Crore whereas loss due to forced outage hours created the loss of 15.83 hours in KGAHPP. Similarly, in MHPP there was a loss of 63.14 Crores due to planned outage hours and a loss of 17 Lakhs due to forced outage hours. Moreover, in MMHPP there was a loss of 42.53 Crore in revenue due to planned outage and a loss of 21 lakhs due to forced outages. In total, the loss of generation in this FY in these three HPPs due to outage hours counts for the loss of 182.76 Crores.

Table 4. 35 calculates the revenue loss due to planned outage and forced outage hours in FY 2078/079. This year KGA HPP improved its performance and drastically reduced the loss in revenue to 6.84 Crore from 60.88 Crores. Despite that there was significant loss in revenue due to forced outage i.e., 21.79 Crores. Similarly, in MHPP there was a loss of 41.97 Crore due to planned outage and a loss of 95 Lakhs due to forced outages which was quite higher than the last year. Moreover, MMHPP yielded the loss of 14 Crores due to planned outage and lost 1.03 Crore due to forced outages. This year due to the generation loss in these HPPs yielded the loss of 86.59 Crores.

Table 4. 36 shows the calculation of loss of revenue due to planned outage and forced outage in these HPPs. This year KGAHPP drastically increased the planned outage hours as there was overhauling of two units which generated loss of 113.72 Crores along with the loss of revenue due to forced outage of 22.48 Crores. Similarly, MHPP yielded the loss of 33.62 Crores due to planned outage and a loss of 45 Lakhs due to only 13 hours of outage throughout the year. Moreover, in MMHPP there was a loss of 42.98 Crores due to planned outage and a loss of 39 Lakhs due to forced outage hours. Thus, this year due to outages in these HPPs, 213.65 Crores was lost.

Table 4. 37 shows that in FY 2080/081, there was a revenue loss of 103.68 Crores due to outages in these HPPs. KGAHPP reduced the loss to 46.62 Crores which is 67.10 Crores less than the previous year. Also, MHPP and MMHPP reduced the generation loss which resulted the loss of only 13 Lakhs in MHPP and only 30 Lakhs in MMHPP. This year these power plants significantly improved their performances and reduced the total loss to 103.68 hours.

Table 4. 34: Revenue Loss due to Maintenance in FY 2077/078

S.No.	Name of HPP	Annual Generation Target (MWh)	Planned Outage Hour (Hrs)	Forced Outage Hour (Hrs)	Per Day Generation (MWh)	Rate of Electricity (Rs.)	Revenue Loss Due to Planned Outage Hour (Rs. In Crores)	Revenue Loss Due to Forced Outage Hour (Rs. In Crores)
1	Kali Gandaki A	884508.07	913.57	237.48	2423.31	6.6	60.88	15.83
2	Middle Marsyangdi	456789.01	1235.87	6.17	1251.48	6.6	42.53	0.21
3	Marsyangdi	468429.08	1,788.97	4.77	1283.37	6.6	63.14	0.17
						Total	**166.55**	**16.21**

Table 4. 35: Revenue Loss due to Maintenance in FY 2078/079

S.No.	Name of HPP	Annual Generation Target (MWh)	Planned Outage Hour (Hrs)	Forced Outage Hour (Hrs)	Per Day Generation (MWh)	Rate of Electricity (Rs.)	Revenue Loss Due to Planned Outage Hour (Rs. In Crores)	Revenue Loss Due to Forced Outage Hour (Rs. In Crores)
1	Kali Gandaki A	896479.27	101.33	322.68	2456.11	6.6	6.84	21.79
2	Middle Marsyangdi	452301.10	410.90	30.34	1239.18	6.6	14.00	1.03
3	Marsyangdi	465220.39	1,197.47	26.98	1274.58	6.6	41.97	0.95
						Total	**62.82**	**23.77**

Table 4. 36: Revenue Loss due to Maintenance in FY 2079/080

S.No.	Name of HPP	Annual Generation Target (MWh)	Planned Outage Hour (Hrs)	Forced Outage Hour (Hrs)	Per Day Generation (MWh)	Rate of Electricity (Rs.)	Revenue Loss Due to Planned Outage Hour (Rs. In Crores)	Revenue Loss Due to Forced Outage Hour (Rs. In Crores)
1	Kali Gandaki A	879661.86	1715.92	339.19	2410.03	6.6	113.72	22.48
2	Middle Marsyangdi	435779.50	1309.11	11.80	1193.92	6.6	42.98	0.39
3	Marsyangdi	459695.11	970.75	13.01	1259.44	6.6	33.62	0.45
						Total	**190.33**	**23.32**

Table 4. 37: Revenue Loss due to Maintenance in FY 2080/081

S.No.	Name of HPP	Annual Generation Target (MWh)	Planned Outage Hour (Hrs)	Forced Outage Hour (Hrs)	Per Day Generation (MWh)	Rate of Electricity (Rs.)	Revenue Loss Due to Planned Outage Hour (Rs. In Crores)	Revenue Loss Due to Forced Outage Hour (Rs. In Crores)
1	Kali Gandaki A	893071.00	692.87	215.25	2446.77	6.6	46.62	14.48
2	Middle Marsyangdi	453638.00	583.15	8.85	1242.84	6.6	19.93	0.30
3	Marsyangdi	469378.00	628.12	3.66	1285.97	6.6	22.21	0.13
						Total	**88.76**	**14.92**
						Grand Total	**508.46**	**78.22**

