ELECTRICAL-ELECTRONIC ASSEMBLY

Teaching and Learning Material

National Vocational Certificate Level 3

Version 1 - July 2015

EUROPEAN UNION
Kingdom of the Netherlands
german cooperation
DEUTSCHE ZUSAMMENARBEIT
NORWEGIAN EMBASSY
Supported by giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Islamic Republic of Pakistan
Islāmī Jumhūrī-ye Pākistān
NAVTTC

Published by
National Vocational and Technical Training Commission
Government of Pakistan

Headquarter
Plot 38, Kirthar Road, Sector H-9/4, Islamabad, Pakistan
www.navttc.org

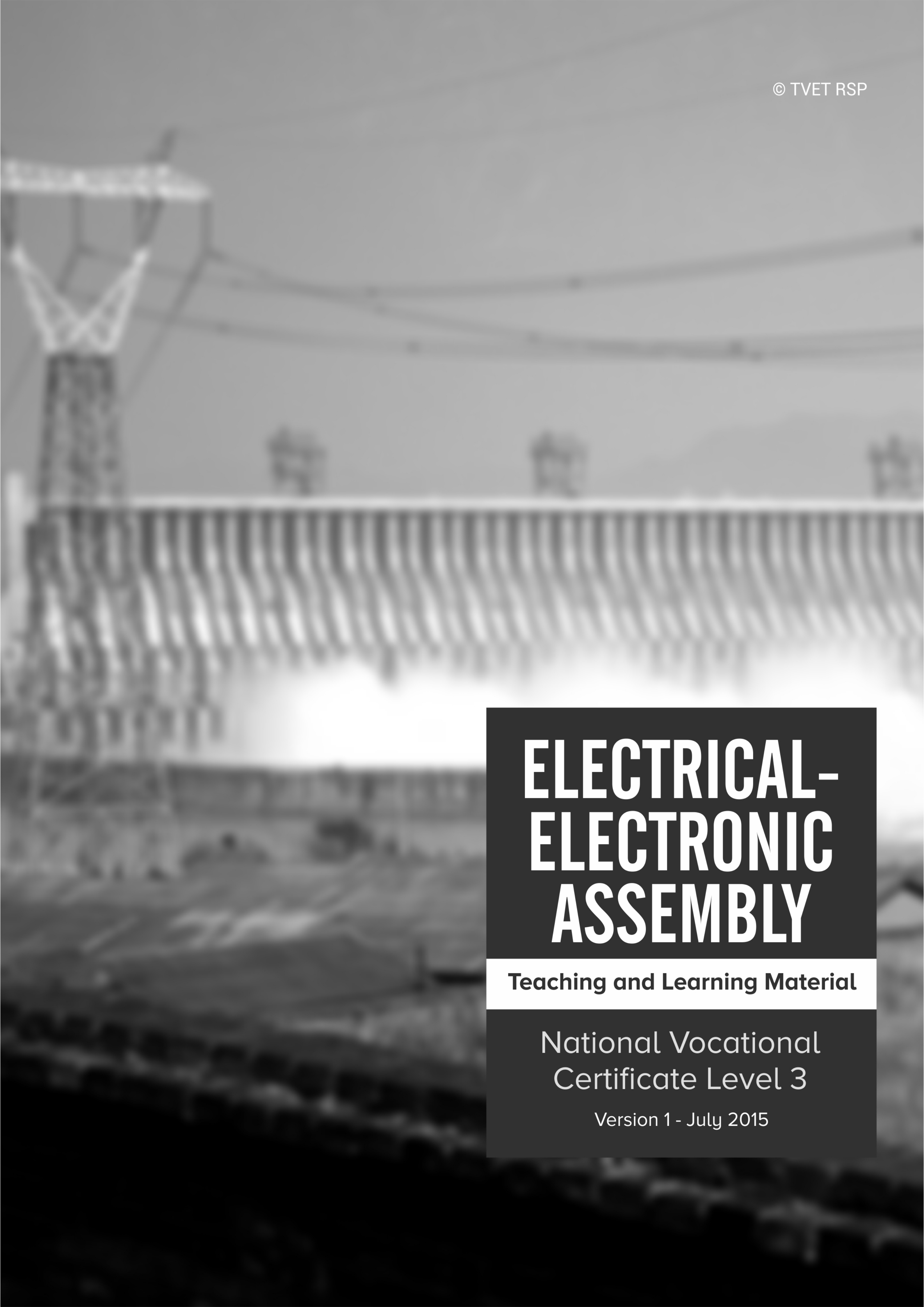
Responsible
Director General Skills Standard and Curricula, National Vocational and Technical Training Commission
National Deputy Head, TVET Reform Support Programme, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Layout & design
SAP Communications

Photo Credits
TVET Reform Support Programme

This document has been produced with the technical assistance of the TVET Reform Support Programme, which is funded by the European Union, the Embassy of the Kingdom of the Netherlands, the Federal Republic of Germany and the Royal Norwegian Embassy and has been commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ). The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in close collaboration with the National Vocational and Technical Training Commission (NAVTTC) as well as provincial Technical Education and Vocational Training Authorities (TEVTAs), Punjab Vocational Training Council (PVTC), Qualification Awarding Bodies (QABs)s and private sector organizations.

Document Version
July, 2015
Islamabad, Pakistan



ELECTRICAL-ELECTRONIC ASSEMBLY

Teaching and Learning Material

National Vocational Certificate Level 3

Version 1 - July 2015

Teaching and Learning Material

Certificate course

Micro Hydro Power

“MHP - Operator”

PNVQF LEVEL 3

Module 1

Plant Operations

Table of Contents

Module-01: Plant Operations 15

Learning Unit 1: Introduction To Hydropower 15

Topic 1: Introduction to Hydropower 15

Historical Context of Hydropower 16

Potential and Relevance 17

Classification of hydropower plants 17

Topic 2: Relevance of MHP in the context of rural electrification and poverty alleviation 18

Micro-hydropower - an appropriate energy source 20

Topic 3: Fundamentals of MHP Technology 22

Energy and power 22

Head and flow 22

Potential and kinetic energy in water 23

Hydropower potential 23

Electric power output 24

Site configuration 25

Main systems of a MHP scheme: 27

Learning Unit 2: Micro Hydro Components 31

Topic 1: Civil Structures 31

Diversion weir and intake 33

Sandtrap / Settling basin 37

Headrace Channel 39

Forebay Tank 40

Trash rack 42

Penstock Pipe 43

Anchor blocks and supports 44

Expansion joints 45

Penstock valves 46

Powerhouse& Tailrace 47

Topic 2: Electro-Mechanical Equipment 51

Turbine 51

Mechanical transmission 54

Generator 58

Control System 60

Topic 3: Transmission & Distribution 66

Poles 66

Cables and Cable Accessories 68

Step up / down transformers 69

House connection 70

Learning Unit 3: Plant Operations 74

Topic 1: Pre-start checks 75

Topic 2: Plant Operation 78

Hydraulic System Startup 78
Routine operational tasks during operation 80
Hydraulic system shut-down 85
Emergency system shut-down 86

Outline for the internal Assessment

MODULE 1: PLANT OPERATIONS			
Learning Units (LU)	**Theory**	**Practical**	**Formative Assessment**
1. Introduction into Hydro Power	20	40	Using a water source, tap, hosepipe, cardboard and other required materials build a simple model water wheel.
2. Micro Hydro Components	50	80	On a white board draw / sketch a conventional MHP project indicating all main components.
3. Plant Operations	30	80	On a white board produce a flow diagram indicating the process of start-up and shut down of a MHP scheme.

Planning of the assessment for the Module:

MODULE 1: PLANT OPERATIONS				
LEARNING UNIT (LU)		**FORMATIVE ASSESSMENT PROJECTS**	**SCHEDULED DATES**	
LU 1	Introduction into Hydro Power	Using a water source, tap, hosepipe, cardboard and other required materials build a simple model water wheel.		
LU 2	Micro Hydro Components	On a white board draw / sketch a conventional MHP project indicating all main components.		
LU 3	Plant Operations	On a white board produce a flow diagram indicating the process of start-up and shut down of a MHP scheme. Compliment this with a table listing all main tasks the operator is responsible for.		

Guidelines for Trainers/Teachers and Trainees

Practice orientation

1. As a general guideline work should be 20% theoretical and 80% practical work, but outline must be appropriate. Theoretical part could be increased, if suitable for the subject/LU.
2. Punctuality is compulsory so that no academic or practical work remains uncovered. It is also the responsibility of teachers to ensure 100% attendance of trainees.
3. Manage a visit to the relevant industry, if possible. The trainees will be more excited to do work in their fields.
4. Use group activities, practical work, projects, individual and group assignments and student's individual assessment.

Facilitation instead of lecturing

1. The teachers should act as facilitators. The center of training must be student. It is the duty of teacher to make constructive environment of classroom for theory and practical assignments.
2. Normally the theory part is completed first, exceptions are possible, then demonstrate the practical work yourself. The trainees should perform the practical work under supervision and guidance of the instructor. Promote the discussions for better understanding of academic and practical work. The following techniques can be used for this purpose:
    a. Lecture- Minimize the time period.
    b. Use of story- Use a real story for better understanding of a problem and its solution to trainees

Introduction into the learning objectives of each Learning Unit

Provide a brief and summarizing introduction into the objectives of the LU and explain what the learner will know and be able to do in the end.

Interacting with trainees – the participatory approach

3. There should be no sternness in the class that a student could not express his ideas or concerns and not as much freedom that a student destroys the collective discipline of learning. It is the duty of a teacher to maintain a good and moderate environment in class so that a student could succeed in attaining his goal.
4. In this module, a weekly schedule has been included for trainees to give feedback or opinion about their training. The trainers must take

feedback from trainees by using a chart and try to improve the training process in the light of feedback.

The assessment strategy

5. This module includes an assessment guide for teachers and trainees to inform them about the whole assessment process. The teachers will use it for assessing the ability of the trainees to perform what they have learnt.
6. The formative assessment serves to check progress in learning and is mainly based on oral questioning, practical assignments and little projects. The results will be documented and presented for the integrated assessment at the end of the module.
7. At the end of the module the integrated assessment will be conducted through a panel of persons. Only if all formative assessments has been passed the learner is eligible for the integrated assessment

Organizational aspects of training delivery

8. The teachers will keep in view the following instructions during the daily lesson planning:

    a. The seating plan in the class should be arranged to increase allow interaction amongst the trainees.
    b. The teacher/instructor will present the summary of previous lesson and ask questions.
    c. The teacher/instructor will present a brief introduction into the new objectives
    d. The teacher/instructor delivers the subjects according to his lesson plan (could be lecturing or practical demonstration and trainee practice)
    e. Collect feedback of trainees regarding their perception about the subject they are learning.
    f. Provide sufficient time to trainees for learning so that they understand the relation between theory and practical work.

Toolbox for teachers and instructors

In the following a toolbox is outlined which the teacher/instructor should use during the training sessions.

TOOL 1: INDIVIDUAL OR GROUP WORK - PRESENTATION

Explanation: The teacher/instructor will present the trainee or a group of trainees a **well defined theoretical task**. The trainees are divided into 3 or 4 groups. The time to solve the problem is specified and should be within the current training session. Each group will present its solution of the problem in an appropriate way, be it on flip chart, a short presentation or result of work

Define theoretical task, not more than 4 lines
Individual / Group result/presentation:

TOOL 2: PRACTICAL ASSIGNMENT / PROJECT

Explanation: The teacher will present the trainees a well defined assignment which requires practical work. The assignment is done individually or in groups. The time to solve the problem is specified and could be within the training session, but could also stretch over a week at the maximum. The result will be presented individually or as per group.

Note: Such an assignment could be also used as a formative assessment.

Define practical assignment, not more than 4 lines
Group result/presentation:

TOOL 3: PRACTICAL DEMONSTRATION

The most powerful tool for any technical training is the demonstration of works processes and the practicing of the trainees. However, a well executed demonstration must be well designed and prepared:

1. Read the procedure mentioned in the Learner Guide for the relevant Learning Unit before demonstration.
2. Arrange all tools, equipment and consumable material that are required for demonstration of a skill.
3. Explain how the skill relates with the skills already learnt, describe the expected results and show the objects to trainees.
4. Carry out demonstration in a way that it can be seen by all trainees.
5. Identify critical or complex steps, or steps that involve safety precautions to be followed.
6. Explain theoretical knowledge where applicable and ask questions to trainees to test their understanding.
7. Allow the trainees to repeat the demonstration, either individually or in groups
8. Walk around and provide hints and support to the trainees.
9. Repeat critical steps in demonstration, if required.
10. Let the trainees summarize what they have learnt.

TOOL 4: DAILY LESSON PLAN

The daily lesson plan is the most powerful tool to prepare and structure efficient learning. The lesson plan needs to be completed by the teacher for every lesson. The teacher/instructor needs to plan their lessons right in advance and come to the class fully prepared to implement the session in a professional way:

1. Introduce yourself and the Learning Unit, and state the Learning Outcomes of the session clearly to activate attention of learners.
2. State the Learning Objectives of the lesson. This allows the trainees to organize their thoughts on what they will learn and to perform. Also state some questions to recall prior knowledge of trainees to arouse their interest and motivation.
3. In the main part of the lesson present the new information or material to be learned. Perform demonstrations and use relevant media including handouts, power-point slides, flip chard and white board.
4. At the end and in conclusion of the session summarize and review the lesson delivered. Ask probing question to verify, if a transfer of knowledge and skill has been achieved.

Name teacher/instructor:	
Date:	
Subject, course title:	
Learning Unit No.	
Learning Outcome No.	
Recommended Visual Aids:	
Learning Outcome:	

Activity 1: Revision of Previous Lesson

Activity 2: Today's Lecture

The instructor will explain the following points in detail:

1.
2.
3.

Activity 3: Practical Work

The instructor will perform a demonstration and ask the trainees to do the following practical work.

1.
2.
3.

Activity 4: Presentation/Assignment/group activity

Give the following projects or assignments to student

1.
2.
3.

Activity 5: Analysis of absorption of the taught lesson

Ask a probing question to verify if a transfer of knowledge and skill has been achieved.

TOOL 5: WEEKLY EVALUATION

A simple tool to capture the learning progress and to identify potential problems is a feedback form with smileys. At the end of each week (or a specific day) the teacher should use the evaluation form below to receive anonymous feedback for the week. The teacher must summarize all forms on one sheet, analyze the results and draw conclusions. If other facilitators are involved in the delivery of the training, the results should be shared with them.

Weekly Evaluation

Class: ______________

Subject: _____________

Date: __________________

Method of Evaluation	☺	😐	☹
1-Did you learn any new thing during the week?			
2-Did you learn something new today?			
3-Was it easy to understand the lesson?			
4-Was the practical work well demonstrated?			
5-Did you learn from others during group work?			

Any other opinion or comments:

____

____

TOOL 6: SELF-ASSESSMENT AT THE END OF A LU

The self-assessment at the end of each Learning Unit must be simple questions (without answers!!!!) and with a max of 10 questions. Questions must be in relation with the content of the LU. The self-assessment is not checked and cannot be used as formative assessment.

Question (simple)	**Answer by trainee**

Module-01: Plant Operations

Learning Unit 1: Introduction To Hydropower

Topic 1: Introduction to Hydropower

Renewable energy sources are energy sources that are not depleted or "consumed" when their energy is harnessed. They are also sometimes referred to as sustainable energy sources. Therefore renewable energy sources are distinct from non-renewable sources such as fossil fuels, which must be consumed (burnt) to release their potential energy. Renewable energy sources include solar, wind, hydro, biological processes (biomass & biogas) and geothermal. Within these categories there are numerous different ways the energy is harnessed.

Traditional uses of wind, water, and solar power are already widespread. Although simple forms of renewable energy have been harnessed for centuries (water wheel driven mills for example), larger scale production of electricity using renewable energy sources has emerged significantly only during the last decades. Increased awareness of the negative impacts of fossil fuels and their diminishing availability has contributed to rapid development of renewable energy technologies globally. This is, however, particularly noticeable in developing countries especially those where many rural communities do not have access to a reliable energy source. In such environments, small-scale isolated energy networks often represent the only viable option for energy access.

Many countries actively promote the harnessing of renewable energies through the introduction of favorable energy policies. Several statutory definitions of the term renewable energy have been adopted to define eligibility.

Hydropower, as one of the renewable energies, is defined as follows:

Energy generated from the potential or kinetic energy of water

The potential or kinetic energy of water is converted into energy and then distributed to consumers in the form of electricity.

For small schemes, of the type addressed in this manual, the rotational shaft power of the turbine can also be used for providing direct mechanical drive. This approach is mostly used for agricultural processing tasks such as grain milling, rice husking, coffee grinding etc.

To convert the energy of the water into shaft power, a variety of turbine exist. These vary from very simple technology such as wooden waterwheels to highly sophisticated turbines incorporating flow control and variable speed mechanisms. Although conventional turbines have existed for more than a century, it is only over since the 1980's that the small scale local production of reliable well performing turbines has gained momentum and popularity.

Historical Context of Hydropower

The first water wheel was developed centuries ago and represented the main source of energy through the Middle Ages and remained so until the 19th century, when it was gradually replaced by the steam engine. Nevertheless waterpower still represents a major source of electricity generation in many countries, although the waterwheel has to a large extent been replaced with more efficient water turbines.

The main use of this waterpower for centuries was for milling grain. Water mills appeared throughout the Roman Empire during the third and fourth centuries.

Much of the technology of water wheels from the Roman and the Hellenistic civilizations was perfected by the Islamic world where they used it to power their sophisticated irrigation systems. In Europe, water wheels came into widespread use only during the tenth century. The Doomsday Book (eleventh century) lists 5624 water mills in England, which corresponds to about one water mill per 300 inhabitants at that time.

The early water wheels were mainly of the undershot type. Water passed under the wheel, driving the paddles. Undershot wheels are easy to install and they were a common sight on rivers and streams. Many of these water mills were mounted on barges, meaning their operation was independent of the water level of the river.

During the late middle ages, more efficient overshot water wheels emerged supplying energy for an increasing range of applications including pumps, hammers, grinding wheels, saws, and lathes.

Overshot wheels are more efficient because they harness more of the energy in the flow of water. Their efficiency was further increased with the replacement of the paddles with buckets, whereby the weight of water in the buckets added to the driving force acting on the wheel. They can reach efficiencies in excess of 60%.

Figure 1: Modern day steel overshot waterwheel for electricity generation.

Figure 2:Traditional wooden overshot waterwheel providing mechanical power to a grain mill in the 1930's.

Through the 20th century, the advancements made in hydropower technology resulted in many plants being constructed throughout the world including the European colonies in the South and South East Asia. These were constructed to supply energy to tea plantations and their factories, to power mining operations and to electrify towns and settlements.