Table 4. 38: Revenue Loss due to Planned Outage

FY	KGAHPP	MMHPP	MHPP
2077/078	60.88	42.53	63.14
2078/079	6.84	14.00	41.97
2079/080	113.72	42.98	33.62
2080/081	46.62	19.93	22.21
Total	**228.07**	**119.45**	**160.94**

Table 4. 39: Revenue Loss due to Forced Outage

FY	KGAHPP	MMHPP	MHPP
2077/078	15.83	0.21	0.17
2078/079	21.79	1.03	0.95
2079/080	22.48	0.39	0.45
2080/081	14.48	0.30	0.13
Total	**74.59**	**1.94**	**1.69**

Table 4. 38 and Table 4. 39 summarizes the revenue loss of three power plants in last four years. KGAHPP had more loss in revenue due to both planned outage and forced outage. Similarly, MMHPP had less loss in revenue due to planned outage and MHPP had less loss due to forced outage hours.

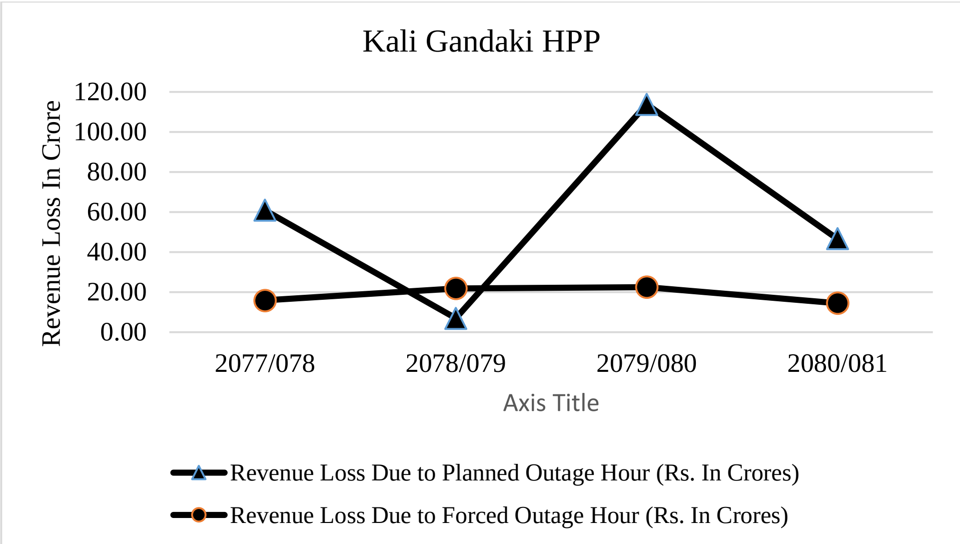

Figure 4. 26: Loss of Revenue in KGAHPP in Different FY

Figure 4. 26 shows the pattern of revenue loss due to planned outage and forced outage in KGAHPP in four years. In FY 2079/080, the revenue loss was maximum as two units were overhauled. As the revenue loss due to planned outage decreased, the revenue loss due to forced outage increased. However, there was not so much difference in revenue loss due to forced outage.

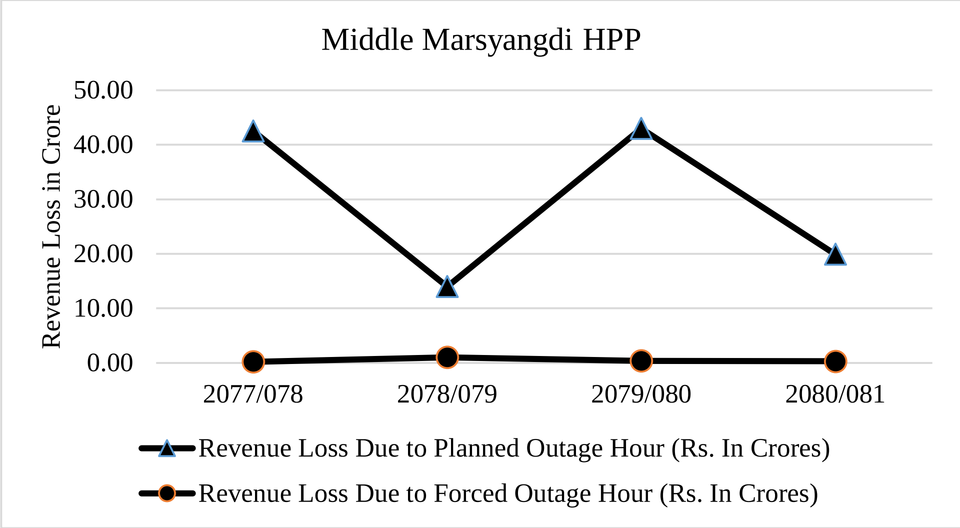

Figure 4. 27: Loss of Revenue in MMHPP in Different FY

Figure 4. 27 shows the revenue loss due to planned outage and forced outage in MMHPP. The pattern was similar to KGAHPP but the value was significantly less because of less outage hours. Similarly,

Figure 4. 28 shows the pattern of loss of revenue in MHPP over the years. The loss due to planned outages went on decreasing as it was done in an effective and well-planned manner. The loss due to forced outage was less than a crore in every year.