In many tea growing countries (e.g. Indonesia, India, Sri Lanka), the first turbines were installed between 1880 and 1890. At this time the turbines provided direct shaft power to tea rollers and other processing machinery in the factory. Later, with the advent of turbine and generator technology, hydroelectric power plants were built. For example in Indonesia in 1910 forty private tea plantations owned hydropower plants, in 1925 there were already 400 with a total capacity of 12.5 MW [1]). The capacity of the plants was between 30 and 150 kW. At this time generation of electricity with fossil fuels was approximately 5 times more expensive than generation with hydropower plants. Moreover, one of the most important factors when selecting the location for a tea factory was the availability of a viable location for the installation of a hydropower plant. The electro-mechanical equipment for these schemes was imported from Europe.

Figure 3: An abandoned MHP scheme in a tea estatein Sri Lanka.

Figure 4:AMHP scheme providing mechanical drive in a sisal plantation in Tanzania.

Sadly many of these schemes providing mechanical power were abandoned due to a combination of subsidized diesel fuel and the relatively small size of many of the power plants. In recent years, however, with the removal of fuel subsidies in many countries and the increased awareness to the importance of harnessing renewable energy sources, small-scale hydropower is experiencing resurgence in popularity as an appropriate energy source.

Potential and Relevance

Today more than 750 GW of hydropower capacity is installed worldwide, generating approximately 2.87 million GWh of electricity per year. An additional 120 GW of generating capacity is currently under construction. Although exact figures are impossible to obtain, it is estimated that approximately 20% of the world's electricity demand is generated with hydropower.

Classification of hydropower plants

Besides the technical classification of hydropower that will be described later, hydropower plants are also classified by their size.

---

[1] 1 HP = 0.7736 kW)

Although there are numerous different definitions existing, for the purpose of this manual we will adopt the following classification as adopted by many international organizations (e.g. UNIDO):

Term	Power Output
Pico Hydro	< 500 W
Micro Hydro	500 W to 100 kW
Mini Hydro	100 kW to 1 MW
Small Hydro	1 MW to 10 MW
Full-scale (large) hydro	> 10 MW


Figure 5: Pico hydro turbine units are installed widespread in SE Asia for producing a few watts for lighting individual houses.


Figure 6: A large hydropower scheme used to supply power to cities and towns.

This manual will primarily focus on micro hydropower therefore will address schemes between 0.5 to 100 kW installed capacity. Nevertheless, much of the terminology and principles equally apply for schemes of a larger size. The information provided in this manual is applicable for run-of-river hydropower in general, independent of the size of the plant.

Topic 2: Relevance of MHP in the context of rural electrification and poverty alleviation

Micro-hydro power has been increasingly used as an alternative energy source, especially in remote areas where other power sources are not viable. Small-scale hydropower systems can be installed at small rivers or streams with little or no discernible negative environmental effects. Most small-scale hydropower systems do not include a dam to create seasonal storage but are built as “run-of-the-river” hydropower plants.

The most common application for domestic energy supply is to convert to mechanical power into electricity through the use of an electrical. However, micro-hydro power has traditionally been harnessed to power small-scale industrial uses through direct drive applications where "shaft power" is used.

There are a number of misconceptions about energy, which should be dispelled in order to encourage the development community to think more seriously about issues related to energy supply, energy access and energy use:

It is sometimes heard that the poor do not see energy as a priority or are willing to pay for energy. The poor may not use the term ‘energy’, but they can spend far more time and effort obtaining energy services than the better off; and they spend a substantial proportion of their household income on energy just for basic human survival - cooking, keeping warm, etc. In fact many poor people often already pay more per unit of energy than the better off, partly due to inefficient conversion technology they are forced to use.

In poor areas of the world, many remote communities still do not have access to electricity. Micro hydropower allows such communities to generate their own electricity. Many international development organizations and governments support MHP development through technical assistance programsaddressing technology transfer, project financing, policy development etc.

Figure 7:Typical rural village in a mountainous area supplied with a stand-alone MHP project.

Figure 8:Access to energy provides opportunity for cottage industry development in rural villages.

In particular in development programs targeting rural welfare and economic development in the context of reaching the Millennium Development Goals (MDG’s) see rural electrification as a key objective. Energy services can play a variety of direct and indirect roles in helping to achieve the MDGs:

To halve extreme poverty -- access to energy services facilitates economic development - micro-enterprise, livelihood activities beyond daylight hours, locally owned businesses, which will create employment - and assists in bridging the ‘digital divide’.

To reduce hunger and improve access to safe drinking water -- energy services can improve access to pumped drinking water and 95% of staple foods need cooking before they can be eaten.

To reduce child and maternal mortality; and to reduce diseases -- energy is a key component of a functioning health system, for example, lighting operating theatres, refrigeration of vaccines and other medicines, sterilization of equipment and transport to health clinics.

To achieve universal primary education; and to promote gender equality and empowerment of women -- energy services reduce the time spent by women and children (especially girls) on basic survival activities (gathering firewood, fetching water, cooking, etc.); lighting permits home study, increases security and enables the use of educational media and communications in schools, including information and communication technologies (ICTs).

Environmental sustainability -- improved energy efficiency and use of cleaner alternatives can help to achieve sustainable use of natural resources, as well as reducing emissions, which protects the local and global environment.

Micro-hydropower - an appropriate energy source

Small-scale hydropower features many advantages compared to conventional energy sources. These include:

- uses a renewable source of energy, i.e., water in the catchment area is not depleted but continuously replaced thanks to the hydrological cycle;
- relies on a non-polluting, indigenous source of energy;
- can replace petroleum-based generating systems, which rely on imported fuels;
- is a well-proven technology, well beyond the research and development stage and
- due to the small size their impact on the environment (river ecology etc.) can be kept at a very low level.

There are also a number of disadvantages that need to be considered when comparing MHP to other energy sources. These are:

- associated with high capital (investment) costs;
- requires a considerable amount of specialist know-how which is not always locally available; note, that MHP is not simply a scaled-down version of full-scale hydropower but uses unique design and construction techniques;
- MHP schemes require a simple but continuous effort for operation and maintenance which rural communities are not always prepared to provide (lack of organizational capacities, lack of cash: issues which have to be considered carefully during planning).

Compared to other renewable energy sources such as wind and solar power, MHP has a number of key advantages:

- high efficiency of 70 - 90%, which is substantially better than any other energy technology
- high capacity factor of typically more than 50% (depending on the system layout), compared to 10% for PV and 30% for wind and therefore reliably operating in captive micro-grids
- high level of predictability, varying with annual rainfall patterns
- slow rate of change; the source from which power is generated varies only gradually from day to day (not from minute to minute)
- good correlation with demand over the day and over the year i.e. output constant also at night; in most regions power demand is higher during times of greater river flow

- proven, long-lasting and robust technology; systems can readily be engineered and implemented to last for 50 years or more and can relatively easy be handled on village-level

Hydropower in general and small-scale hydropower in particular is considered environmentally benign. Most micro hydropower plants are designed as “run-of-river”-schemes, which mean that only small diversion structures are required to be built in the river. Water is in some cases stored to cover daily peaks but no water is stored over a longer period (seasonal). Therefore run-of-river installations do not carry the same kind of adverse effect on the local environment as large-scale hydro.

Summarizing it can be said that small-scale hydropower is one of the most cost-effective, environmentally friendly and reliable energy technologies for providing clean electricity generation.

Topic 3: Fundamentals of MHP Technology

Energy and power

Energy is the work done in a given time, measured in Joules.

Electricity is a form of energy, but is generally expressed in its own units of kilowatt-hours (kWh) where 1 kWh = 3600 kilojoules and is the electricity supplied by 1 kW working for 1 hour

Power is the energy converted per second, i.e. the rate of work being done. It is measured in watts, where 1 watt = 1 Joule/second.

Head and flow

There are two major parameters to consider when designing a micro-hydro system. These are the available water flow or river discharge and the operating head. The flow is the constantly available river discharge. This will vary depending on the seasonal conditions and requires careful analysis to ascertain the optimal design discharge for a given scheme. The head is the elevation amount drop between the level in the forebay tank and the turbine and remains constant. The greater the head and / or the flow, the more power output can be attained.

Head

Although design and selection of materials for the civil structures and penstock is made to ensure a smooth passage of flow from the intake through to the turbine, some energy losses due to friction and other disturbances in the waterways will occur due to friction.

These losses are usually accounted for in power output calculations by reducing the total head available at the site. The following definitions apply:

Static or gross head: H_g [m] is defined as the difference in the headwater and tailwater elevation. It represents the theoretical head that would be available if no losses occurred.

Effective or net head: H_n [m] is the gross head minus the head losses incurred in the hydraulic system. This represents the actual head available for power generation. The head losses for MHP schemes are usually in the order of 10 % of the gross head.

Flow

Flow or discharge: The design flow Q [m^3/s] will depend on a number of factors specific to the site. These will include what type of MHP scheme is being planned. For example design flow for a stand-alone village electrification project will be different to that of a grid connected scheme. Accurate design flow can only be fixed after a hydrological study has been carried out to ascertain the available stream flow over the course of a full year i.e. covering both wet and dry periods. Careful stream flow measurements are taken at different times of the year and compared. Together with historical rainfall data with care relatively accurate flow estimates can be made. It is also important to consider flood flows when deciding on the design flow.

Potential and kinetic energy in water

Energy can occur in a number of forms. These include potential, kinetic, strain, heat to name a few. Water in a shallow reservoir at the top of a hill possesses greater potential energy than water compounded at the bottom of the hill. If the water is released at the top of the hill through a river, it will lose its potential energy through friction in the riverbed and turbulence.

If the water is channeled down the hill through a pressure pipe, this potential energy is captured and can be “turbinated” (passed through a turbine) to generate mechanical power. Some energy will be lost to friction in the pressure pipe; however, careful design of the pipe will minimize these losses.

The total energy available from the volume of water at the top of the hill is the weight of the water times the vertical distance (head) it can theoretically fall to reach the turbine.

$$E_{pot} = m ´\ g ´\ H$$

with
m = mass of water in kg
g = gravitational acceleration (9.81 m/s^2)
H = head in m

Since the mass of water is volume (V) * density (ρ) we can write:

$$E_{pot} = V ´\ r ´\ g ´\ H$$

Equation 1

Hydropower potential

Power is expressed as energy per unit time

$$P = \frac{V ´\ r ´\ g ´\ H}{t}$$

Since volume per unit time equals flow we can write:

$$P_{hydr} = Q ´\ r ´\ g ´\ H_n$$

Equation 2

with P_{hydr} = **hydraulic power** in Watts [W], not taking into account reductions due to the efficiency of the equipment (turbine, generator etc.)

Q = flow in m^3/s
ρ = density of water = approx. 1000 kg/m^3
g = gravitational acceleration = 9.81 m/^{m2}
H_n = net head in meters [m]

Electric power output

Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of *head* and *flow rate*.

Equation 4 gives the hydraulic power available at the turbine. However, conversion of energy in the turbine - hydraulic into mechanical - and in the generator - mechanical into electrical - always results in some losses being incurred. This is expressed by the term efficiency. This is the ratio between power output and power input (for generation machinery). Thus, the electric output of an MHP scheme can be expressed as follows:

$$P_{el} = P_{hydr} \times \eta_{total}$$ **Equation 3**

or

$$P_{el} = Q \times \rho \times g \times H_n \times \eta_{total}$$ **Equation 4**

with P_{el} = electric power output in [W]

η_{total} = overall efficiency of equipment

η_{total}

Good quality turbines can have hydraulic efficiencies in the range 80 to over 90% (higher than all other prime movers), although this will reduce with size. Micro-hydro systems (<100kW) tend to have efficiencies in the range of 60 to 80%.

Overall or total efficiencies η_{total} of MHP turbines, drive systems and generation facilities (generator, transformer if required) are usually in the order of 50 to 70% excluding losses for electrical transmission from the powerhouse to the load centre.

For very preliminary estimates the following simplified equation can be applied:

Several components in Equation 6 are known:

ρ = density of water = ~ 1000 kg/m^3

g = gravitational acceleration = 9.81 m/s^2

For the overall efficiency η_{total} we may assume 70%, provided that equipment of reasonable quality is installed (otherwise a reduction is required).

Hence the equation can be simplified as follows:

$$P = 7 \times Q \times H \quad \text{[kW]}$$

with $\mu_T \times \rho_W \times g = \frac{70\% \times 1000 \times 9.81}{1000[W \rightarrow kW]} \cong 7$

Site configuration

The following describes the two most common hydropower site configurations and their main layout characteristics. These are:

1. Run-of-river
2. Storage

Run-of-river

Run-of-river schemes are by far the most common type of micro / mini hydropower to be found. Run-of-river schemes do not stop the stream flow but rather divert a portion of it via an intake structure into a conveyance structure. In most cases this will be a headrace channel which channels the water to a forebay / head tank where it enters a pressure pipe and is conveyed under pressure to the turbine. Some schemes are design whereby the flow enters the penstock directly after the intake / settling basin therefore avoiding the need for a headrace channel. Upon exiting the turbine the water is returned to the stream via a tailrace channel.

The diversion weir constructed in the river results in minimum negative impacts to the river as the seasonal flow pattern downstream of the scheme is not affected through the presence of the power plant. In some cases, small reservoirs for daily storage can be integrated into the scheme design. Such facilities allow for covering peak demands over a number of hours.

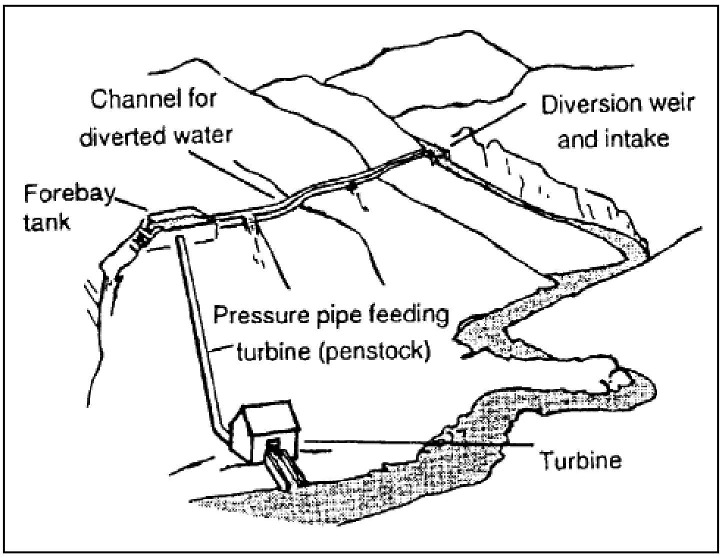


Figure 9: Run-of-river MHP.

Storage systems

Storage systems (mainly featuring large dams) are not relevant in the context of micro / mini hydropower. A storage scheme uses a dam to halt river flow inundating the land upstream of the dam creating a reservoir. The height of the dam will determine how great an area will be inundated and therefore how great the storage capacity of the reservoir will be. Water flow into the turbines is controlled to optimize the plants operation. The ability to store water creates flexibility in the schemes operation. The storage facility can be used for both long (seasonal) and short-term (peak hour) storage of water. Seasonal operation means the reservoir will be filled during the wet season with the stored water carefully released over the course of the dry season to supplement the reduced flow into the reservoir. Peak hour storage means water is collected during the daytime when the plant is not operated and released in large volumes over a relatively short period of time i.e. during peak system load hours. Many large dams are multi functional whereby they supply hydropower plant in combination with supplying irrigation water for agriculture. A common problem with large dams is over time the accumulation of silt upstream of the dam structure. As this builds up the storage capacity of the reservoir diminishes. In many cases it is neither technically nor financially feasible to remove this silt accumulation.

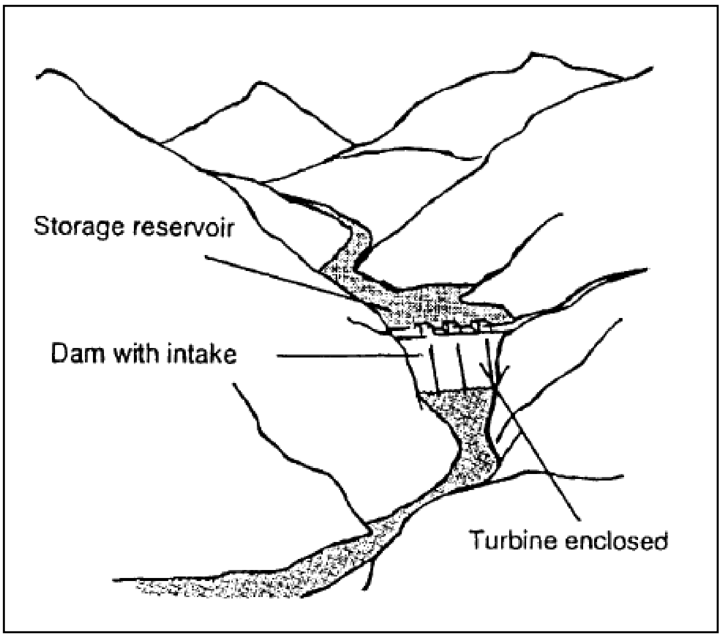


Figure 10: Hydropower scheme with storage in the river.

Pumped-storage plants

Although not relevant in the context of small-scale hydro, pumped-storage plants should be mentioned as a specific type of storage scheme. Pump-storage plants are large-scale power plants (several MW up to several GW)and are designed to “store” generating capacity by pumping water into a higher reservoir during off-peak periods. The stored water is then released to generate power when the grid network requires additional capacity i.e. during peak load periods. These plants are integrated into large grid networks that are supplied by other, more slowly reacting, power plants such as large thermal or nuclear plants. The main advantage of the pumped-storage power plant (and hydropower in general) is that they can be adjusted to the actual demand within a very short period (modern hydropower plants can start-up within less than a minute!).

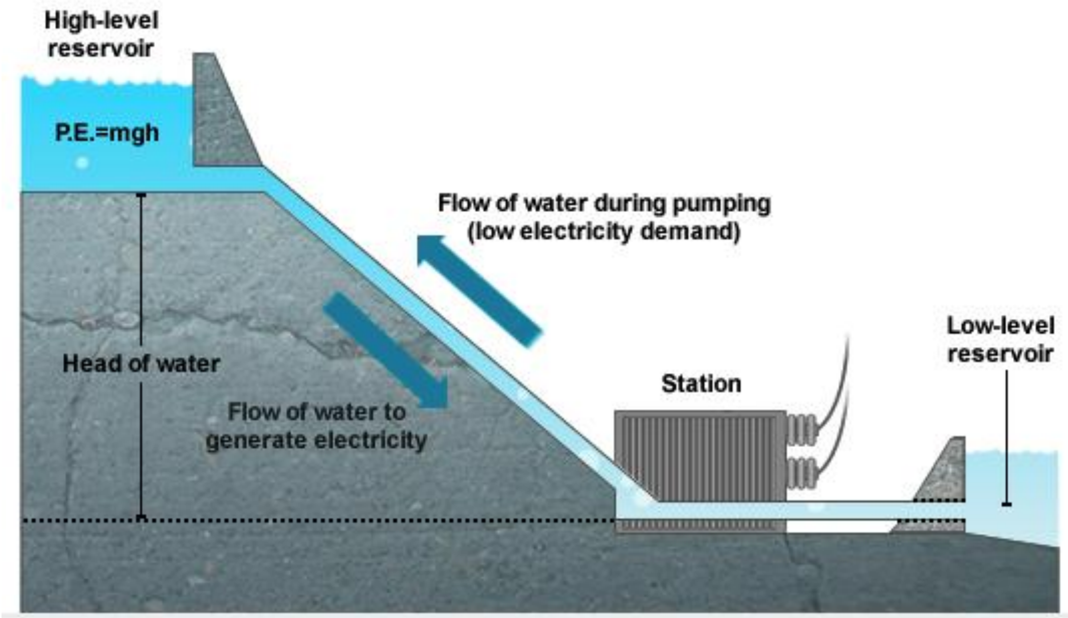


Figure 11: Illustration of a pump storage hydropower scheme.

Although there is no generally accepted definition for low, medium and high head power plants, the following is categorization can is commonly used for small-scale schemes:

• Low head plants	H < 15m
• Medium head plants	H = 15 to 50m
• High head plants	H > 50m

Main systems of a MHP scheme:

An MHP consists of three major systems:

a) the **hydraulic system** (intake, spillway, de-silting chamber, headrace, forebay and penstock)
b) the **generating and control system** (turbine, generator and controller
c) the **load / consumer system** (electrical load appliances)

An aerial overview and plan illustration of a typical MHP are presented in the following figures.

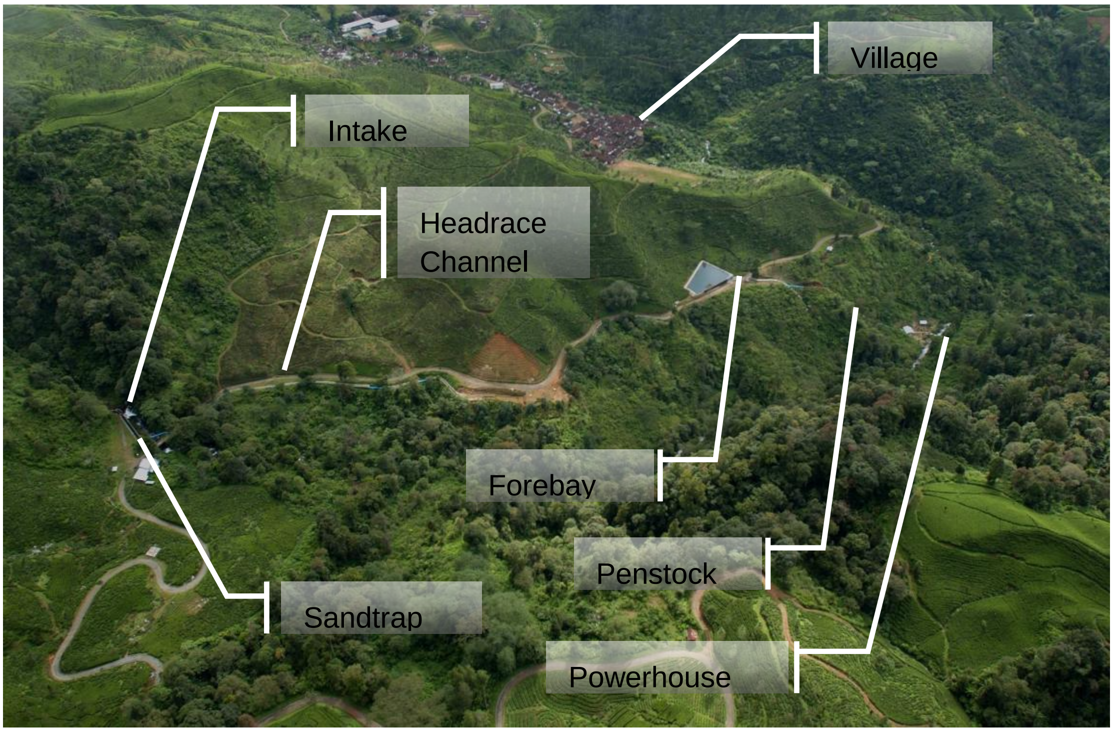


Figure 12: Aerial view of an actual MHP installation showing the main system components.

The principal components visible in this aerial view are the main civil structures, the powerhouse and the load center (village).

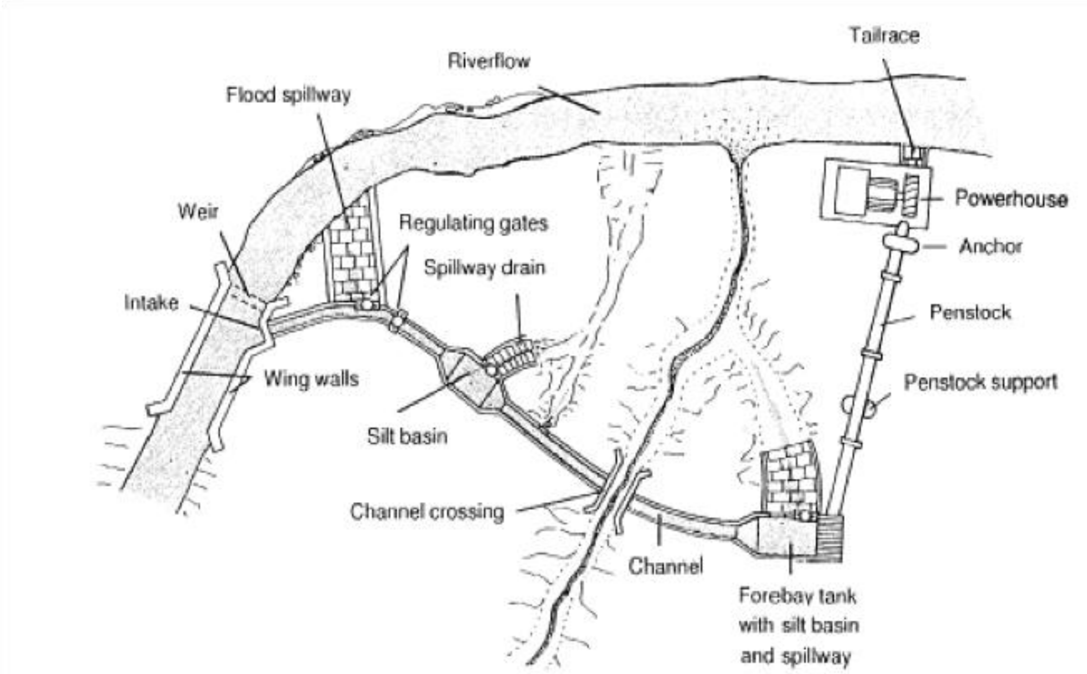


Figure 13: A plan view illustration showing the typical arrangement of a run-of-river MHP.

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present briefly the development in hydropower from the very early installations through to modern day projects. This should include the following:

- Explain what the most common applications were for hydropower using the first turbine types and how these have changed with technological development.
- Explain what defines micro and mini hydropower from large-scale hydropower.
- Explain what the term “run of river” means and what its main characteristics are.

INDIVIDUAL / GROUP PRESENTATION:

Present why small-scale hydropower plays such an important role in the context of rural electrification and community development in developing countries. Describe the main uses of micro hydropower projects in rural villages and describe examples of how access to energy in these environments contributes to improved welfare of the communities.

PRACTICAL ASSIGNMENT:

Calculate the electrical power output for the following site conditions:

- Head (Hn): 25 m
- Flow (Q): 325 l/sec

Calculate the electrical output for other known or imaginary site conditions.

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
What is the simplest type of a MHP?	
Besides electricity, what type of energy can a MHP supply?	
What are the 2 parameters that determine power output of a MHP?	
What is meant by the term "run of river"?	
Why is the purpose of a reservoir for a MHP?	
What is the potential lifetime of a MHP?	
Why are MHP projects popular for isolated villages?	
Why is their a difference between gross and net head ?	

Learning Unit 2: Micro Hydro Components

Topic 1: Civil Structures

The main civil components and their function:

Diversion weir

The diversion weir diverts the required flow from the stream or river through the intake into the water conveyance system of the hydro power plant.

Intake orifice

The intake orifice provides the inlet to the conveyance system.

Intake gate

The intake gate regulates the inflow from the river to the water conveyance system of the power plant. It permits complete shutdown of the flow into the channel. This is required to conduct periodic maintenance and during dangerous flood conditions.

Settling basin / sand trap

The settling basin (or sand trap) is essentially a channel with an enlarged cross section and depth resulting in a lower flow velocity of the water. Due to the reduced flow velocity, gravel, sand and sediments are able to settle to the bottom and therefore don’t enter the headrace channel and more importantly the turbine.

Headrace channel

The headrace channel conveys the design flow of water from the intake to the forebay with a minimum loss of head. Depending on its length it will also contain spillways and pipe bridges where an open channel construction is not possible.

Spillway and spillway channels

Excess water entering the intake is discharged back into the river via spillways situated along the headrace channel and also at the forebay. These spillways are also very important in the case of the water conveyance system getting blocked (for example complete trash rack blockage at the forebay or a landslide over the headrace).

Forebay tank

The forebay forms the transition from the headrace to the penstock. In some cases the forebay is constructed to allow storage for peak power demands and/or to act as a final settling basin. The forebay is equipped with a trash rack and flushing facility.

Penstock

The penstock (or pressure pipe) channels the flow from the forebay to the turbine. Steel pipes are most common, however, PE, PVC, HDPE pipes are becoming more widely used with their increased availability. The penstock is supported by anchor blocks and sliding supports. Expansion joints allow longitudinal expansion of the pipe induced as a result of temperature changes.

Powerhouse

The powerhouse houses the generating and control equipment protecting it and securing it. The powerhouse can also include basic accommodation for the operator.

Tailrace channel

The tailrace channel conveys the water back into the river after passing through the turbine.

This brief summary on civil structures provides introductory information and is aimed at those operating and maintaining micro hydropower plants. It provides descriptions of the main functions and design features of the various components that form a micro hydropower scheme. Module 2 focuses on the maintenance of these structures to ensure sustainable operation and maximum lifespan of the scheme.

This manual is prepared with a focus on hydropower schemes for rural electrification in developing countries with a size of below 200kW. Nevertheless, much of the information provided can be considered valid for schemes of a larger size (mini hydropower) operating in isolated mode, in small hybrid grids or even interconnected to the larger (national) grids where the general layout of the civil components is similar.

It is worth mentioning that fundamental differences exist in the selection of the desired capacity of a scheme depending on the specific application (i.e. stand alone, captive, grid connected, etc.). The selection and feasibility of a certain design capacity is, besides the technical boundaries of the location, mainly an economic consideration. In this context of community based rural electrification projects it is not the primary target to find advanced technical solutions to minimize the operation and maintenance manpower requirements. More often due to limited budgets for the construction, cheaper simpler labor intensive approaches are adopted when compared to similar sized projects built in more developed environments.

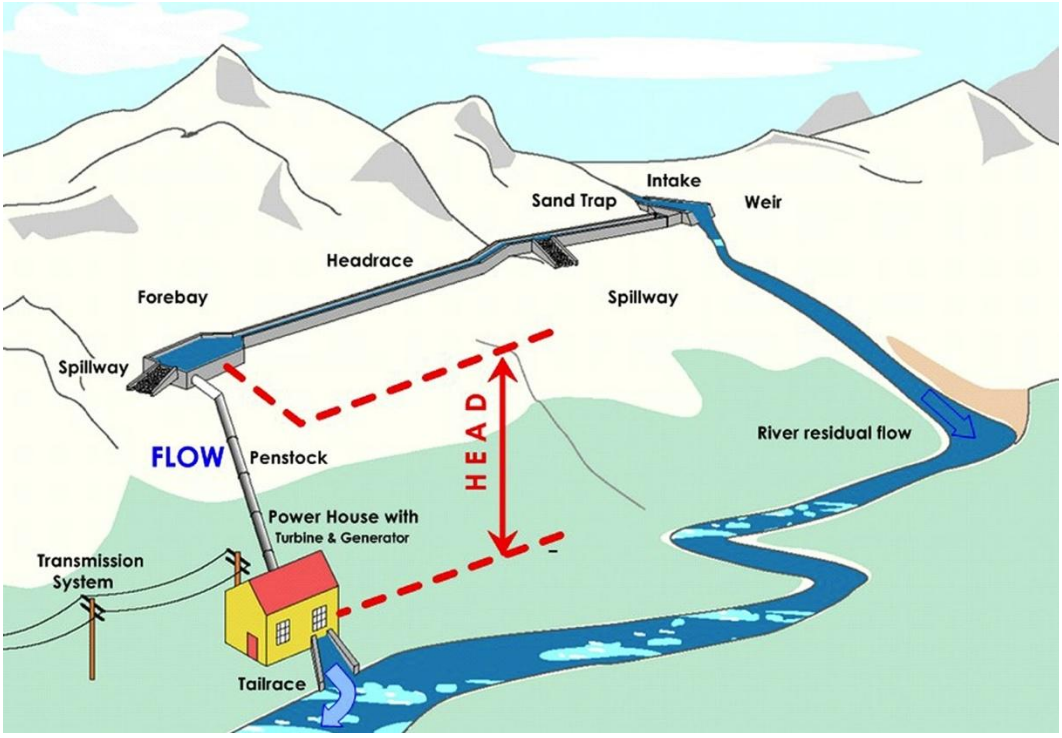


Figure 14: Schematic view of a typical run-of-river mini-hydropower scheme with the main components named.

Diversion weir and intake

The diversion weir redirects part of the stream flow required for power generation from the stream or river through the intake orifice into the water conveyance system of the hydro power plant. Ideally the weir should be located a few meters (2-10) downstream from the intake. If possible it should aim to utilize existing large boulders and rocks to minimize construction and provide additional strength and protection.

The intake is a critical component of every hydropower scheme. It serves as a transition between the river with constantly varying flow conditions, and the headrace channel for which a controlled flow of water in both quality and quantity must always be maintained. The intake must permit a controlled flow of water from the river into the conveyance system to ensure correct operation of the scheme.

An intake gate regulates the inflow and permits the closing off of the flow into the headrace channel. This is necessary when carrying out repairs and maintenance and is also necessary during high flood conditions to protect the civil structures from potential damage.

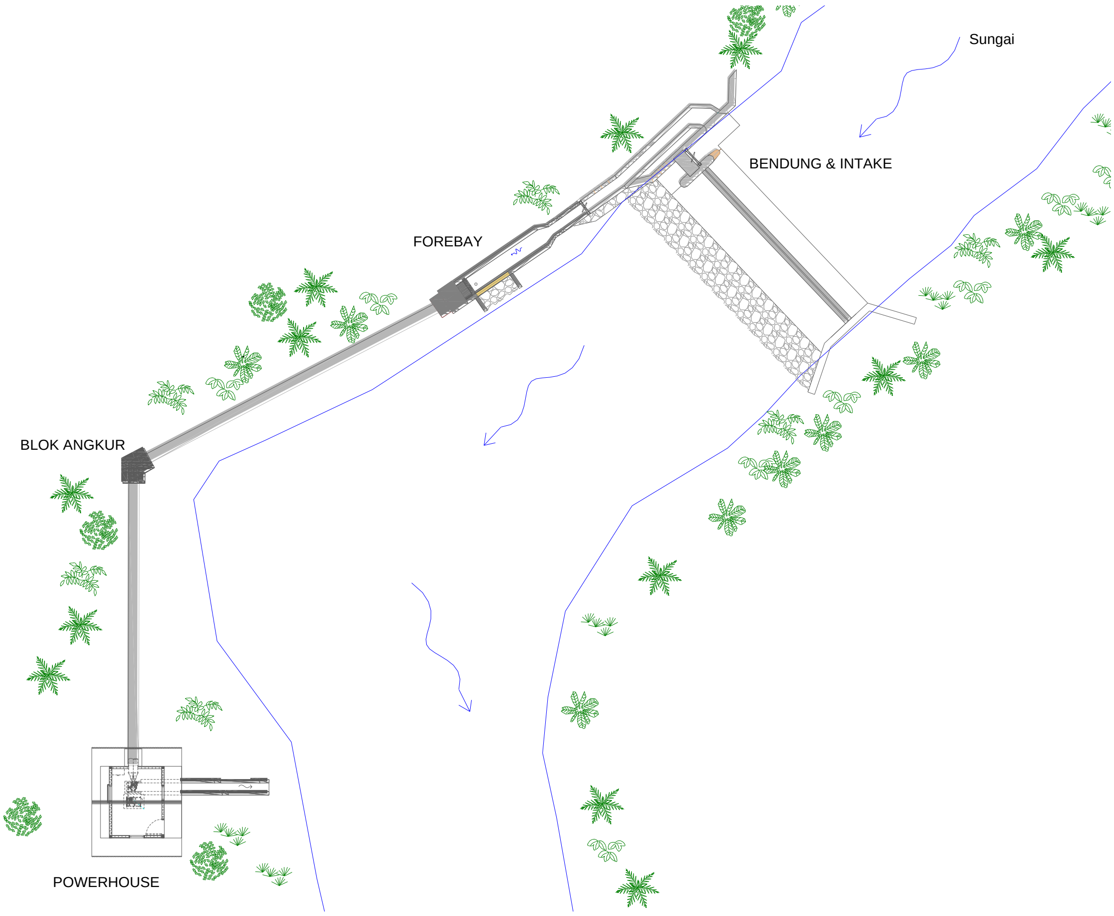


Figure 15: Plan view of a typical weir and intake structure. Note the combined settling basin / forebay tank positioned immediately after the intake enabling early cleaning of the water.

Weirs and intake structures are mostly constructed from stone masonry or concrete. The intake's design requires very careful consideration and due to their critical nature, must be designed by an experienced civil engineer familiar with "wet" civil construction. An incorrectly designed and constructed intake will influence the function and durability of all other downstream components of a scheme and will seriously undermine the performance of a MHP scheme.

Intakes can vary from simple semi natural types utilizing the natural topography and lay of the river to divert flow into a channel to large reinforced concrete / stone masonry structures. Sometimes this can be achieved by simply repositioning large rocks and boulders in the river. Depending on their exact location, the intake can be integrated into the weir construction of represent a separate fully independent structure.

The most appropriate design for a specific site is determined by a number of factors. These include:

- the quality and quantity of water required;
- the flood characteristics of the river;
- the topography and soil conditions at the site;
- the nature of the catchment area;
- whether a weir or a dam is constructed at this site;
- the financial capital available for its construction; and
- the relative capital vs. labor resources available for construction, operation and maintenance of the structure.

To identify the optimal location for an intake the following factors should be carefully considered and assessed:

- natural bends along the river often ease the diverting of the flow into the intake;
- accessibility of the selected intake location, as large amounts of construction materials is required.

One of the basic functions of the intake is to reduce the amount of debris and sediments carried by the incoming water. To achieve this trash racks and skimmers are often necessary. Depending on the water quality, the sand trap / settling basin is sometimes integrated into the design.

Figure 16: A semi natural intake structure whereby the stream flow is diverted to the powerhouse without construction of a weir.