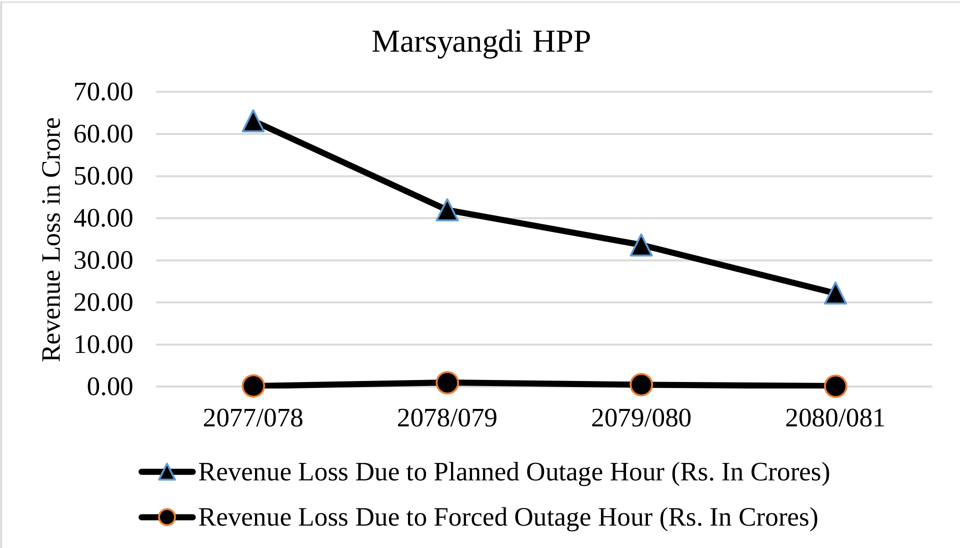

Figure 4. 28: Loss of Revenue in MHPP in Different FY

From all the above calculations, it is found that, the most frequently occurred problem on mechanical components was leakage and blockage in cooling system. Another was silt accumulation in desander which caused the outage of plant. These problems mainly occurred in rainy season due to high flood carrying large amount of silt and sediments. Though the forced outage hours were not so much high, the generation loss and revenue loss caused by these outages were significantly high because of high generating capacity of these power plants.

In these four years, there was a total loss of 508.46 Crores from planned outage and a loss of 78.22 Crores from forced outages. KGAHPP had maximum loss in revenue among these three power plants. The planned outage cannot be eliminated, but can be minimized. The forced outages could be prevented. If only, these power plants can further reduce these forced outage hours than 78.22 Crores could be saved. This much amount plays a significant role in constructing a new power plant generating up to 4 MW (taking the average cost of constructing a hydropower as NRs. 18 Crores per MW of electricity [11]).

Moreover, if we do not consider building a new power plant, we can use a portion of the revenue to encourage the staff to hire a new team of highly qualified, well-trained individuals who will be in charge of reducing the amount of time spent on maintenance, shutting down, and improving the installed power plants by extending the operating hours of their machinery. However, it is entirely dependent upon the necessity of organization.

Furthermore, on comparing the results of the research with that of ROR (medium-hydro) power plants, we can observe that the outage hour in ROR plants is significantly higher than in these PROR plants. However, the generation loss and revenue loss for these PROR plants are found to be more than ROR plants even for such less outage hours. Hence, it can be concluded that these plants should be more critically maintained to reduce the outage hours and it has significant impact of revenue for NEA.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Mechanical components in hydropower faced frequent problems due to various reasons, the main reason being the presence of silt in water. The silt includes rocks, minerals and even quartz which causes abrasive erosion in hydropower components. Frequent problems that occurred in hydropower are erosion and cavitation in runner blades, spiral casing, turbine housing, draft tube, leakage in guide vanes, leakage in balancing pipes, leakage and blockage in water cooling system, leakage in air coolers, pressure variation due to flow variation, accumulation of debris and sediments in desander and trash rack during monsoon. The most frequent outage was due to desander flushing which was done at least 109 times in four years and the other one was problem in water cooling system i.e., 43 times in four years.

According to the collected data, all these HPPs faced the frequent problem in water and air-cooling system and in shaft seal along with the silt accumulation in desander basin. These problems caused forced outages in the plants resulting in unexpected loss in generation. All these three power plants held an overhauling of one unit each year because of which the frequency of occurrence of problems were minimized. In FY 2077/078, KGAHPP had the forced outage and planned outage of 237.48 hours and 913.57 hours respectively. In FY 2078/079, the forced outage further increased to 322.68 hours whereas planned outage decreased to 101.33 hours. However, in FY 2079/080, planned outage significantly increased to 1715.92 hours as there was an overhauling of two units. Also, the forced outage increased to 339.19 hours. Moreover, in FY 2080/081, there was a significant amount of planned outage and a forced outage of 692.87 hours and 215.25 hours respectively. Compared to KGAHPP, MMHPP and MHPP had less forced outages. MMHPP had 6.17 hours of forced outage n FY 2077/078, slight increased to 30.34 hours in FY 2078/079 and again with some improvement decreased to 11.80 hours in FY 2079/080. In FY 2080/081, MMHPP further improved its performance and decreased the force outage to only 8.85 hours throughout the year. Similarly, MHPP also had only 4.77 hours of outage in FY 2077/078. The forced outage increased in FY 2078/079 to 26.98 hours. However, in FY 2079/080, MHPP planned the maintenance so well that the forced outage decreased to 13.01 hours and further decreased to only 3.66 hours of forced outage throughout the year.