Figure 17: Conventional weir and intake structure.

Controlling the volume of flow in the headrace canal is also an important task. Gates are used to control the flow; however, a spillway allowing surplus water to spill back into the river is also normally required. Controlling the water level at the intake is critical to avoid the risk of excess flows entering the headrace channel. Flooding of the headrace channel can lead to over spilling along the length of the channel and at the forebay triggering landslides with potentially fatal consequences. In particular the channel, penstock and powerhouse are susceptible to serious damage as a result of flooding.

The weir and intake have to be designed for Q_{design}, whereby the maximum calculated flood flow has to be able to pass over the weir without damage to the structure and upstream and downstream adjoining land. For large scale hydro minimum 100year flood levels are used as the basis for weir design. For micro hydropower normally 50yearflood flows are deemed adequate for design purposes.

There are two types of weirs, run-of the-river (conventional) intakes and drop intakes (also known as Tyrolean type intakes).

Conventional intakes are by far the most common and consist of a weir, diverting the useful water into the orifice of the intake. Ideally they are positioned on the outer side close to a bend in the river whereby natural sedimentation will accumulate on the opposite side of the river to the intake due to slower stream flow speed. This helps keep the intake relatively free from sedimentation and reduces the risk of material entering the channel through the intake orifice.

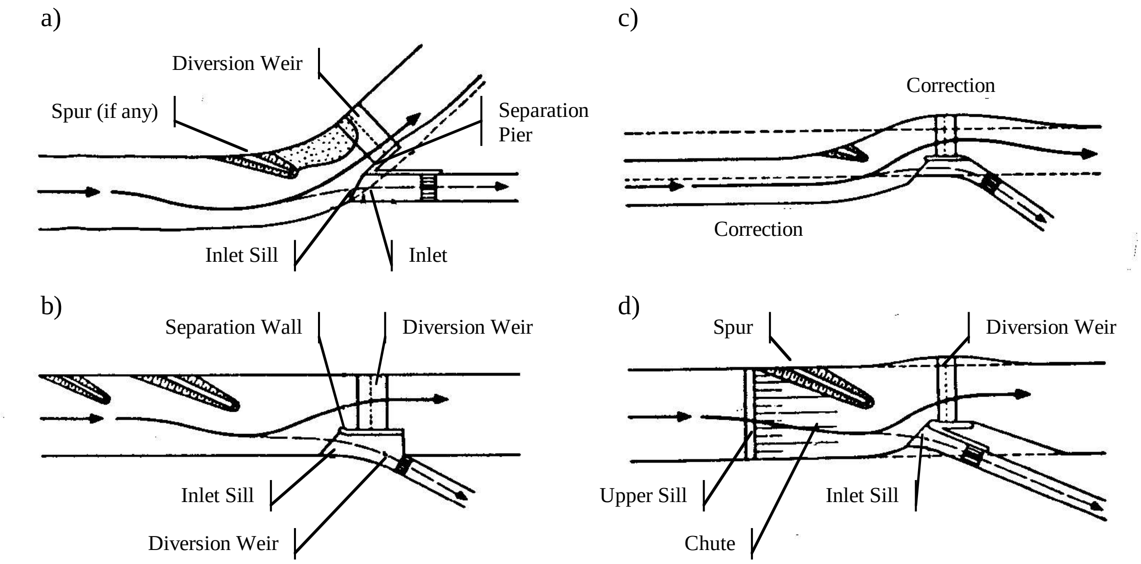


Figure 18: Typical layouts for the intake a) in bends, b), c), d) on straight stretches

Drop intakes placed literally across a river or creek. They are mostly used in narrow gorges where the river has a relatively steep decline. They require a strong foundation on which to place the intake structure. Drop intakes are particularly well suited for locations in steep terrains where sacrificing some of the available head for the purpose of the intake is not critical. Due to their self cleaning characteristics they are also suitable where access to the intake is difficult.

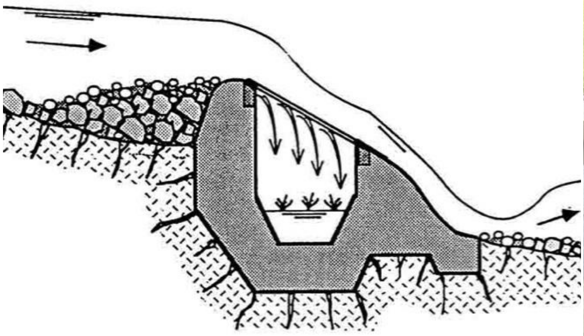


Figure 19: Cross section of a drop intake.

Figure 20: Drop intake transition from open channel to underground pipe.

The main components of a drop intake are:

- A forebay excavated in rock to produce more regular and turbulence free flow on the rack.
- Two openings with slots that can be closed with stop logs, on the right side of the intake; the logs can easily be taken out if necessary for cleaning the forebay or the rack.
- An intake opening with stop logs permitting the closure of the intake.
- A service footbridge.
- Stairs on both sides of the opening.
- A trash rack with a 70 % slope (for Qdesign < 3.5 m3/s)

Figure 21: Typical stone masonry weir and intake structure.

Figure 22: Weir and intake view from slightly upstream. The intake orifice is visible just above the water level.

Figure 23: Less conventional weir structure. The weir is partly concrete and partly created with stop logs. This enables thorough flushing upstream of the weir.

Figure 24: Combined concrete and stop log weir construction.

Sandtrap / Settling basin

Depending on the quality of water and the operating head and subsequent pressures inflicted on the turbine, a sand trap / settling basin of some type will be required.

The settling basin should be positioned at a safe place and as close to the intake as possible to reduce the distance gravel and debris being conveyed along the channel. This will help minimize maintenance. As a general rule it should be designed to enable the settling of particles of 0.3 mm size.

There are numerous factors that need to be considered in designing and positioning the sand trap / settling basin of a scheme. Ideally the sand trap is positioned as close as possible to the intake. This ensures that the unwanted material (i.e. the amount of sand and other particles carried with the water) entering the conveyance system via the intake is captured and removed as early as possible thus reducing any negative impacts it has on the operation and maintenance of the scheme.

Figure 25: Parallel settling basins located immediately after the intake.

Figure 26: Example of a setup with 2 parallel settling basins enabling scouring to take place without the need to shut down the plant.

A properly dimensioned and positioned sand trap will reduce the unwanted material from settling along the headrace channel and entering the penstock where it can adversely affect the lifespan of the turbine and penstock due to its abrasive nature. To what extent this material can inflict damage on the turbine and penstock will depend on the size and hardness of the particles and the pressure (head) under which they pass through the pressure system.

To enable the sand / grit particles to settle in the basin, the flow velocity of the water passing through the structure has to be reduced to a specific velocity whereby they have time to sink to the bottom of the vessel. Standard formulas can be used to calculate the cross sectional area and length of the basin necessary to ensure the correct speed of flow is attained.

The accumulated sediment in a settling basin must be regularly emptied. This is carried out by flushing via a scouring facility / gate usually back into the river. Depending on the specific design of the settling basin, a trash rack and spillway will be often be integrated into the structure. Positioned soon after the intake and as close as possible to the river helps facilitate easy flushing and spilling of excess flow.

In some circumstances settling basins are constructed in tandem. This enables them to be flushed individually without the need to close the power plant down during flushing. This is an important consideration for schemes where draining the hydraulic structures entirely represents a major operation. For low cost micro hydro installations, however, this is rarely the case due to cost restrictions.

In very compact hydropower plants where it deemed unnecessary to have an independent settling basin, an enlarged forebay tank doubles up as a settling facility (see forebay tank section). This approach is perfectly acceptable on schemes where the head is relatively low (< 30m), the suspended material in the water is not overly abrasive and the type of turbine used is resilient to such water conditions (e.g. cross flow turbine type).

Figure 27: Conventional settling basin with a spillway over its full length. A pipe bridge exit to leading to headrace is visible.

Figure 28: Recently constructed combined forebay / settling basin for a micro hydropower installation.

Headrace Channel

The headrace channels function is to convey the required volume of water from the intake to the forebay with minimum head losses incurred.

The headrace should aim to follow stable level ground wherever possible and be as short as is technically viable whilst keeping head losses to a minimum. Where the terrain is deemed too precarious for the construction of an open channel, a headrace pipe can be considered as an alternative (HDPE for example).

Headrace channels for micro and mini hydropower projects are normally constructed from stone masonry and / or concrete. For very small low cost schemes alternative materials depending on availability are also used such as timber, PVC pipe, and unlined earth channels. The selection of material is often dictated by cost limitations. The headrace channel can often represent a significant portion of the civil works cost. The type of material used will dictate the cross-sectional profile of a headrace as each material will have its own maximum permissible water velocities. For example earth channels require the water to travel very slowly to avoid erosion whereas concrete channels can withstand relatively high water velocities travelling through them. Permissible velocities range between 0.40 m/s for unlined earth channels up to 4.50 m/s for concrete flumes. It should also be noted that the higher the velocity the less sedimentation will occur along the headrace.

When selecting headrace material it is important to consider the implications it will have on operation and maintenance demands. A concrete channel if properly constructed should require almost no maintenance whereas a stone masonry construction will require periodic repair and maintenance.

Figure 29: Low cost unlined earth headrace channel. Such a channel is only suitable for very small flows.

Figure 30: Trapezium shaped concrete lined channel.

The headrace channel has to be designed in accordance with the natural topography of the site. In general the channel will attempt to follow the natural contours of the land whilst maintaining a gradual slope of approximately of 0.0012 m over a length of 1 m(12 cm per 100 m length of channel).

For relatively long headrace channels it is necessary to equip the channel with spillways along its length. Although the desired amount of flow should be controlled at the intake, in the event of too much water entering the channel due to flood conditions or in the event of a landslide blocking the channel, it must be possible for the excess flow to spill back to the river safely and not overflow indiscriminately causing landslides.

Figure 31: Ariel view of stone masonry headrace channel with spillway and pipe bridge visible.

Figure 32: Stone masonry headrace channel in operation.

Forebay Tank

The forebay tank also commonly referred to as the head pond forms the transition between the non-pressure and pressure systems of a hydropower scheme or more specifically the headrace channel and the penstock pipe. The forebay serves the following important functions:

- Facilitates a smooth constant flow of water into the penstock pipe
- Blocks the entry of any foreign elements into the penstock pipe
- Allows final sedimentation to take place (the forebay can be the primary or secondary sedimentation facility)
- In some situations can provide storage for short periods
- Facilitates the spilling of the water back to the source as a result of excess flow travelling down the headrace or due to the turbine valve being closed

In some cases the forebay is combined with a small storage pond. This facilitates running of the power plant with a greater flow than is actually available in the river at that time. The greater the volume of storage capacity the longer the scheme can operate in this way. This facilitates very efficient operation of a scheme where the daily load curve experiences relatively short peak periods (e.g. tea factories where they require a relatively high power supply at specific times of the day). During such periods the storage outflow can be larger than the inflow. When the power demand reduces the outflow becomes smaller than the inflow, the storage will be naturally replenished.

Figure 33: Forebay tank with spillway, trash rack (submerged) and flushing gate.

Figure 34: Large forebay / storage tank enabling the plant to supply power in excess of stream flow capacity for limited (peak load) periods.

Depending on the range of functions required, the design of the forebay will vary somewhat. The following illustrations show the common features integrated into most forebay tank designs.

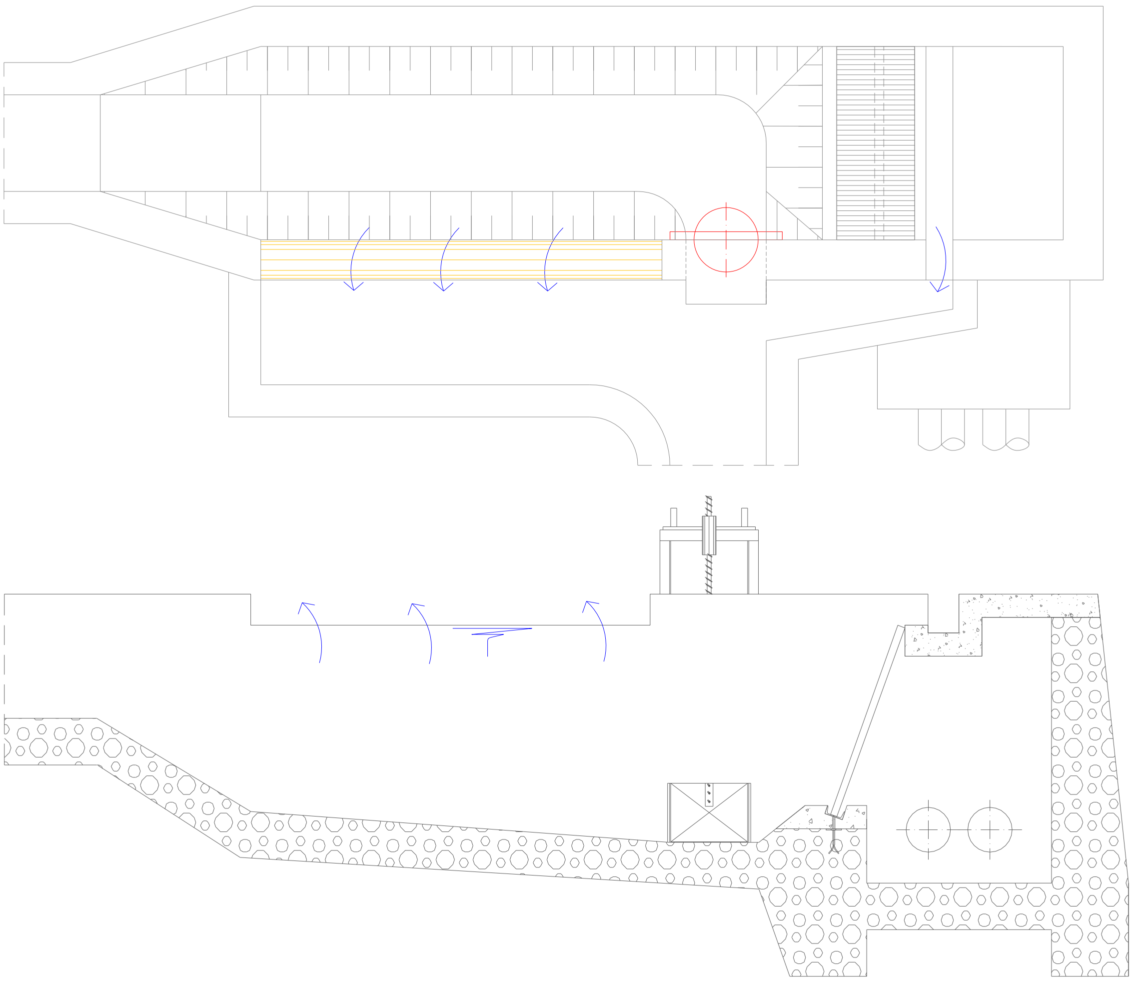


Figure 35: Plan and section view of a typical forebay tank showing main features

For schemes with relatively short headrace channels the forebay can be usually be combined with the settling basin. The forebay must be positioned where it is possible to construct a spillway that it capable of channeling the full operating flow safely back to the source in the event of the supply to the turbine being closed off.

Trash rack

The trash rack carries out the final straining of the water before it enters the penstock and subsequently the turbine. The obvious importance of not permitting foreign objects into the turbine means that the dimensioning of the trash rack is critical. Normally the trash rack comprises of vertical steel bars spaced at approximately 1 cm distance with a number of horizontal supports placed over its length. The rack must of a robust construction to be able to withstand the weight of water acting upon it in situations when the trash rack is clogged and it has to withstand the full pressure of the water acting on it. The rack is positioned at an angle of 60 -80 degrees.

Figure 36: View of trash rack positioned in settling basin.

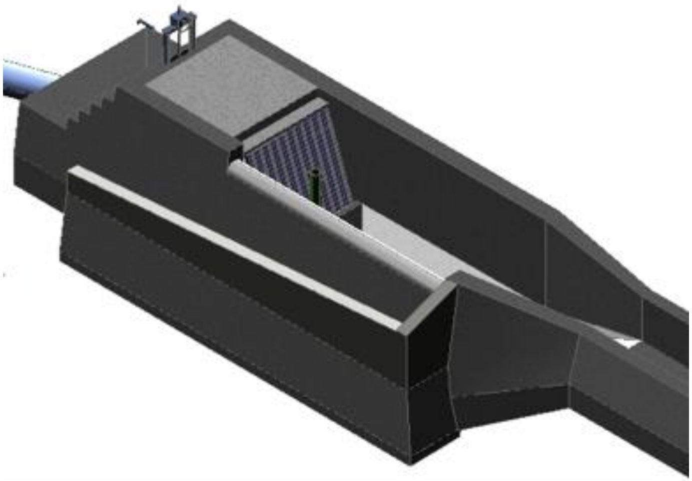


Figure 37: Schematic overview of a typical forebay tank showing spillway, trash rack and penstock.

Attention must also be paid to providing adequate access to the trash rack to facilitate easy cleaning. A facility for disposing of the debris once removed from the rack must also be provided.

A clean properly dimensioned trash rack is crucial to the operation of a scheme. A blocked trash rack will result in air entering the pressure system, a situation that can have potentially damaging effects on the scheme.

Figure 38: A good example of a properly made trash rack from 1cm steel flat bar in operation – keeping unwanted visitors out!.

Figure 39: Submerged trash rack in forebay. A self-cleaning effect is created with the excess flow taking floating debris over the spillway.

Penstock Pipe

The penstock pipe conveys the water under pressure from the forebay tank to the turbine in the powerhouse. Ideally the penstock should be kept as short as possible to minimize the head losses incurred through the waters passage down the pipe.

The penstock should be kept as short and as straight as possible to minimize head losses. It must be securely anchored to be able to withstand both the weight and pressure acting upon it. It can be erected either above or below ground, however, if the pipe is buried it will need to be adequately protected against corrosion. The pipe material must be able to resist the static pressure plus an additional 50% increase in pressure which can be induced through the “water hammer” effect. Usually steel pipes are used, which offer the highest technical and maintenance advantages. Most steel penstocks are installed above ground facilitating easy maintenance. PVC pipes ideally should be buried to protect them from direct sunlight. PVC penstocks have increased in popularity for low cost installations and particularly where operating heads are relatively low.

The penstock route must be drained properly to prevent the anchors and sliding blocks from scouring.

Figure 40: Typical above ground spiral welded steel penstock pipe. Anchor blocks and supports clearly visible.

Figure 41: Flanged cast iron penstock pipe suspended above ground on concrete supports.

Anchor blocks and supports

Above ground penstocks require anchor blocks to be positioned at specific points along their length to secure the pipe from forces induced as a result of the pressure within the pipe. They are required at each bend in the pipe and at approximately every 30-40m of straight pipe sections depending on the size of the pipe and the head of the scheme.

Penstock supports are also required at regular intervals between the anchor blocks and prevent the penstock from bending under the weight of the water and the pipe. They should allow for forward and reverse movement of the pipe but should prevent any lateral movements.

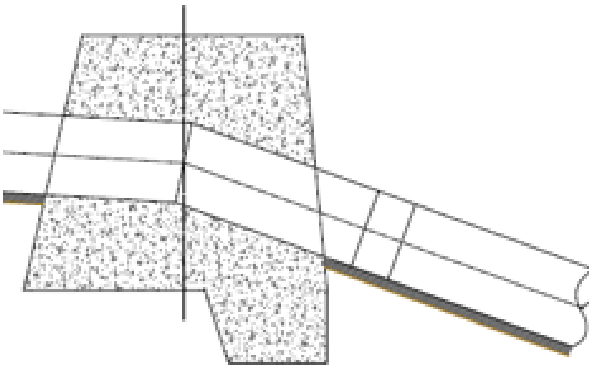


Figure 42: Figure 43 Section view of a typical penstock anchor block.

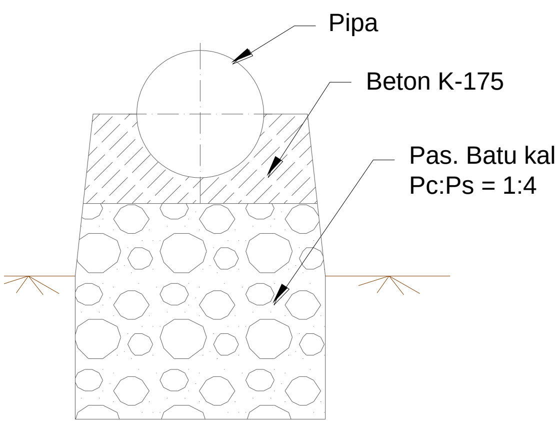


Figure 44: Section view of a penstock sliding support.

Figure 45: Twin steel penstock pipes and anchor blocks before entry into the powerhouse.

Figure 46: PVC penstock pipe installed on a low cost community based MHP.

Expansion joints

Expansion are joints are required for above ground mounted steel penstocks where as a result of thermal expansion the pipe expands and contracts depending on the temperature. These temperature variations can be substantial especially when the pipe is empty and exposed to direct sunlight compared with when operating and full of water. Without suitable expansion joints fitted the risk that its connection to the forebay will crack resulting in leakage. Anchor blocks can also crack under the pressure of expansion.

The most common type of expansion joints are the mechanical sliding type. These must be fitted downstream of each anchor block therefore providing an expansion facility for each section of pipe between its anchor points. This means for long penstocks multiple expansion joints will be necessary.

Figure 47: Expansion joint fitted correctly immediately after a anchor block.

Figure 48: The most common type of joint is the mechanical sliding type pictured here.

Where penstocks are buried there is no requirement for fitting expansion joints as the temperature variations are negligible.

Penstock valves

Valves are used to regulate the flow of through the penstock. For very low cost schemes they are often not included due to their relatively high cost. Nevertheless the inclusion of a valve in the penstock makes operation and control of the scheme more convenient. There are two main types of valve used:

1. Gate valve
2. Butterfly valve

The most common type used is gate valves due to their significantly lower price.

Ideally a stop valve should be placed at the lower end of the penstock enabling the turbine to be fully isolated when the valve is closed.

Where a valve is installed at the top of the penstock[2], care need to be taken when closing the valve so as not to create a vacuum in the penstock as the water drains. To permit air to enter the penstock during emptying and exit during filling, the penstock must be fitted with a ventilation / breather pipe at or close to the top of the penstock.

Figure 49: Ventilation / breather pipe at the upper end of the penstock enabling air to exit and enter the pipe during filling and emptying.

Figure 50: Typical penstock valve / gate positioned in the forebay.

[2] For small-scale low cost projects, fitting a valve at the top of the penstock is the most common approach as it represents a simple and cost effective method of being able to close the scheme down. When fitted at the top of the penstock, the valve is sometimes substituted with a simple fabricated gate. This is possible because the pressure acting upon it at the top of the penstock is relatively small and if properly fabricated and fitted leakage through the gate is minimal therefore it is still possible to seal off flow into the penstock.

Powerhouse& Tailrace

Powerhouse

The powerhouse houses the turbines, the generators and other electro-mechanical equipment of the plant and must be capable of protecting the equipment from all possible weather conditions. Depending on the individual scheme size, location and type of operation it can also include accommodation facilities for operators and a small office / workshop if necessary. However, for very simple low cost schemes located relatively close to the load center, the powerhouse is usually a very simple construction housing only the electro-mechanical equipment. It can be constructed from bricks or timber or a combination of both. It should be dimensioned large enough to facilitate convenient operation and maintenance of the equipment. It must be properly ventilated to allow the heat to disperse effectively. If the scheme is fitted with an ELC, ideally the ballast load should be mounted on the outside of the powerhouse. If, however, for particular reasons the ballast is mounted inside the powerhouse then the adequate ventilation is essential to ensure the powerhouse doesn't overheat.

Positioning of the powerhouse is a critical decision when designing a scheme. It must be located safely above the maximum flood level of the river on level ground and a not exposed to potential landslides. Where deemed necessary it can also be positioned a distance inland from the river to provide additional safety from river flood flows.

Figure 51: Simple powerhouse construction with double door for easy access of equipment.

Figure 52: Typical powerhouse and tailrace situated alongside an irrigation channel.

Tailrace

The tailrace conveys the water exiting the turbine back to the source river and depending on the location of the powerhouse will vary in length. For micro hydropower schemes, however, it is normally relatively short. It is important to keep the tailrace as straight as possible to ensure fluent flow of the water back to the river.

Figure 53: View from riverbank of penstock, powerhouse and straight tailrace returning the water to its original source.

Figure 54: Double level powerhouse and tailrace. As flood protection the powerhouse is positioned well away from the river.

Design and construction of the tailrace channel is similar to that of the headrace and most commonly constructed from stone masonry.

Learning Unit Assignments:

ASSIGNMENT / PRACTICAL:

Sketch a typical “run of river” type micro hydropower installation with an operating head of 20m and having a headrace channel 100m long. On the sketch show all the main the civil structures. For each of the components illustrated on the sketch, list 3 functions.

INDIVIDUAL / GROUP PRESENTATION:

The intake is a critical component of a scheme. Present examples of 2 approaches to construction of an intake for a run of river scheme. This presentation should explain the reasons behind:

- Design type
- Position of intake
- Chosen material of structure

Describe the biggest danger posed to an intake structure and also list 3 effects of a poorly design intake.

PRACTICAL DEMONSTRATION:

Conduct an onsite tour of an existing MHP scheme describing each of the civil components to the rest of the group highlighting areas where you think there are mistakes in the design / construction and how you would propose to improve the overall design.

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
Where is an intake located?	
Why is it necessary to have an intake?	
What is the function of the weir at intake?	
What does the headrace channel do?	
Is it possible to have an MHP without a headrace channel?	
What needs to be considered when positioning the powerhouse?	
Why is it necessary to have a trash rack?	
What material is normally used for a trash rack?	

Topic 2: Electro-Mechanical Equipment

The electro-mechanical equipment is that used to convert the energy of the water into electricity. This equipment comprises of the following main components:

Turbine

The turbine converts the potential energy in the pressurized water into mechanical or shaft power. Where this shaft power is used to drive a generator, electricity is generated. The turbine is connected either directly to the generator or via a mechanical step-up transmission. This is usually by means of a conventional belt and pulley arrangement or gearbox depending on the speed required for the generator and the size of the scheme. The choice of turbine type depends on the head and the design flow of the proposed installation. Turbine performance is sensitive to operating conditions. They perform at optimum efficiency only under specific head and flow conditions.

There are 2 main categories of turbine types. These are:

1. Impulse Turbines
2. Reaction Turbines

Impulse Turbines

There are 3 main types of impulse turbines. These are:

1) Pelton
2) Turgo
3) Crossflow.

These turbines are used for medium and high head applications. Impulse turbines have a number of distinct advantages over reactions turbines for small-scale micro hydro installations. They are easier to fabricate and maintain without the need for large sophisticated machine shop tools. They are less sensitive to cavitation and slight variations in operating conditions and have flatter efficiency curves therefore creating a wider application range. In particular the cross flow turbine is very suitable for mid range head conditions (15m – 75m) and is by far the easiest turbine to manufacture hence its widespread application for micro hydropower rural electrification projects.

The crossflow turbine (or sometimes called the Banki or Ossberger turbine) developed by the Australian Anthony Michell, the Hungarian Donát Bánki and the German Fritz Ossberger. Michell obtained patents for his turbine design in 1903, and the manufacturing company Weymouth made it for many years. Ossberger's first patent was granted in 1933.

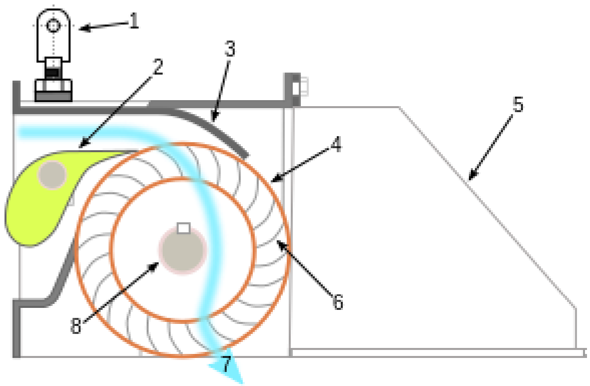


Figure 55: Cross sectional view of a cross flow turbine showing the runner, guide vane / valve and housing.

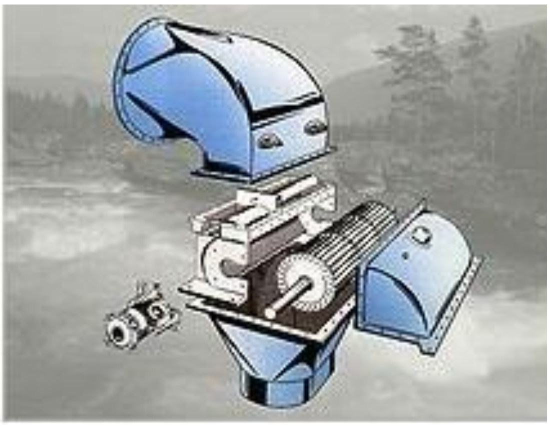


Figure 56: Exploded view of a Ossberger crossflow turbine illustrating the main components

The kinetic energy of the flow is converted into rotational mechanical energy. The jet is in contact with only a part of the runner for a certain period of time.

The turbine geometry (nozzle-runner-shaft) ensures that the water jet is effective. The water inflicts energy onto the runner twice, once when entering the runner and again when exiting the runner. Approximately 2/3 of the power is transferred on the initial pass with the remaining 1/3 of the power transferred to the runner when the water exits the runner.

Figure 57: Typical cross flow turbine installation.

Figure 58: Pelton turbine undergoing maintenance.

The main disadvantage of impulse turbines is they are not suitable for low head-high flow conditions.

Reaction Turbines

There are 2 main types of reaction turbines commonly used. These are:

1) Francis
2) Propeller

The francis turbine is the most common type of reaction turbine in use due to its relatively wide application range. It is used on schemes with both high and low head depending on the flow conditions. It is, however, rarely used on micro hydropower schemes due to its complex construction. It's complicated design and sophisticated fabrication requirements mean that is cannot be produced by small-scale fabrication workshops of the type capable of producing cross flow and pelton turbines.

Figure 59: A horizontal shaft francis turbine.

Figure 60: A francis turbine runner.

There are a variety of types of propeller turbine ranging from the very simple fixed runner blade and guide vane type to the sophisticated Kaplan turbine where both can be adjusted.

The most common type of propeller used on micro hydropower schemes is the vertical shaft open flume type. These types have an adjustable guide vane and a fixed runner blade. Some fixed blade types do allow for the manual setting of the runner blade angle (e.g. they a number of positions suitable for different flow conditions i.e. high / low flow conditions).

Figure 61: Locally manufactured twin propeller turbines operating on a low head scheme. The guide vanes (visible) are adjusted by a flow control device.

Figure 62: Locally manufactured propeller turbine.

Mechanical transmission

The mechanical transmission (or drive system) transmits the rotational power from the turbine to the required application. For the production of electricity this will be an electrical generator (most common application) and for mechanical drive applications this could be a grain mill, husker, coffee grinder, etc.

In order to generate electrical power at a stable voltage and frequency, the drive system needs to transmit power from the turbine to the generator shaft in the required direction and at the required speed. Where the speed of the turbine is not compatible with the speed of the generator (commonly 1000 or 1500 rpm), a step-up transmission is required. The most typical step-up drive systems for micro-hydropower installations are V and flat belt drives. Gearboxes are rarely used for small-scale schemes due to their high cost and their relatively complex maintenance requirements.

Belt drive

Modern synthetic flat belts are capable of transmitting up to 500 kW of power at optimum efficiency (0.96 to 0.98). Gearing ratios can go up to 5 for flat belts.

V-belts are readily available and a major advantage over flat belts is that they do not require such precise alignment of the machinery compared. This can be a major factor where maintenance resources and skilled manpower are limited. They are, however, only suitable for relatively small power outputs (<30 kW) and due to their limited power transmission capacities.

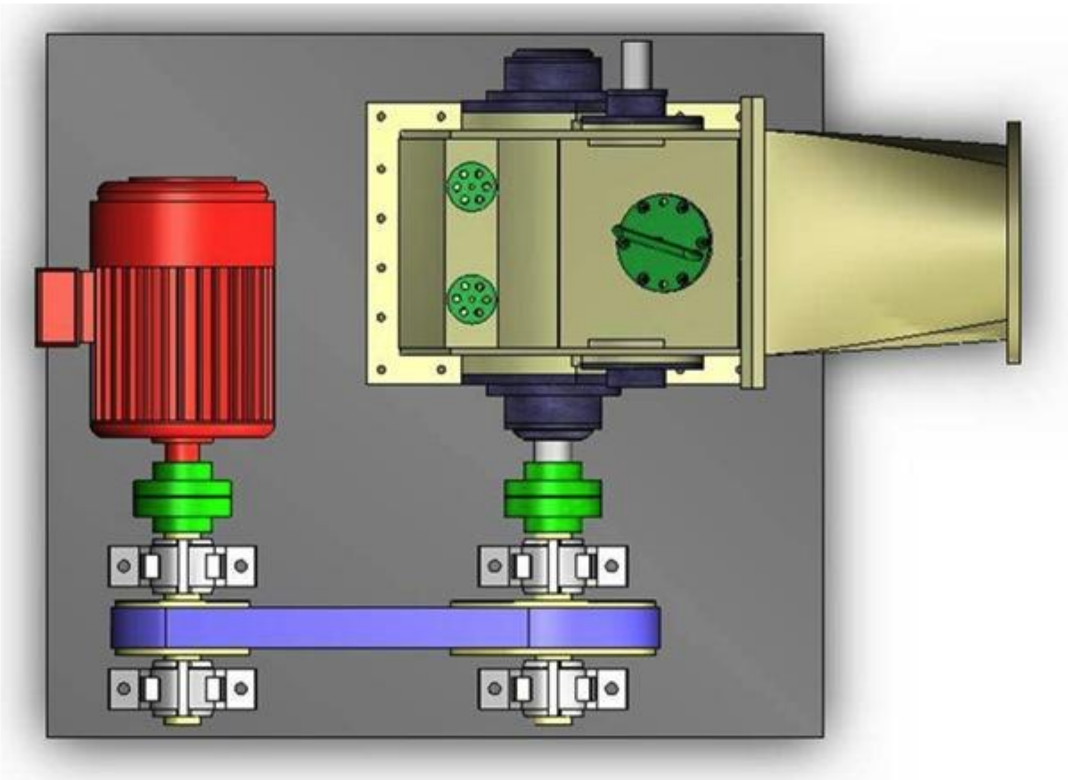


Figure 63: Schematic view of a conventional belt drive step-up transmission commonly used for micro hydropower installations.

Figure 64:Flat belt transmission arrangement.

Figure 65:V belt transmission arrangement.

For higher power ranges and gearing ratios, gearboxes are used. These require less space than flat belts but are expensive and maintenance intensive (oil change, alignment, wear and eventual replacement of bearing and gears).

Direct Drive

Where the speed of the turbine can be matched to that of a standard generator speed, direct drive can be used. This is usually only possible on relatively high head schemes where the high pressure results in rotational speed of the turbine reaching levels close to that of the standard nominal speed of generators. For large hydro schemes customized generators can be ordered having unconventional speeds (750 rpm for example), however, this approach is not viable for micro hydro projects due to the cost implications.

There are 2 possibilities for direct drive transmission. These are:

1. Direct drive from shaft to shaft via a coupling
2. Direct drive from shaft to shaft via a intermediary shaft and coupling

The shaft-to-shaft option is only possible for relatively small power outputs where the torque levels on the turbine shaft remain within acceptable limits.

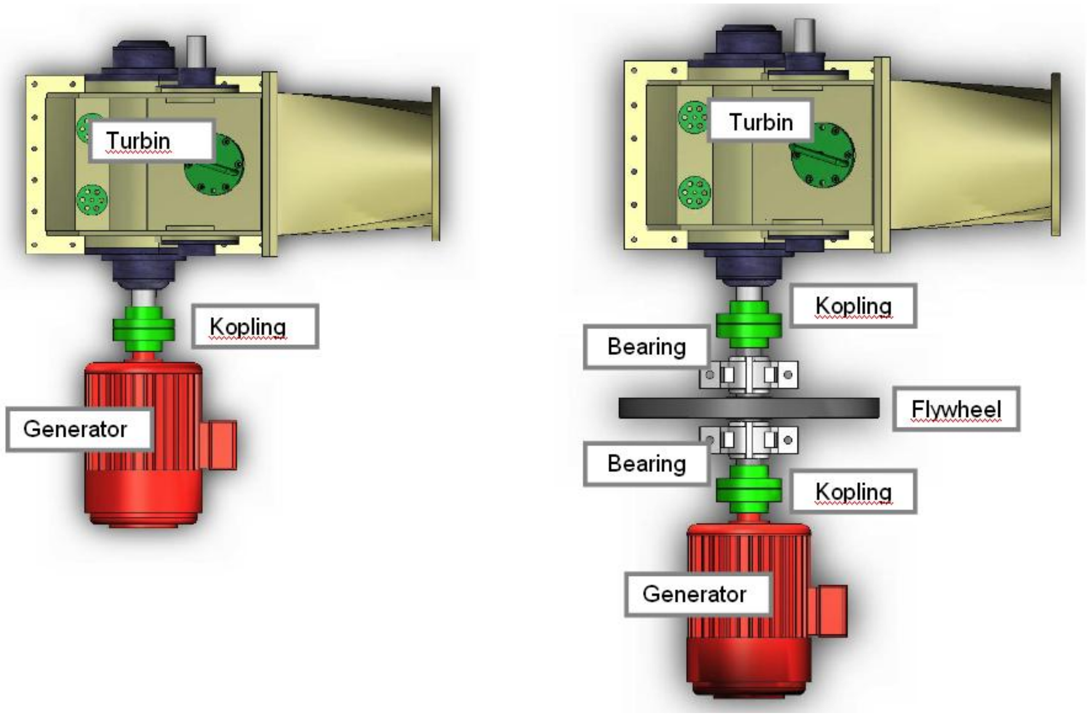


Figure 66: Schematic view of 2 direct drive transmissions used for micro hydropower installations. The first shows the turbine directly coupled to the generator shaft via a coupling. The 2nd shows the integration of a intermediary driveshaft, coupling and flywheel assembly into the transmission.