The plant factor, capacity factor and performance factor of the hydropower was calculated with the help of collected data. It shows that the plant factor of the power plants ranges from 65% to 80% for all the power plants. The plant with the best plant factor is MHPP at 72.13% followed by MMHPP at 70.80% and Kali Gandaki at 68.71%. The capacity factor of the plant is found to be above 90% for all plants during all the research years. MMHPP had the highest capacity factor at 109.20% followed by KGAHPP at 102.86% and MHPP at 93.26%. Low-capacity factor of MHPP can be attributed to operational inefficiency. The performance factor of the selected hydropower showed that the power plants struggled to achieve their generation target in all but one year. Here, we can see a lot of scope for improvement. Although the percentage data is small, the total revenue loss due to it is more significant.

The availability and reliability analysis from the collected data shows that the availability factor of all three power plants ranges from 70 % to 85 %. KGAHPP had maximum availability factor in FY 2078/079 i.e., 84.44%. having high availability factor suggests that the repair and maintenance work were done properly. It had the lowest availability factor in FY 2077/078. Similarly, MMHPP was most available in FY 2078/079 with the availability factor 83.05 %. In FY 2079/080, there were some issues in water cooling system which reduces the availability to 73.74% but in FY 2080/081, there was an improvement in maintenance works which increased the availability of plant by 6.56 % reaching 80.30 %. Moreover, MHPP had lowest availability factor in FY 2077/078 i.e., 73.17% and highest in FY 2078/079 i.e., 84.45 %.

The cost of generation of per unit electricity was calculated for the respective power plants. The cost per unit electricity was found to be in the range of Rs. 1.5 to Rs. 4 per unit electricity. MHPP had the lowest cost per unit at just Rs. 1.85 per unit while MMHPS had the highest cost per unit at Rs. 3.74 per unit. The generation cost of KGAHPP was found to be Rs. 2.55 per unit.

The loss in generation due to the outage hours caused by maintenance was analyzed and found that MMHPP had great generation with minimum loss in generation. The total loss in generation by maintenance in these three hydro power plants in these four years was 2,55,640.33 MWh which caused the revenue loss of 586.68 Crores. This loss is due to both planned outages and forced outages. Planned outages cannot be eliminated totally but with proper planned maintenance forced outages can be prevented. The total loss in generation due to forced outage hours of only 1220.19 in four years was 38,368.197 MWh resulting in loss of 78.22 Crores. This loss is equivalent to the cost for constructing a new hydro power plant generating 4 MW. However, the socio-economic and environmental challenges in construction of new hydropower means that it is more viable to repair and maintain the current hydro power plants. This amount can also be utilized in motivating the staffs in power plants which can further enhance the quality of maintenance and repair works.

Hence, though these power plants have little forced outages, the loss in generation and the loss in revenue is significant which suggests that these plants should be taken utmost care and repair and maintenance should be done more effectively to enhance the operational efficiencies.

5.2 Recommendation

- Most of the problem were occurred in the cooling system during the monsoon season, hence a more effective cooling system can be designed to prevent frequent outages in all the plant. The water for cooling is taken directly from penstock. This water can be treated before it enters the cooling pipes to prevent the leakage from heat exchangers.
- To minimize the forced outages and sudden trip of plant, continuous monitoring of each and every component along with recording the data and analyzing the recorded data must be done properly. The leakage, sound and vibration are the major signals of defects. For this, different monitoring devices such as, vibration sensor, should be installed. The record of maintenance should be taken properly and regularly without missing any minor maintenance and clearly mentioning whether the parts are repaired or replaced. This helps in planning further maintenance programs.
- To minimize the outages through desander flushing, frequent excavation and syphon suction methods can be used instead of conventional flushing methods. Additionally, upstream sediment trapping and erosion control can also be effective to reduce sedimentation which will reduce desander flushing outages.
- A study can be conducted to apply the various techniques along with financial evaluation of each method to solve the frequently observed problem. This will enable us to make the power plants more reliable and operate more efficiently.

- Although the outage hour during the study period was not significant, the ageing of power plant may bring more challenges. Hence, it is of utmost importance to properly maintain these power plants.

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APPENDIX I: Questionnaire

Questionnaire for field visit:

A. Salient Features

1	Name of hydro power plant	:
2	Address	:
3	Type of plant	:
4	Intake river name	:
5	Design head	:
6	Design flow	:
7	Dam gate type	:
8	Penstock	:
9	Installed capacity	:
10	Overall efficiency of the plant	:
11	Plant operating hour/day	:
12	Year of commissioning	:
	Turbine	
13	Manufacturer	:
14	Type	:
15	Rated output	:
16	Rated speed	:
17	Rated discharge	
	Generator	:
18	Manufacturer	:
19	Rated output/voltage	:
20	Rated frequency	:
21	Power factor	:
22	Power transformer	:
23	Transmission Route	:

B. Power Production Issues

1	Plant Condition	:
2	Plant Operator	:
3	Operation Condition	:
4	Maintenance Type	:
5	Frequent Problem on	:
6	Silt Problem	:

C. Questionnaire for Problems in Mechanical Components

Components	Problems	Frequency of Occurrence	Causes	Solution
Runner				
Guide Vanes				
Bottom Ring				
Draft Tube				
Bearing				
Cooling System				
Valves				
Shaft Seal				
Balancing Pipes				
Others				

APPENDIX II: Salient Features

A. Salient Feature of Kali Gandaki A HPP

Name of River	Kaligandaki and Andhikhola
Type	Peaking run-of-river (6 hours daily peaking)
Annual Design Energy	842.57 GWh
Gross Head	130 m
Maximum Net Head	115 m
Catchment Area	7618 km^2 of Kaligandaki and 476 km^2 of Andhikhola
Average annual flow	288 m^3/s
Riparian Release	4 m^3/s
<u>Turbine</u>	
Manufacturer	Toshiba, Japan
Type and Number	Vertical Shaft Francis, 3
Rated Discharge	47 m^3/s
Rated Output	48 MW each
Rated Speed	300 RPM
<u>Generator</u>	
Manufacturer	Toshiba, Japan
Rated Capacity	56.5 MVA each
Rated Output/Voltage	13.8 KV
Rated Frequency	50 Hz
Power Factor	0.85
Governor	Digital Governor
<u>Transformer</u>	
Power Transformer	56.5 MVA, 13.8/132 KV, 3
Transmission Line	132 kV, Single Circuit to Pokhara Substation and Double Circuit to Butwal Substation

B. Salient Feature of Middle Marsyangdi HPP

Name of River	Marsyangdi
Type	Peaking run-of-river (5 hours daily peaking)
Annual Design Energy	398 GWh
Gross Head	110 m
Maximum Net Head	98 m
Catchment Area	2729 km2
Average annual flow	99.5 m3/s
<u>Turbine</u>	
Manufacturer	Voith
Type and Number	Vertical Shaft Francis, 2
Rated Discharge	42.4 m3/s
Rated Output	37.928 MW
Rated Speed	333.33 rpm
<u>Generator</u>	
Manufacturer	ALSTOM
Rated Capacity	39 MVA
Rated Output/Voltage	11 KV
Rated Frequency	50 Hz
Power Factor	0.85 to 0.90
Governor	Electro-hydraulic Governor
<u>Transformer</u>	
Power Transformer	42.5 MVA, 11/132 KV, 6, Single Phase
Transmission Line	132 kV, Damauli: 42.68 km & New Marsyangdi: 31.5 km

C. Salient Feature of Marsyangdi HPP

Name of River	Marsyangdi
Type	Peaking run-of-river (4 hours daily peaking)
Annual Design Energy	467.45 GWh
Gross Head	95 m
Maximum Net Head	90.5 m
Catchment Area	3850 km2
Average annual flow	210 m3/s
Riparian Release	10% of Design Discharge
<u>Turbine</u>	
Manufacturer	Voith
Type and Number	Vertical Shaft Francis, 3
Rated Discharge	30.5 m3/s
Rated Output	26 MW
Rated Speed	300 rpm
<u>Generator</u>	
Manufacturer	Siemens
Rated Capacity	30 MVA each
Rated Output/Voltage	11 KV
Rated Frequency	50 Hz
Power Factor	0.85
Governor	Digital Governor
<u>Transformer</u>	
Power Transformer	10 MVA, 11/132 KV, 9, Single Phase
Transmission Line	132 kV, Suichatar:84 km, Bharatpur: 25 km, New Marsyangdi-1: 7 km & New Marsyangdi-2: 7 km

APPENDIX III: Running and Outage Hours of Powerhouse

Table 1: Monthly Running and Outage Hours of Kali Gandaki A HPP (F/Y 2077/078)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2077/078	Shrawan	2164.30	58.20	22.53	58.97	139.70	2304.00
	Bhadra	2138.73	46.47	0.00	46.80	93.27	2232.00
	Ashwin	2083.52	0.00	58.02	18.47	76.48	2160.00
	Kartik	1801.53	0.00	356.00	2.47	358.47	2160.00
	Mangsir	1546.42	34.47	576.25	2.87	613.58	2160.00
	Poush	1205.98	0.00	878.52	3.50	882.02	2088.00
	Magh	1094.07	0.00	1057.48	8.45	1065.93	2160.00
	Falgun	986.62	0.00	1094.37	7.02	1101.38	2088.00
	Chaitra	1041.67	0.00	1177.33	13.00	1190.33	2232.00
	Baisakh	1211.45	24.00	968.47	28.08	1020.55	2232.00
	Jestha	1567.83	602.17	50.20	11.80	664.17	2232.00
	Ashadh	2047.67	148.27	0.00	36.07	184.33	2232.00
	Total	**18889.78**	**913.57**	**6239.17**	**237.48**	**7390.22**	**26280.00**

Table 2: Monthly Running and Outage Hours of Kali Gandaki A HPP (F/Y 2078/079)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2078/079	Shrawan	2256.33	22.10	0.00	25.57	47.67	2304.00
	Bhadra	2175.50	20.25	7.53	28.72	56.50	2232.00
	Ashwin	2130.70	8.88	51.65	40.77	101.30	2232.00
	Kartik	1787.45	8.32	348.82	15.42	372.55	2160.00
	Mangsir	1955.30	0.00	127.12	5.58	132.70	2088.00
	Poush	1612.00	0.00	532.62	15.38	548.00	2160.00
	Magh	1254.55	0.00	829.43	4.02	833.45	2088.00
	Falgun	1232.95	0.00	920.25	6.80	927.05	2160.00
	Chaitra	1722.78	0.00	425.60	11.62	437.22	2160.00
	Baisakh	1783.80	0.00	395.10	53.10	448.20	2232.00
	Jestha	2150.18	6.07	20.40	55.35	81.82	2232.00
	Ashadh	2191.20	35.72	16.72	60.37	112.80	2304.00
	Total	**22252.75**	**101.33**	**3675.23**	**322.68**	**4099.25**	**26352.00**