Flywheel

A flywheel is a rotating mechanical device that is used to store rotational energy. Flywheels have a significant moment of inertia, and thus resist changes in rotational speed. Depending on the type of control system adopted a flywheel may be necessary to ensure smooth operation of the power plant.

Figure 67: Shaft-to-shaft direct drive transmission. In this installation a flywheel is positioned on the far end of the generator.

Figure 68: Shaft-to-shaft direct drive arrangement. This scheme does not have a flywheel as it is controlled with an ELC.

Pulleys and Coupling

Pulleys and couplings transmit power from one shaft to another. The size of the coupling and coupling shaft are dimensioned according to the power (or Torque) to be transmitted. The most common type of couplings used in micro hydropower projects are flexible couplings. Proper alignment of couplings is critical to their lifetime and requires skilled manpower and the correct equipment.

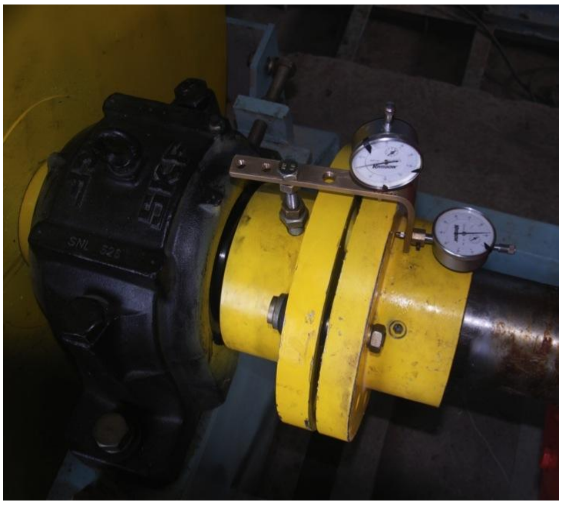


Figure 69: Typical flexible coupling being aligned using a dial test indicator gauges.

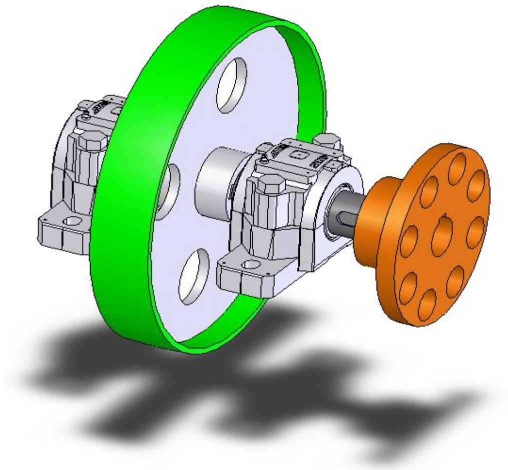


Figure 70: Schematic view of a typical flat belt pulley and coupling arrangement.

Cast iron V belt pulleys are normally easily available in standard diameters and belt section sizes. This means achieving the necessary step up ratio is possible to achieve the correct turbine and generator speed. For flat belts, the pulleys must be fabricated. It is critical that the profile on the pulley is machined exactly as per the belt supplier's specifications to ensure the maximum belt efficiency is reached.

Figure 71: Typical drive belt arrangement showing V belt drive via a secondary lay-shaft with flexible coupling connecting to the generator.

Figure 72: A high efficiency flat belt drive. The step-up ratio is high indicating low head / speed.

Generator

The generator converts the mechanical (rotational) power from the turbine into electricity.

There are 2 types of generator, synchronous and asynchronous (induction). Details of the available options within these 2 categories are as follows:

1. Synchronous Generators
    a. Brushless synchronous
    b. Brush type synchronous

2. Asynchronous Generators
    a. Induction Motors used as Generators (IMAG) – *stand alone MHP*
    b. Asynchronous – *grid-connected MHP*

1a. Synchronous brushless generator

Modern or larger generators use a set of rotating diodes to energize the magnetic field without wear of brushes. The excitation machine is integrated in the generator for smaller outputs (up to 1MW) or external for lager generators.

All brushless synchronous generators posses an automatic voltage controller (AVR). The AVR controls the voltage in a certain range of frequency and load. Normally operating parameters can be adjusted by potentiometers on the board. For grid connection the voltage setting can often be made with an external potentiometer in the controller panel. This is required for the synchronizing process itself and for fine tuning the power factor during grid connection.

- Widely used in most forms of power generation (diesel, gas, hydro, etc.)
- Very good efficiency characteristics (>85%)
- Available in a wide range of sizes from 3 kW - 1000 MW from many different manufacturers
- Modern generators are brushless and provided with Automatic Voltage Regulator (AVR)
- Simple in operation and maintenance
- Standard industrial types cannot withstand overspeed for extended periods

1b. Synchronous brush type generator

In the present day only used in very small and/or cheap generators. An excitation generator is integrated to the synchronous generator and brushes are used to transfer and control the excitation current. These generators need permanent supervision and exchange of the brushes in regular intervals. There is as well wear of the slip rings and refurbishment may be required after some years. It is very important to have spare brushes available.

- normally made in China
- very cheap 40 - 60 USD / kW
- frequent replacement of the brushes is required (6 - 12 months)
- manual voltage regulation / sometimes no regulation facility

- low efficiency <80%
- not very reliable (problems with bearings, windings, rectifier etc.)

2a. Induction Motor As Generator (IMAG) - for standalone MHP

For very small output stand alone MHP schemes (up to 30kW) induction motors may be used as generators (IMAG). Here a special controller is required, the induction generator controller (IGC).This type of motor / generator is extremely robust consequently there is virtually no maintenance required beyond periodic checking of bearings particularly if the drive pulley is fitted directly on the generator shaft.

- is essentially an induction motor used as generator (IMAG)
- widely available from the range of 1/4 HP to MW
- very robust and simple construction, no slip ring or diode in the rotor.
- relatively low efficiency compared to synchronous generators (~65%)
- over speed proof
- cannot withstand large start up current from end users due to possible loss of magnetism excitation
- No built in voltage regulation and difficult to control voltage and frequency
- Most commonly used for grid connected applications where voltage and frequency are controlled by the grid

2b. Asynchronous generators – for grid connected MHP

Very robust and simple generators used only for grid-connected schemes. Similar to IMAG, however, more suitable for larger outputs as they use a special winding design to achieve higher efficiencies. Efficiencies are similar to synchronous generators > 90%. The main disadvantage is that compensator capacitors are required to increase the cos phi (reduce apparent power). These capacitors are expensive and require maintenance and periodic replacement. A power reverse relay switch is also required to ensure that the generator is not operating as motor if the turbine is closed.

Both synchronous and asynchronous generators are available in both single and three phase versions.
As a general rule the following application guidelines can be assumed for micro hydropower projects:

Size of scheme	<10kW	10kW – 25 kW	>25kW
Type of generator	Synchronous or asynchronous single or three phase	Synchronous or asynchronous three phase only	Synchronous three phase only

Figure 73: Brush type synchronous generator.

Figure 74: Synchronous generator connected via a flat belt drive to a cross flow turbine.

Control System

The control system controls the speed of the turbine and subsequently generator. This will directly influence the voltage and frequency of the electricity generated. Depending on how sophisticated the control system is, other functions can include:

- protection
- measurement
- monitoring
- human machine interface communication

For micro hydropower systems it is not always obligatory to include a control system if the controlling of the power plant can be manually controlled satisfactorily. Moreover in the past even small scale industrial applications relied on the manual control of turbines. This was largely due to the prohibitively expensive mechanical governors required. With the advent of electronic and PLC based controllers, the relative cost of control systems has been reduced significantly making them more accessible even for small-scale projects. Nevertheless in the context of low cost small-scale micro hydropower projects it is necessary to mention manual control as a viable alternative.

Manually Controlled

Control of the power plant is carried out manually by adjusting the opening of turbine guide vane to ensure the power output is equivalent to that of the load. This system is commonly used on very small low cost micro hydropower installations where it is not financially viable to install a flow control device. This approach can work adequately for basic rural electrification projects where the load fluctuations are not excessive. In many villages it is normal practice for the households to leave lights on all night therefore the fluctuations in load are relatively small therefore sometimes not requiring any adjustment of the turbine regulator.

Where fluctuations do occur then the presence of the operator is required to adjust the turbine regulator. In reality what normally happens is that the operator soon becomes familiar with the load pattern of the village and will visit the power house to make the necessary adjustments at specific times over the period of operation to ensure the voltage and frequency remains within acceptable limits.

The main characteristics of manual control are as follows:

- No need for relatively expensive control device
- Simple operation
- Less sophisticated system therefore less to go wrong
- Frequency and voltage will fluctuate based on load change and operator response resulting in reduced life time of electronic appliances due to voltage/frequency spikes
- More labour intensive as the operator must monitor closely voltage and frequency throughout operation, in some cases operator must stay in the power house through the night
- Inconvenient for operator if the power house is located far from the village
- Limited flexibility on the consumer side (normally with fixed load i.e. either disciplined consumers or no consumer switches fitted).

Automatically Controlled

There are 2 main types of control system used on small hydropower schemes. These are:

1. Flow control: regulate the flow entering the turbine to maintain power generated is equal to power consumed.
2. Load control: regulate the electrical load between consumer load and dummy load (usually an air or water heater) with power output fixed.

The main characteristics of the 2 systems are as follows:

Flow Control

- Normally used for small scale hydro >250 kW and for industrial or commercial (on grid) application
- Rarely suitable for stand-alone rural electrification systems
- Sophisticated electronics and hydraulics therefore can only be maintained by qualified expert.
- Risk of water hammer effect and runaway / overspeed of generator in the event of failure, thus careful design of entire hydraulic system is required.
- Response to load changes is slower then electronic controllers therefore will require a fly wheel assembly to be integrated.

Load Control

- Generated Frequency and Voltage are stable (220-230 V / ±50 hz)
- Avoid damage to electrical appliances such as lamps, TVs, radio, motors, etc. caused by frequency and voltage fluctuation
- No water hammer is created during operation due to fixed power output

- Fast reaction time therefore capable of handling sudden changes in load.
- ELCs are much cheaper compared to flow control devices, thus more affordable for low budget project and village electrification schemes.
- Phase angle control based ELC create harmonic distortion on the current/voltage waveform which can cause problems for specific appliances.
- Generator is always loaded which might affect lifetime. Because of this over rating / sizing the generator is necessary.
- Due to their sophisticated electronics, maintenance and repair can only be carried out by experts / manufacturer. This is a logistical problem for schemes in remote locations.
- Dummy / ballast load is normally a tubular air heater type or water heater industrial standard.
- The rated total power of the ballast must be overrated by 20-30% of turbine power.

Figure 75: Typical manually controlled cross flow turbine governed by an electronic load controller (ELC).

Figure 76: Example of a flow control device. The guide vane is adjusted by the small hydraulic ram visible that is controlled by a PLC based intelligent control system.

There are 2 types of load controllers commonly used. These are:

Electronic Load Controller (ELC)

- Used for synchronous generator
- The main controlled parameter is the frequency
- Voltage is controlled by Automatic Voltage Regulator (AVR)

ELC controllers are used with synchronous generators. They operate in combination with the Automatic voltage controller (AVR) of the generator and control the frequency of the generator. They are more reliable than the IGC, mainly because voltage is stabilized by the AVR of the generator and no capacitors are needed. They are available in analogue and digital form.

For analogue types, operating parameters are set with adjustable potentiometers on the printed circuit boards (PCB). More modern digital versions use microprocessors for setting the operating parameters. The advantage of digitally adjusted boards is that the parameters can be programmed during commissioning and the operator cannot misadjust them. Replacement main boards can also be pre-set and subsequently installed without adjustment required.

Induction Generator Controller (IGC)

- Used for asynchronous generator / induction generator
- The main controlled parameter is the voltage
- Frequency determined by the speed and capacitor size

The induction generator controller (IGC) is still used in low cost schemes below 30kW. It works with cheap induction motors used as generators (IMAG). Capacitors supply the IMAG with the necessary apparent power to create the required magnetic field for the power generation. The frequency is not controlled and depends on the size of the capacitors, power and the cos Phi of the consumer load.

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present / explain the 2 main category of turbines existing and explain for what type of head and flow they are mostly commonly used. Under each of the 2 categories list at least 2 different turbine types and for each of the individual turbine types explain the following:

- How and where the water enters and exits the turbine
- How flow is regulated

Describe their individual suitability for rural electrification projects.

INDIVIDUAL / GROUP PRESENTATION:

Present / explain the function of a drive transmission and describe the difference between direct and belt drive solutions. Describe the main components of a drive transmission and the difference between flat and V belt drives and their applications.

Present the 2 main types of control system commonly found on MHP projects explaining their principle operating characteristics. Describe the advantages and disadvantages of the 2 approaches.

PRACTICAL DEMONSTRATION:

Conduct an onsite tour of an existing MHP scheme featuring a cross flow turbine and ELC controller. In the powerhouse identify the following components:

- Turbine and turbine regulating guide vane / valve
- Generator and base frame + position adjusters
- Mechanical drive transmission
- Controller / Electrical panel
- Controller ballast load

Explain the function of each of the components identified.

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
Name 2 different turbine types?	
How can a turbine drive the generator?	
What are common speeds for the generator to rotate at?	
What type of lubrication do turbine bearings have?	
What controls the flow into the turbine and how can this be adjusted?	
What type of belt drives are commonly used for MHP?	
What type of couplings is commonly used for MHP?	
What is the most critical adjustment for a flexible coupling?	

Topic 3: Transmission & Distribution

The transmission and distribution network for micro hydropower projects is a critical component and contributes greatly to the overall efficiency and performance of the scheme. It also influences greatly the complexity of operation and must, therefore, be carefully designed to compatible with the demands of the scheme. The overall voltage drop in a transmission and distribution network should not exceed 10%.

The cable network should aim to follow the shortest possible route to the various load centers unless not viable due to the topography of the site. The design of the grid network will consider the distance of the powerhouse from the load center(s) and size of the load. In reality for many schemes budget restrictions mean that only low voltage transmission and distribution is possible resulting in a limit on the distance the load centers can be from the power supply. Safety issues are also a serious consideration when deciding on the type of grid network. Where medium voltage lines are used there is a need for step-up / down transformers and different technical standard of cables, cable accessories and cable poles. These will all have a significant impact on cost and safety requirements of a project.

Figure 77: Typical transmission line using traditional un-insulated cables.

Figure 78: Distribution line using standard "twisted" insulated aluminum conductors and accessories.

Poles

The selection of material for the transmission and distribution network of a scheme will depend on a number of factors. Availability of material is the main consideration and this of course influences the cost of materials. Safety will also be a major consideration. Where medium voltage transmission lines are to be erected the safety requirements will be significantly more demanding requiring a minimum distance between cable and ground and also structurally the poles must fulfill minimum strength criteria to guarantee against failure. As a general rule for the height of the cables above ground is a minimum of 5 m for medium voltage and 4 m for low voltage. It is important to consider the amount of “sag” in the cable between the poles when to designing the network to ensure these minimum clearances are achieved.

For micro hydropower projects, cable poles are normally made from the most readily available materials that can fulfill the technical requirements (strength, height, cost etc.). These include:

1. Reinforced Concrete
2. Hard Timber
3. Galvanized Steel

Steel Reinforced concrete pole

For low voltage lines, the advent of insulated aluminum cables has improved the safety standards of low cost stand-alone grids considerably. These cables are much easier to suspend on the poles with standardized cable hangers, tensioners, clamps and other accessories becoming more and more readily available. In earlier times timber poles were the most common, however, with ever decreasing timber supplies, alternative materials have become much more common even in rural remote areas. One of the most popular approaches to cable poles is locally cast steel reinforced concrete poles. These are relatively easy to produce and can be cast directly at the location where they will be erected. This has the added advantage of reducing the likelihood of damage during transport.

They simply require a wooden mould where the steel reinforcement bars are placed and the concrete is poured in. They are then left to set for a number of days before erection can take place.

Figure 79: Locally cast concrete cable pole being erected.

Figure 80:Steel reinforced concrete poles being cast on site. This has the advantage of avoiding transport and the likelihood of damage.

Timber

Traditionally timber poles were the most common material used for cable poles. This was due to the ease of availability, particularly so in remote rural areas. This situation is changing rapidly with the availability of high quality timber for poles becoming more and more restricted. Where available, the value of such timber means that it is normally uneconomic to be used for poles. Additionally the improved availability of alternative materials has also contributed to the trend away from the use of timber.

Steel

Steel poles are widely used in environments where local production exists, usually steel producing countries. Where steel is used the gauge of steel must be sufficient to withstand the tension imposed through cable tensioning. This means the poles are normally made from 2 different diameters, a larger diameter for the lower section and slightly smaller for the upper section. At least 1 - 1.5meter length of the pole must be setin cement in the ground to secure it properly and protect it from corrosion.

Figure 81: Example of a typical timber cable pole.

Figure 82: Example of a 2 section steel cable pole.

Cables and Cable Accessories

Small village MHP are mostly working with 3 phase low voltage lines. Single phase distribution is normally only used below 5kW.

As a rule of thumb low voltage power lines can be used up to a distance of 2-3km. By far the vast majority of rural electrification schemes utilize low voltage transmission and distribution lines. Cable cross section is calculated according to the current in the line. The material and the cross sectional area defines the specific resistance (Ohm/m). With the ohm law the voltage drop per m can be calculated. The energy loss/m of the cable can also be calculated. This is important to assess the efficiency of the power distribution network.

Low voltage distribution:

The 2 types of cable most commonly used for low voltage lines are individual copper / aluminum conductors (ACSR) or aerial bundled conductors (ABC) also commonly know as “twisted” conductors. Both require different suspension and tensioning arrangements. For the traditional single un-insulated conductors, suspension bars and ceramic insulators must be secured to the cable poles. This adds complexity to the design and production of the cable poles and the overall transmission / distribution system.

Use of ABC or insulated twisted cables are becoming more and more common due to their ease of use. They are much more convenient and easy to erect compared with the single un-insulated conductors as they are suspended to the poles and tensioned by using a range of standard accessories. These comprise hangers, tensioners and clamps and are mass produced and normally available wherever twisted cables are procured.