Table 3: Monthly Running and Outage Hours of Kali Gandaki A HPP (F/Y 2079/080)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2079/080	Shrawan	2183.27	29.03	0.22	19.48	48.73	2232.00
	Bhadra	2182.42	21.20	1.03	27.35	49.58	2232.00
	Ashwin	1530.22	575.53	75.78	50.47	701.78	2232.00
	Kartik	1989.68	111.00	46.25	13.07	170.32	2160.00
	Mangsir	1869.75	0.00	209.12	9.13	218.25	2088.00
	Poush	1944.13	0.00	141.81	2.06	143.87	2088.00
	Magh	1140.17	0.00	933.43	14.40	947.83	2088.00
	Falgun	1079.28	42.38	1034.43	3.90	1080.72	2160.00
	Chaitra	1060.82	239.48	846.50	13.20	1099.18	2160.00
	Baisakh	1291.77	279.15	653.03	8.05	940.23	2232.00
	Jestha	1963.68	0.00	221.15	119.17	340.32	2304.00
	Ashadh	1754.95	418.13	0.00	58.92	477.05	2232.00
	Total	**19990.13**	**1715.92**	**4162.76**	**339.19**	**6217.87**	**26208.00**

Table 4: Monthly Running and Outage Hours of Kali Gandaki A HPP (F/Y 2080/081)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2080/081	Shrawan	2196.45	58.35	0.40	48.80	107.55	2304.00
	Bhadra	2190.32	14.45	0.67	26.57	41.68	2232.00
	Ashwin	2088.50	19.10	13.28	39.12	71.50	2160.00
	Kartik	1663.85	448.77	38.38	9.00	496.15	2160.00
	Mangsir	1771.67	0.00	373.92	14.42	388.33	2160.00
	Poush	1258.23	0.00	829.77	0.00	829.77	2088.00
	Magh	1256.23	0.00	831.77	0.00	831.77	2088.00
	Falgun	863.69	0.00	1283.30	13.00	1296.31	2160.00
	Chaitra	1092.00	0.00	1065.72	2.28	1068.00	2160.00
	Baisakh	1365.03	0.00	794.97	0.00	794.97	2160.00
	Jestha	2043.45	24.75	202.02	33.78	260.55	2304.00
	Ashadh	2058.23	127.45	18.03	28.28	173.77	2232.00
	Total	**19847.66**	**692.87**	**5452.22**	**215.25**	**6360.34**	**26208.00**

Table 5: Monthly Running and Outage Hours of Middle Marsyangdi HPP (F/Y 2077/078)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2077/078	Shrawan	1463.20	64.97	6.50	1.33	72.80	1536.00
	Bhadra	1447.33	32.58	7.57	0.52	40.67	1488.00
	Ashwin	1381.32	23.87	33.53	1.28	58.68	1440.00
	Kartik	1261.03	18.70	159.72	0.55	178.97	1440.00
	Mangsir	1176.22	263.78	0.00	0.00	263.78	1440.00
	Poush	871.80	6.80	513.40	0.00	520.20	1392.00
	Magh	796.45	7.08	636.47	0.00	643.55	1440.00
	Falgun	721.13	6.75	662.43	1.69	670.87	1392.00
	Chaitra	705.23	781.07	1.20	0.50	782.77	1488.00
	Baisakh	837.01	8.77	641.92	0.30	650.99	1488.00
	Jestha	1301.80	2.00	184.20	0.00	186.20	1488.00
	Ashadh	650.88	19.50	817.62	0.00	837.12	1488.00
	Total	**12613.40**	**1235.87**	**3664.56**	**6.17**	**4906.60**	**17520.00**

Table 6: Monthly Running and Outage Hours of Middle Marsyangdi HPP (F/Y 2078/079)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2078/079	Shrawan	1432.12	41.08	62.60	0.20	103.88	1536.00
	Bhadra	1448.13	29.37	10.50	0.00	39.87	1488.00
	Ashwin	1426.41	30.07	31.52	0.00	61.59	1488.00
	Kartik	935.48	289.77	204.75	10.00	504.52	1440.00
	Mangsir	1241.10	0.33	150.57	0.00	150.90	1392.00
	Poush	1078.62	0.83	358.93	1.62	361.38	1440.00
	Magh	863.67	2.35	522.73	3.25	528.33	1392.00
	Falgun	795.40	1.10	642.68	0.82	644.60	1440.00
	Chaitra	1194.23	1.03	242.77	1.97	245.77	1440.00
	Baisakh	1300.41	1.57	180.52	5.50	187.59	1488.00
	Jestha	1361.95	9.40	110.57	6.08	126.05	1488.00
	Ashadh	1513.42	4.00	17.68	0.90	22.58	1536.00
	Total	**14590.94**	**410.90**	**2535.82**	**30.34**	**2977.06**	**17568.00**

Table 7: Monthly Running and Outage Hours of Middle Marsyangdi HPP (F/Y 2079/080)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2079/080	Shrawan	1431.93	34.55	18.20	3.32	56.07	1488.00
	Bhadra	1472.03	9.45	6.52	0.00	15.97	1488.00
	Ashwin	1415.17	26.92	44.53	1.38	72.83	1488.00
	Kartik	1393.50	23.93	22.57	0.00	46.50	1440.00
	Mangsir	1163.08	1.00	225.87	2.05	228.92	1392.00
	Poush	943.15	0.00	496.45	0.40	496.85	1440.00
	Magh	767.97	53.58	570.45	0.00	624.03	1392.00
	Falgun	382.37	672.00	385.63	0.00	1057.63	1440.00
	Chaitra	412.48	340.85	686.67	0.00	1027.52	1440.00
	Baisakh	803.17	3.23	681.32	0.28	684.83	1488.00
	Jestha	1391.18	34.25	110.57	0.00	144.82	1536.00
	Ashadh	1356.60	109.35	17.68	4.37	131.40	1488.00
	Total	**12932.63**	**1309.11**	**3266.46**	**11.80**	**4587.37**	**17520.00**

Table 8: Monthly Running and Outage Hours of Middle Marsyangdi HPP (F/Y 2080/081)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2080/081	Shrawan	1479.44	47.43	2.65	6.48	56.56	1536.00
	Bhadra	1422.89	62.38	2.73	0.00	65.11	1488.00
	Ashwin	1422.67	16.83	0.00	0.50	17.33	1440.00
	Kartik	1422.08	5.82	11.00	1.10	17.92	1440.00
	Mangsir	1200.58	2.42	237.00	0.00	239.42	1440.00
	Poush	892.58	5.42	494.00	0.00	499.42	1392.00
	Magh	732.63	5.02	654.35	0.00	659.37	1392.00
	Falgun	726.64	332.43	380.93	0.00	713.36	1440.00
	Chaitra	794.89	3.23	641.88	0.00	645.11	1440.00
	Baisakh	1111.97	4.50	371.33	0.20	376.03	1488.00
	Jestha	1445.47	34.30	56.23	0.00	90.53	1536.00
	Ashadh	1417.16	63.37	6.90	0.57	70.84	1488.00
	Total	**14069.00**	**583.15**	**2859.00**	**8.85**	**3451.00**	**17520.00**

Table 9: Monthly Running and Outage Hours of Marsyangdi HPP (F/Y 2077/078)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2077/078	Shrawan	2211.08	86.58	5.78	0.55	92.91	2304.00
	Bhadra	2059.95	151.00	21.05	0.00	172.05	2232.00
	Ashwin	1978.90	123.95	56.93	0.22	181.10	2160.00
	Kartik	1605.18	375.08	179.73	0.00	554.81	2160.00
	Mangsir	1807.87	2.17	349.07	0.00	351.24	2160.00
	Poush	1394.68	172.42	520.00	0.00	692.42	2088.00
	Magh	1248.02	2.47	909.52	0.00	911.99	2160.00
	Falgun	1095.45	15.58	976.97	0.00	992.55	2088.00
	Chaitra	1136.23	2.33	1093.43	0.00	1095.76	2232.00
	Baisakh	1281.25	69.61	881.13	0.00	950.74	2232.00
	Jestha	1783.55	192.11	256.34	0.00	448.45	2232.00
	Ashadh	1627.28	595.67	5.05	4.00	604.72	2232.00
	Total	**19229.44**	**1788.97**	**5255.00**	**4.77**	**7048.74**	**26280.00**

Table 10: Monthly Running and Outage Hours of Marsyangdi HPP (F/Y 2078/079)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2078-079	Shrawan	2015.29	279.60	5.33	3.78	288.71	2304
	Bhadra	2071.98	146.12	13.90	0.00	160.02	2232
	Ashwin	2127.43	57.33	47.24	0.00	104.57	2232
	Kartik	1487.82	350.80	321.38	0.00	672.18	2160
	Mangsir	1850.80	164.68	72.08	0.43	237.19	2088
	Poush	1834.72	1.93	322.07	1.29	325.29	2160
	Magh	1452.00	6.40	629.65	0.00	636.05	2088
	Falgun	1371.40	9.95	778.62	0.00	788.57	2160
	Chaitra	1780.50	5.10	357.10	17.18	379.38	2160
	Baisakh	1921.40	37.98	272.64	0.00	310.62	2232
	Jestha	2135.80	51.55	44.65	0.00	96.20	2232
	Ashadh	2205.63	86.03	8.03	4.30	98.36	2304
	Total	**22254.77**	**1197.47**	**2872.69**	**26.98**	**4097.14**	**26352.00**

Table 11: Monthly Running and Outage Hours of Marsyangdi HPP (F/Y 2079/080)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2079-080	Shrawan	2103.92	126.70	0.97	0.42	128.09	2232
	Bhadra	2177.28	52.32	0.73	1.67	54.72	2232
	Ashwin	1753.27	448.82	25.37	4.55	478.74	2232
	Kartik	1954.00	129.35	76.65	0.00	206.00	2160
	Mangsir	2001.87	4.17	79.97	2.00	86.14	2088
	Poush	1636.78	1.17	520.05	0.00	521.22	2160
	Magh	1314.00	2.70	770.44	0.00	773.14	2088
	Falgun	1201.11	7.45	951.47	0.00	958.92	2160
	Chaitra	1169.00	25.75	965.25	0.00	991.00	2160
	Baisakh	1371.97	28.72	831.32	0.00	860.04	2232
	Jestha	2145.00	34.25	124.37	0.00	158.62	2304
	Ashadh	2118.28	109.35	0.00	4.37	113.72	2232
	Total	**20946.48**	**970.75**	**4346.59**	**13.01**	**5330.35**	**26280.00**

Table 12: Monthly Running and Outage Hours of Marsyangdi HPP (F/Y 2080/081)