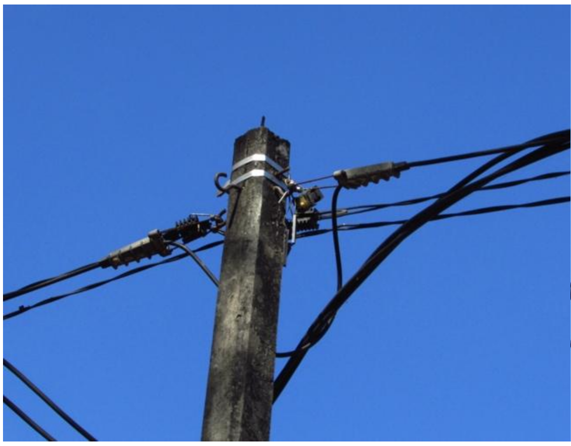


Figure 83: Locally cast concrete pole and low voltage ABC twisted cable & accessories.

Figure 84: Standardized ABC twisted cable tensioner.

Medium voltage distribution:

For higher power outputs>30kW and long distances, medium voltage transmission may be required. For medium voltage lines, normally 3 power lines are mounted on poles equipped with insulators. The cables must be suspended a minimum distance above ground for safety reasons.

Sometimes a 4th cable as neutral line is installed above the three phase lines. This cable is connected to earth at each 10th pole. This earth cable also serves as lightning protection.

Lightning arrestors must be installed at the end of the transmission line. These arrestors may be damaged if a lightning strike hits the line therefore must be regularly checked and replaced as appropriate.

Step up / down transformers

Step-up / down transformers are required where the distance between the power house and the load center is such that excessive losses would occur in low voltage transmission lines. Although losses can be mitigated by increasing the size of the cable, beyond a certain point it becomes neither technically nor economically viable to transmit power at low voltage. Under these circumstances it is necessary to step the voltage up at the powerhouse and then upon arrival at the load, step the voltage down to 220 volts prior to distribution. By doing this losses in the cable are reduced to acceptable standards. For micro hydropower schemes a distance of approximately

3 km is deemed the maximum permissible distance to transmit power at low voltage without incurring excessive losses in the cable.

The inclusion of medium voltage transmission lines complicates the scheme considerably and has major implications on the cost of the scheme and also the operational demands. For micro hydropower projects, medium voltage transmission is only normally a viable option where the power output is > 25 kW and the local operating capacity of the village is able to handle such a system.

Figure 85: Typical step-up / down transformer. The medium voltage lines are suspended on the top of the poles with the insulated low voltage cable below.

Figure 86:Step-up transformers must be positioned at a safe height above ground as in the picture or protected with a safety cage.

Grounding and lightning protection

Proper grounding and lightning protection are very important for stand-alone rural electrification grids to ensure satisfactory safety standards are achieved.

Lightning arrestors should be fitted at suitable distances along the length of the transmission line. Grounding should be combined with the lighting arrestors. Grounding is done using copper cable and plate buried at an adequate depth.

Qualified electrical engineers must be involved in the design and installation of these components. For further information on this topic please refer to the recommended reference material for this topic listed at the end of the chapter.

House connection

Wiring of house installations should follow normal installation standards as defined by the respective government authorities or national electricity utilities. These standards will follow accepted technical and safety standards and must include a short circuit breaker and fuse. Depending on the size and level of sophistication of the scheme, consumption and subsequent tariff system will use a kWh meter or an alternative limiting device. In particular for small schemes where the installation of kWh meters is deemed too expensive, a common approach is to limit consumption with the installation of a suitably sized mini circuit breaker (MCB). Where this approach is adopted fixed tariffs are applied based on the size of the MCB and not based on actual energy consumption. There are advantages and disadvantages of both approaches and suitability will depend on numerous technical and non-technical.

Figure 87: Typical house connection comprising meter, MCB and fuse box.

Figure 88: To control consumption houses are normally provided with a limited number of light bulbs and sockets.

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present / explain the function of the low voltage distribution network. Explain the different types of cable most commonly used for rural electrification projects. Describe where it is necessary to use a medium voltage transmission lines and describe the main differences to be considered when operating a medium voltage supply. In particular describe what additional safety aspects must be considered when operating at medium voltage.

INDIVIDUAL / GROUP PRESENTATION:

Present the different types of materials most commonly used for cable poles for village electrification projects describing the advantages and disadvantages of the various types.

PRACTICAL DEMONSTRATION:

Conduct an onsite tour of an existing stand-alone MHP scheme with a low voltage distribution grid network. Identify the following components:

- Low voltage cables / conductors
- Cable posts, supports, cable hangers and tensioners
- House connection including kWh meter and / or consumption limiting device

Measure the overall length of the distribution network, the number of poles, height of the cables from the ground and distance between cable poles. Based on the measurements, mark the overall suitability of the network on a scale of 1 (lowest) -10 (highest)

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
What is the difference between transmission and distribution lines?	
At what voltage do distribution lines operate?	
Name 3 materials commonly used for cable poles?	
When is it necessary to use a transformer?	
How are insulated (ABC) cables suspended from the poles?	
What are the main components on a house connection panel?	
What is a normal distance between powerhouse and load center?	
How can the consumer load be limited?	

Learning Unit 3: Plant Operations

Provided the scheme has been properly designed and constructed, the basic operational procedures for a micro hydropower plant are not overly complex. It is normally sufficient to have one operator who is responsible for the start up and shut down of the plant and periodic monitoring of intake, forebay and powerhouse at regular intervals over the course of operation.

The inherent nature of fluctuating consumer load and changing stream flow conditions due to heavy rain and flood flows present the main challenges for stand-alone schemes. They lack the stability of large integrated grid networks and therefore rely on regular operational checks and monitoring to ensure a continued smooth operation.

The following describes the main tasks associated with starting up, monitoring of operation and shutting down a stand-alone micro hydropower scheme. Due to the very location specific nature of MHP projects, in reality each power plant will be different and will have individual characteristics and demands that require special attention or focus on behalf of the operators. A variety factors influence the exact operational conditions of a scheme. These include:

- Size of the power plant
- Number of consumers
- Type of consumers
- Distance of power plant from the load center
- Number of different load centers (e.g. hamlets and their distance apart)
- Length of daily operation
- Climatic conditions in particular rainfall characteristics of the site
- Length of headrace
- Flow and head of power plant
- Material and type of civil structures
- Level of sophistication of electro-mechanical equipment
- Others.

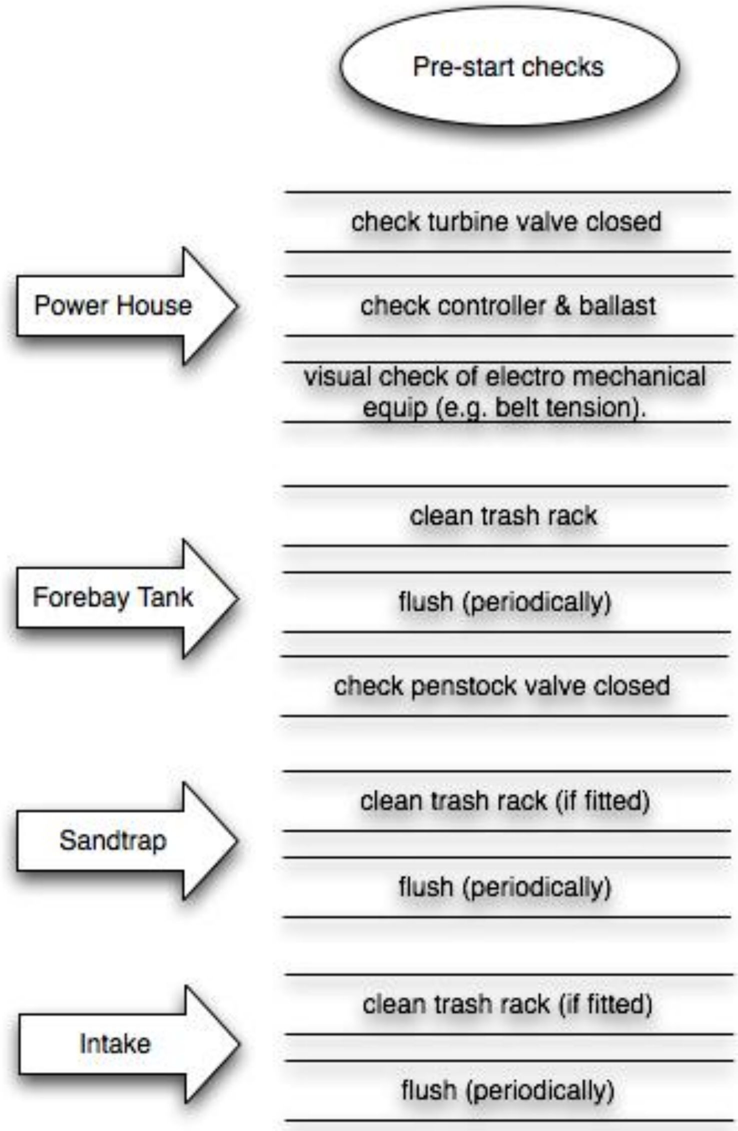
Because the main focus of this manual addresses stand-alone rural electrification MHP projects, the following procedures relate primarily to such systems operating in combination with an electronic load control (ELC) system.

For applications such as grid connection adopting different type of control systems, where the procedure differs, special reference is provided as below:

grid connected: description in italics

The different types of grid-connected schemes are numerous with a broad variety of designs and operational approaches therefore the information provided here is not exhaustive. It provides only basic information where there is a distinct difference in operational procedures compared with stand-alone projects.

Topic 1: Pre-start checks



Step 1:

Prior to releasing water into the hydraulic system, it is important to make sure that the turbine valve (guide vane) is in the fully closed position. The small by-pass valve (if any) must also be closed.

A general visual inspection of the generating equipment should be made to identify any defects. Periodically closer inspection of mechanical transmission should be made in particular belt tension where fitted.

The switch connecting the load should be in the off position. If the scheme features an electronic load controller (ELC), the ballast should be checked for condition and if a water ballast load is used, that there is sufficient water in the ballast tank.

Figure 89: Ensuring the turbine guide vane / flow valve is fully closed.

Figure 90: Periodic inspection of the ballast load and cables is important.

Step 2:

The trash rack located in the forebay should be cleaned and free from any obstruction.

Although not necessary on a daily basis, the forebay and / or settling basin should be checked for silt and flushed as required. If flushing is required open the flushing gate before proceeding to the intake.

Figure 91: Cleaning the trash rack whilst the forebay is empty

Figure 92: Flushing the forebay tank.

Step 3:

If access to the intake is via the headrace channel then inspection of the headrace is carried out on route to the intake. If a different access route is taken, then periodic inspection of the headrace channel should be carried out to assess its general condition.

Step 4:

If the intake features a trash rack this should be cleaned free from debris. The intake should be fitted with a flushing gate. Flushing of the intake should be carried out as required. This is usually weekly or monthly depending on the level of silt in the river.

If an independent settling basin exists, similarly with the forebay, this will need periodic flushing, however, not normally on a daily basis.

Figure 93: Periodic flushing at the intake is required. This is particularly important after large floods.

Figure 94: Regular inspection of the headrace channel should be made for damage or excessive leakage.

To flush the settling basin, close the gate into the headrace channel. Slowly open the gate at the intake to let water into the settling basin. When the settling basin starts to spill over the spillway, slowly open the flushing / sluice gate in the settling basin. The pressure of the water in the basin will help flush any silt in the basin out through the sluice gate. In some cases it may be necessary to manually assist in dislodging the silt to fully clean the basin.

grid connected:

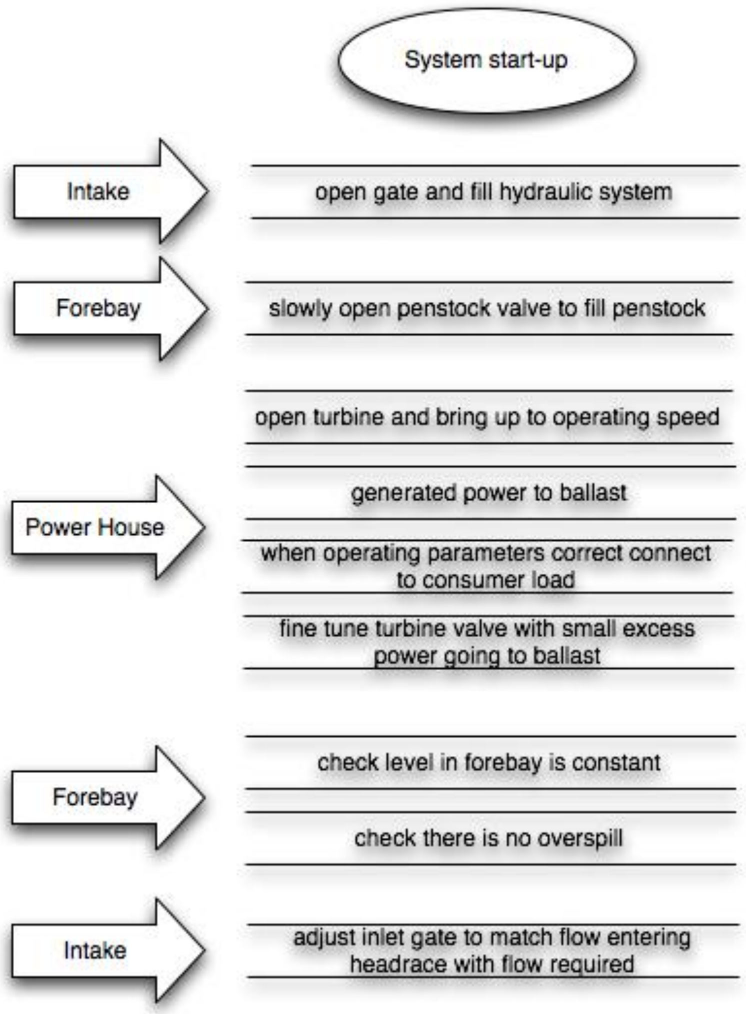
For grid-connected schemes ideally twin parallel settling basin configurations will exist. This enables the settling basin to be flushed without having to stop operation of the scheme. For stand-alone schemes that do not operate on a continuous basis the twin settling basin approach is not as critical.

If fitted ensure the trash rack at the downstream end of the settling basin is clear of any debris before closing the sluice valve enabling the basin to refill. Once it starts to spill over the spillway slowly open the gate letting water into the headrace channel and proceed to the forebay.

If not already open, open the forebay flushing gate or valve and flush out any debris and silt which may have accumulated in the forebay and clean the trash rack at the entrance to the penstock thoroughly. After flushing close the valve to allow the forebay to fill.

Topic 2: Plant Operation

Hydraulic System Startup



Step 1:

When the forebay is full and begins to spill over the spillway, gradually open the penstock gate valve (if fitted) to approximately 50% opening allowing the penstock to fill slowly. Ideally a breather pipe should be fitted at the top of the penstock to permit the air in the penstock to exit as the water fills. Where there is a breather pipe, the air passing through will create a hissing noise. Once this noise ceases, the penstock is and full and the forebay should begin to spill again over the spillway. Once full, the penstock valve can be fully opened.

Figure 95: Opening the gate at the intake allowing flow to enter the headrace channel.

Figure 96: Filling of the forebay tank.

Step 2:

From the forebay the operator then proceeds to the powerhouse. If the system features an ELC control system, check that the controller setting is switched to ballast and not to consumer load. Make a visual check of the ballast load, in the case of water heater ballast check that the tank has ample water in it. Following these checks opening of the turbine guide vane / flow valve can begin.

The turbine will start to rotate and gain speed until it reaches nominal speed. After it has reached nominal speed check that frequency and voltage are 50 Hz and 220 volts respectively. Continue to open the turbine and monitor the ampere meter indicating power going to the ballast load.

Step 3:

Once this load is at a level roughly equivalent to the actual consumer load (the operator will quickly become familiar with this based on daily experience of making these adjustments), the main switch button switching the output from ballast to consumer load can be pressed. Once supplying the consumer load, the setting on the turbine should be fine tuned to its operating position.

For ELC systems ideally the system should run with a small amount of power being dumped to the ballast. This then ensures there is a slight reserve of power whereby if consumer load increases, the system will draw on the reserve energy flowing to the ballast[3]. Without this “spare” capacity, when the load increases the system will become overloaded and the frequency and voltage levels will drop. ELC systems are not very tolerant of such conditions and will eventually trip releasing all the power to ballast. Such an event means the operator will have to restart the system. In order to do this he will first have to ensure the consumer load is reduced to the equivalent of the generated power.

[3] This will require that there is sufficient availability of flow.

Figure 97: Opening the turbine valve and bringing the turbine up to speed.

Figure 98: Once the ballast has been loaded sufficiently, consumer load can be connected.

Grid connected:

For a grid-connected scheme with a flow control devise, the start-up process will be carried out automatically by the controller. The turbine speed will be increased until the operational parameters are correct and able to synchronize. A synchronizer will synchronize the power plant with the grid and then the turbine will open to accommodate full available flow. Normally a level sensor located in the forebay tank will indicate when the turbine should increase / decrease its operating flow thereby maintaining a constant level in the forebay.

Routine operational tasks during operation

Once the scheme is running and supplying the consumers there are a number of tasks that the operator will need to carry out over the course of the plants operation. Depending on the specific operating characteristics of the scheme these tasks will demand a varying degree of vigilance on behalf of the operator. They will also depend very much on the prevalent seasonal conditions. For example it is normal for stand-alone schemes to have insufficient flow to supply the full consumer load during the dry season[4]This factor will influence the extent the operator will need to monitor power output and load and maintain them at satisfactory levels. During the wet / rainy season the task focus will change. During and after heavy rainfalls the operator will need to monitor closely the situation at the intake to ensure the civil structures are not flooded leading to damage. Flood damage to vulnerable civil structures can be fatal for micro hydropower systems.

Forebay water level monitoring

Shortly after operation has started the operator needs to ensure that the “inflow” and “outflow” of water through the hydraulic system is balanced. If the “inflow” is greater than the “outflow” this will result in excess flow being spilled over the spillway at the forebay and / or intake. It is normal to have a small amount of water spilling at the

[4] Ideally stand alone schemes are designed based on “minimum flow” stream flow conditions, however, I n reality this very rarely possible due to the seasonal variation of flow therefore in order to benefit from the flow during most of the year schemes are designed whereby power output will decrease by approx. 25 – 40% during the dry season.

forebay in order to ensure the system remains at full level[5], however, excessive spilling should be avoided.

The reason it is not advisable to have large amounts of flow spilling at the forebay spillway is that this will place significant stress on the spillway structure itself. The spillway structure is a very important civil structure and can be a difficult and expensive construction as it must dimensioned to accommodate and bring the full design flow safely back to the source. Although the construction must be robust enough to handle this flow, the lifetime of the spillway will be influenced greatly by the volume of work it has to undertake therefore minimizing the length and frequency of large spills is preferable. This concept also applies to the headrace therefore conveying large flows through the headrace only to be spilled at the forebay should be avoided.

grid connected:

As described earlier, most grid-connected schemes will have a flow control device to ensure full optimization of the available flow. This means that spilling at the forebay will not happen because constant adjustment of the turbine guide vane will ensure all the water arriving at the forebay is directed through the turbine for power generation. Being able to easily maintain a constant level at the forebay is a major advantage of grid-connected over stand-alone schemes.