	Month	Total Running Hours	Total Scheduled Outage Hours	Total Idle Hours	Total Forced Outage Hours	Total Outage Hours	Total Hours
F/Y 2080-081	Shrawan	2216.02	84.60	3.00	0.38	87.98	2304
	Bhadra	2169.15	54.97	5.58	2.30	62.85	2232
	Ashwin	2123.97	36.03	0.00	0.00	36.03	2160
	Kartik	1825.62	312.70	21.68	0.00	334.38	2160
	Mangsir	1980.75	1.72	177.53	0.00	179.25	2160
	Poush	1501.82	0.45	585.73	0.00	586.18	2088
	Magh	1216.00	21.57	850.43	0.00	872.00	2088
	Falgun	1166.00	1.17	992.83	0.00	994.00	2160
	Chaitra	1273.14	3.93	882.93	0.00	886.86	2160
	Baisakh	1518.72	4.05	637.23	0.00	641.28	2160
	Jestha	2165.77	8.15	129.10	0.98	138.23	2304
	Ashadh	2133.22	98.78	0.00	0.00	98.78	2232
	Total	**21290.18**	**628.12**	**4286.04**	**3.66**	**4917.82**	**26208**

APPENDIX IV: Calculation of Generation Cost

Table 13: Calculation of Generation Cost for FY 2077/078

Name of HPP	Installed Capacity (MW)	Fixed Assets (Rs.)	Annual Generation (MWh)	Rate of Electricity (Rs)	Annual Revenue (Rs)	O & M Cost (Rs)	Depreciation (Rs.)	Royalty (Rs.)	Generation Cost (Rs/Unit)
KaliGandaki A	144	2532.39	817712.86	6.60	539.69	43.18	126.62	53.98	2.74
Middle Marsyangdi	70	2871.59	398846.30	6.60	263.24	21.06	143.58	5.27	4.26
Marsyangdi	69	622.33	398920.10	6.60	263.29	21.06	31.12	26.34	1.97

Table 14: Calculation of Generation Cost for FY 2078/079

Name of HPP	Installed Capacity (MW)	Fixed Assets (Rs.)	Annual Generation (MWh)	Rate of Electricity (Rs)	Annual Revenue (Rs)	O & M Cost (Rs)	Depriciation (Rs.)	Royalty (Rs.)	Generation Cost (Rs/Unit)
KaliGandaki A	144	2405.77	974831.97	6.60	643.39	51.47	120.29	64.35	2.42
Middle Marsyangdi	70	2728.01	468270.00	6.60	309.06	24.72	136.40	6.18	3.57
Marsyangdi	69	591.21	464271.50	6.60	306.42	24.51	29.56	30.65	1.82

Table 15: Calculation of Generation Cost for FY 2079/080

Name of HPP	Installed Capacity (MW)	Fixed Assets (Rs.)	Annual Generation (MWh)	Rate of Electricity (Rs)	Annual Revenue (Rs)	O & M Cost (Rs)	Depriciation (Rs.)	Royalty (Rs.)	Generation Cost (Rs/Unit)
KaliGandaki A	144	2285.48	832678.79	6.60	549.57	43.97	114.27	54.97	2.56
Middle Marsyangdi	70	2591.61	428402.10	6.60	282.75	22.62	129.58	5.66	3.68
Marsyangdi	69	561.65	434558.70	6.60	286.81	22.94	28.08	28.69	1.83

All the costs are expressed in crore.

Table 16: Calculation of Generation Cost for FY 2080/081

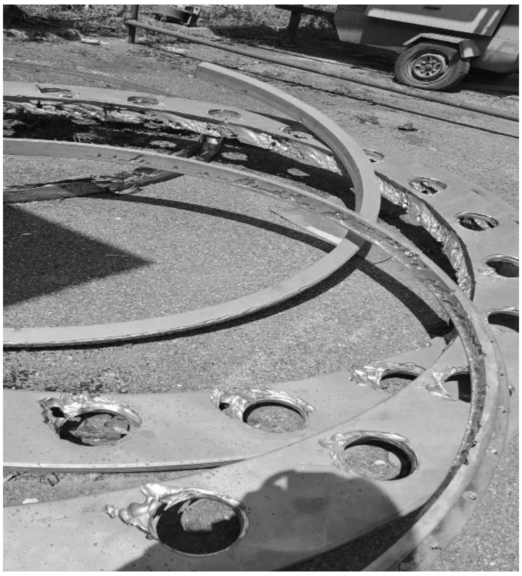
Name of HPP	Installed Capacity (MW)	Fixed Assets (Rs.)	Annual Generation (MWh)	Rate of Electricity (Rs)	Annual Revenue (Rs)	O & M Cost (Rs)	Depriciation (Rs.)	Royalty (Rs.)	Generation Cost (Rs/Unit)
KaliGandaki A	144	2171.20	841596.00	6.60	555.45	44.44	108.56	55.56	2.48
Middle Marsyangdi	70	2462.03	441127.00	6.60	291.14	23.29	123.10	5.82	3.45
Marsyangdi	69	533.57	446082.00	6.60	294.41	23.55	26.68	29.45	1.79

All the costs are expressed in crore.

APPENDIX V: Photos

Damaged Runner

Desander Basin Maintenance



Damaged Facing Plates

Gate Maintenance

Oil Sump Tank Cleaning

Repair of Guide Vanes

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Match Groups

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  Matches with neither in-text citation nor quotation marks
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