In the event that there is excess flow arriving at the forebay then the operator will need to adjust the gate setting at the intake to reduce the inflow into the headrace.

Figure 99: Water spilling over the front of the trash rack. This design facilitates a degree of self-cleaning as the water passes over the trash rack taking floating debris with it.

Figure 100: Water spilling over the side spillway. Flushing is achieved by removing the white PVC pipe visible in the center of the tank. This functions as a flushing pipe plug.

Trash rack monitoring and cleaning

Ensuring an unobstructed passage of flow from the forebay through the trash rack into the penstock is critical to maintaining both full design flow and pressure head are preserved during operation. It is common that over time debris conveyed and accumulated (e.g. leaves dropping into the channel along the headrace) will

[5] For a system without any flow control it is virtually impossible to set the inflow and outflow exactly the same therefore the normal setting is to allow a small amount of flow to spill at the forebay therefore ensuring the system operates under full conditions. Obviously this is only possible where stream flow is sufficient.

accumulate at the trash rack and gradually build up in volume. As a result, the effective surface area of the trash rack will be reduced meaning the flow will have a smaller area to pass through. This will increase the flow velocity and subsequent head loss incurred. The flow that can pass through the trash rack will also be reduced. Given that the turbine guide vane is adjusted for a given flow operating under a given head, when these 2 parameters change the operation of the turbine will also change.

As a consequence the reduced head and flow will generate a reduced power output. As the consumer load is fixed this will result in an overload condition with the power generated unable to supply the connected load. The system will therefore continue to run overloaded or where an ELC is installed trip into the off position.

The trash rack is also susceptible to structural failure and can collapse if not able to withstand the full weight of water acting on it when totally blocked.

To conclude, the effects of a blocked trash rack on the operation of a MHP are numerous and inter-related and will influence greatly the efficient operation of a scheme. It should be noted that very often the importance of proper trash rack design (dimensions, material, positioning etc.) are underestimated resulting in sub-optimal performance and cumbersome operation of a scheme.

Figure 101: Cleaning the trash rack at the forebay. This is a grid-connected scheme therefore no water is spilling over the spillway.

Figure 102: Water in the forebay must be maintained at the full level during operation.

Depending on the type of intake, a course trash rack is sometimes integrated into the intake structure. Different to the trash rack in the forebay, access to the intake is usually more difficult. Firstly it can be located a relatively large distance from the powerhouse meaning regular monitoring of the intake may not be viable[6]. Secondly access to the intake during periods when the trash rack is likely to be clogged i.e. during flood flows can be precarious and extremely dangerous. Consequently wherever possible it should be avoided to have any form of trash rack positioned in the river. It is far preferable to have a submerged orifice intake with a trash rack positioned in the settling basin immediately after the intake where access is easier and safer. A submerged orifice alone ensures a large part of the floating material will

[6] It is not uncommon for the intake to be located a kilometer of more from the powerhouse.

not enter the intake. Depending on the design flow of the scheme, size of river, amount of debris commonly carried by the river and the length of headrace channel it may be possible to have only one trash rack positioned at the forebay tank[7].

Figure 103: A submerged orifice intake. Floating debris can be seen congregating above the sluice gate but not disturbing the clean flow entering the channel.

Figure 104: Intake on a small river. The flow is entering the channel via a submerged orifice. Gate into headrace is closed therefore flow is spilling back to the source.

Electro-mechanical checks

Periodic visual checks at the powerhouse are necessary to ensure there are no problems with any of the electro-mechanical equipment and that it is running within satisfactory operational parameters.

The power output (ampere), voltage and frequency meters should be checked to ensure they are within acceptable operating limits. For stand-alone rural electrification projects +- 10% is commonly deemed acceptable. For schemes with ELC's, the amount of power going to ballast should be monitored regularly. For most stand-alone rural electrification projects consumers are encouraged not to vary their consumption. This means fluctuations in load are relatively small enabling the ELC to handle these comfortably. If, however, a situation arose where a large part of the generated power was being dumped to ballast the operator should reduce flow accordingly by adjusting the turbine guide vane position. Although the ELC and ballast must be designed to absorb the full power output of the scheme such as in the event of consumer load trip or during start up, it is advisable not to allow this situation to prevail for long periods, as this will place unnecessary stress on these relatively sensitive components[8].

[7] On very small installations it is most common to have a combined settling basin / forebay tank incorporating a single trash rack.

[8] ELCs are one of the components on a MHP scheme that most frequently experience breakdown. This is likely due to the relatively complicated and sensitive electronics that they contain.

Figure 105: Checking operational parameters voltage, frequency and consumer load and ballast load.

Figure 106: Voltage and frequency must be maintained between acceptable limits.

If due to larger load fluctuations the operator adjusts the flow into the turbine, it must be understood that this will change the flow of water in the hydraulic system. Reducing turbine flow will increase the volume of water spilling over at the spillway. Conversely increasing flow will require that inflow at the intake is increased to meet the new flow requirement.

After checking that the operating parameters are within acceptable ranges, a general visual observation of the turbine, generator and mechanical transmission should be made each time the operator is at the powerhouse. Routine checking of the turbine bearing temperatures is made by placing a hand on the bearing housing. Providing it is possible to maintain a hand on the housing, the bearings are not too hot. A similar check should be made with the generator. When carrying out these checks great care must be taken not to touch any moving parts. Such checks should only be carried out by an experienced operator.

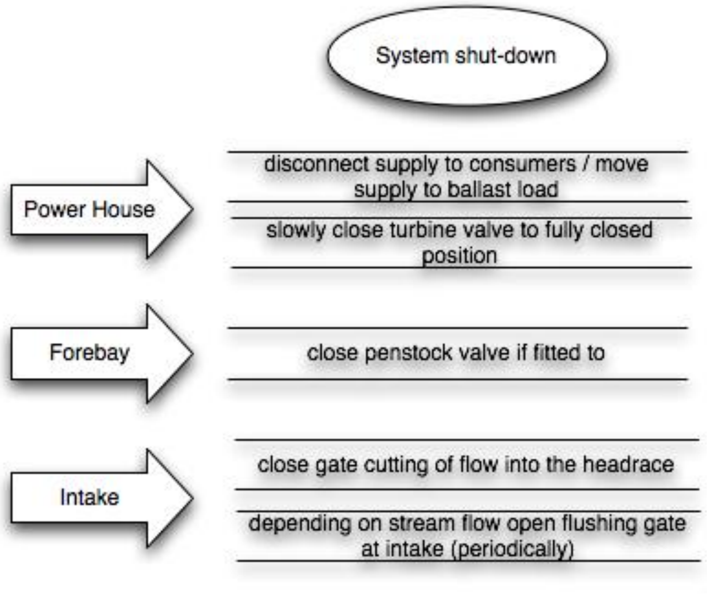
Checking the tension of the drive belts should be carried out periodically when the turbine is stationary or in shut down mode.

Transmission and distribution line checks

The transmission and distribution lines once erected do not require regular attention beyond regular visual checks to ensure that there are no tree branches or other objects that may have fallen or become entangled in the lines.

It is emphasized that any task related to the transmission and distribution lines must be carried out when the power plant is in shut down mode. More details on the general maintenance of this component are presented in Module 2: Plant Maintenance.

Hydraulic system shut-down



To shut down the plant the following steps should be followed:

Step 1:

Disconnect the consumer load re-directing the full power output to the ballast load. Immediately after disconnecting the load proceed to close the turbine guide vane to switch off flow to the turbine. Closing the turbine valve too quickly will cause an increase in pressure in the penstock as a result of water hammer effect. With manually adjusted guide vanes, however, the speed of closure is automatically regulated simply by the speed that that the valve can be manually closed.

As the flow through the turbine reduces, it will begin spilling at the forebay spillway. Eventually all the flow will spill. It is important not to let this condition prevail for too long for the reasons explained previously.

Step 2:

If a valve is fitted in the penstock this should be closed to avoid that the water within the entire hydraulic system doesn't drain through the turbine[9] when the intake gate is closed. Being able to close off fully flow through the penstock means the hydraulic system will remain full when the scheme is not operating thus simplifying the next start-up procedure. This is particularly convenient where the scheme has a long headrace channel and refilling the entire hydraulic system can be a time consuming and cumbersome operation. If there is no isolation valve fitted this is not possible and the hydraulic system will have to be drained[10].

---

[9] In theory the flow should not drain through the penstock as the turbine guide vane has been closed. Nevertheless on many turbines types it is difficult if not impossible to ensure a perfect seal when closed under pressure normally resulting in the gradual draining of the hydraulic system through the turbine.

[10] Very often and particularly on small low cost schemes there is no isolation valve fitted in the penstock.

Step 3:

The next step is for the operator to proceed to the intake and close the intake gate closing off entry of water into the headrace channel.

Figure 107: Headrace access gate at the intake in the closed position.

Figure 108: The penstock shut off valve is commonly positioned in the forebay tank.

An alternative procedure can also be adopted where there is no possibility to seal the hydraulic system or it is deemed more practical to drain the system during shut down. For example on schemes with very short or even no headrace channel this is often the most practical solution. Under these circumstances the consumer load is switched over to the ballast, however, the turbine guide vane is left in its operating position. The operator then proceeds directly to the intake where he closes off water into the headrace. The existing water in the hydraulic system will continue to flow through the structures and drain through the turbine until the entire system is empty. When the power output drops below a certain point the ELC will trip and the generator will stop producing any power. This approach has the advantage that no water is spilled over the spillway during the closing procedure.

Emergency system shut-down

Rapid emergency shut-down (a number of seconds) of the generating equipment is only possible where the hydro system incorporates a automatically (hydraulically) activated butterfly or gate valve in the penstock pipe. Such a facility is normal for grid-connected schemes where it represents an integral feature of the flow control device. This arrangement, however, is not common for small stand-alone MHP schemes. These depend on manual closure of the turbine valve or penstock isolation valve to stop flow into the turbine (a number of minutes). Closing off flow into the hydraulic structures is relatively time consuming for both types of scheme as it requires closure of gates located at the intake structure. The exact time this requires is dependent on the distance between the powerhouse and the intake and also the type of intake gates installed.

The above described start up and shut down procedures apply for typical stand-alone micro hydropower rural electrification installations. The inherent customized nature of MHP where each scheme is different, in particular the layout and design of the civil structures, however, means that there will always be variations in exact operating procedures for each plant. For example the decision whether or not to install an isolation valve in the penstock will often be a financial consideration and not necessarily a technical one. In particularly low cost rural electrification projects will tend to have less sophisticated structures and layout that will likely result in a more labor intensive and probably less efficient operating procedures compared to commercial projects.

For example some schemes will have a penstock isolation valve and some won't. Some will have a settling basin and trash rack at the intake and some won't etc. To summarize it can be said that no two MHP installations are identical and their standard operational procedures (SOP) will reflect these differences and the specific characteristics of the individual design.

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present and explain 4 pre-start checks the operator must carry out prior to operating a MHP. Of these tasks, 2 must be carried out inside the powerhouse and 2 must relate to outside checks.

Present and explain 2 checks that must be carried out on a periodic basis (not necessarily daily).

Present the reasons why these checks are necessary and describe the possible implications on the operation of the scheme if they are not properly carried out.

INDIVIDUAL / GROUP PRESENTATION:

Present / explain implications on the operation of a MHP scheme if the following tasks are not properly carried out by the operator:

- Sandtrap is full
- Trash rack is blocked with leaves
- Accumulation of debris in front of the intake gate
- The forebay tank level is too loe and not constant
- The consumer load is greater than the generated power

Explain what measures must be taken to correct all of the above conditions

PRACTICAL DEMONSTRATION:

At a MHP location assuming the hydraulic system is empty, carry out the following tasks:

- Fill the entire hydraulic system
- Flush the sandtrap and / or forebay tank
- Start up the scheme and connect the consumer load
- Carry out an emergency stop of the scheme (i.e. close down the plant as quickly as possible)

Run the scheme for 1 hour monitoring the following:

- operating voltage and frequency
- level of water in the forebay
- amount of flow going over the spillway

Make the necessary adjustments at the intake gate and turbine flow valve to ensure only a small amount (if any) of flow is spilling over the spillway.

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
Before startup, is the turbine flow valve open or closed?	
At startup, is the consumer load connected?	
What controls the level of water entering the waterways?	
Is it necessary to flush the forebay daily before every startup?	
If there is flood conditions in the river what should be done?	
After flood is it likely to be more or less silt in the sandtrap?	
If lots of water is overflowing at the spillway what does this indicate?	
If it is not possible to connect the consumer load, name 2 possible causes?	

Teaching and Learning Material

Certificate course

Micro Hydro Power

"MHP - Operator"

PNVQF LEVEL 3

Module 2

Preventive and Corrective Maintenance

Table of Contents

Learning Unit 1: Types of Maintenance 15

Topic 1: General Maintenance 15

Maintainability: 15

Pre-requisites formaintenance: 15

System life cycle: 16

Origin of problems: 16

Financial aspects of maintenance 17

Topic 2: Unplanned (reactive) Maintenance: 18

Run to failure maintenance (RTF) 18

Emergency maintenance 19

Topic 3: Planned Maintenance 20

Preventive maintenance 20

Corrective Maintenance 20

Learning Unit 2: Maintenance Tasks & Schedule for Civil Structures 25

Topic 1: Intake and Diversion Weir 25

Maintenance Activity and Frequency: 26

Topic 2: Settling Basin 26

Topic 3: Headrace Channel 28

Topic 4: Forebay 29

Topic 5: Penstock 31

Topic 6: Powerhouse& Tailrace 32

Topic 7: Civil Structure Materials 33

Stone Masonry 33

Brick Masonry 33

Concrete 33

Stone masonry vs. concrete 34

Learning Unit 3: Maintenance Tasks & Schedule for Electro-Mechanical Equipment 37

Topic 1: Turbine 37

Bearings 37

Guide vane / spear valve assembly 38

Runner 39

General 40

Topic 2: Mechanical transmission 42

Belt drives 42

Pulleys and Coupling 43

Topic 3: Generator 45

Asynchronous (including IMAG) 45

Brushless synchronous generator: 45

Brush type synchronous generator: 45

Topic 4: Controller& Ballast Load 47

Topic 5: Powerhouse, Tools & Consumables 50

Powerhouse 50

Tools & Consumables 51

Learning Unit 3.1: Maintenance Tasks & Schedule for Transmission & Distribution 55

Transmission / distribution lines, poles and accessories 55

Cable posts& Accessories 55
Step up / down transformers 55
House connection.. 56

Learning Unit 3.2 Troubleshooting 60

Outline for the internal Assessment

MODULE 2: PREVENTIVE AND CORRECTIVE MAINTENANCE			
Learning Units (LU)	**Theory**	**Practical**	**Formative Assessment**
1. Type of Maintenance	15	20	At an existing MHP identify and photograph examples and evidence of all types of maintenance that have either been carried out or are in need of work.
2. Maintenance task and schedule for civil structures	15	40	At an existing MHP flush both the intake and the settling basin and clean the trash rack ready for start-up of the scheme.
3. Maintenance task and schedule for electro-mechanical equipment			At an existing MHP with a belt drive transmission, remove the drive belt(s), inspect and refit them with correct tension and alignment.
3.1 Maintenance task and schedule for transmission& distribution	30	80	For a selected un-electrified rural village, formulate a draft low voltage distribution network plan with the aim of minimizing losses in the system.
3.2 Troubleshooting			On a white board produce a visual troubleshooting guide for the possible cause of low voltage at the consumer load.

Planning of the assessment for the Module:

MODULE 2: PREVENTIVE AND CORRECTIVE MAINTENANCE				
LEARNING UNIT (LU)		**FORMATIVE ASSESSMENT PROJECTS**	**SCHEDULED DATES**	
LU 1	Type of Maintenance	At an existing MHP identify and photograph examples and evidence of all types of maintenance that have either been carried out or are in need of work.		
LU 2	Maintenance task and schedule for civil structures	At an existing MHP flush both the intake and the settling basin and clean the trash rack ready for start-up of the scheme.		
LU 3	Maintenance task and schedule for electro-mechanical equipment	At an existing MHP with a belt drive transmission, remove the drive belt(s), inspect and refit them with correct tension and alignment.		
3.1	Maintenance task and schedule for transmission & distribution	For a selected un-electrified rural village, formulate a draft low voltage distribution network plan with the aim of minimizing losses in the system.		
3.2	Troubleshooting	On a white board produce a visual troubleshooting guide for the possible cause of low voltage at the consumer load.		

Guidelines for Trainers/Teachers and Trainees

Practice orientation

1. As a general guideline work should be 20% theoretical and 80% practical work, but outline must be appropriate. Theoretical part could be increased, if suitable for the subject/LU.
2. Punctuality is compulsory so that no academic or practical work remains uncovered. It is also the responsibility of teachers to ensure 100% attendance of trainees.
3. Manage a visit to the relevant industry, if possible. The trainees will be more excited to do work in their fields.
4. Use group activities, practical work, projects, individual and group assignments and student's individual assessment.

Facilitation instead of lecturing

1. The teachers should act as facilitators. The centre of training must be student. It is the duty of teacher to make constructive environment of classroom for theory and practical assignments.
2. Normally the theory part is completed first, exceptions are possible, then demonstrate the practical work yourself. The trainees should perform the practical work under supervision and guidance of the instructor. Promote the discussions for better understanding of academic and practical work. The following techniques can be used for this purpose:
    a. Lecture- Minimize the time period.
    b. Use of story- Use a real story for better understanding of a problem and its solution to trainees

Introduction into the learning objectives of each Learning Unit

Provide a brief and summarizing introduction into the objectives of the LU and explain what the learner will know and be able to do in the end.

Interacting with trainees – the participatory approach

3. There should be no sternness in the class that a student could not express his ideas or concerns and not as much freedom that a student destroys the collective discipline of learning. It is the duty of a teacher to maintain a good and moderate environment in class so that a student could succeed in attaining his goal.
4. In this module, a weekly schedule has been included for trainees to give feedback or opinion about their training. The trainers must take feedback

from trainees by using a chart and try to improve the training process in the light of feedback.

The assessment strategy

5. This module includes an assessment guide for teachers and trainees to inform them about the whole assessment process. The teachers will use it for assessing the ability of the trainees to perform what they have learnt.
6. The <u>formative assessment</u> serves to check progress in learning and is mainly based on oral questioning, practical assignments and little projects. The results will be documented and presented for the integrated assessment at the end of the module.
7. At the end of the module the <u>integrated assessment</u> will be conducted through a panel of persons. Only if all formative assessments has been passed the learner is eligible for the integrated assessment

Organizational aspects of training delivery

8. The teachers will keep in view the following instructions during the daily lesson planning:

   a. The seating plan in the class should be arranged to increase allow interaction amongst the trainees.
   b. The teacher/instructor will present the summary of previous lesson and ask questions.
   c. The teacher/instructor will present a brief introduction into the new objectives
   d. The teacher/instructor delivers the subjects according to his lesson plan (could be lecturing or practical demonstration and trainee practice)
   e. Collect feedback of trainees regarding their perception about the subject they are learning.
   f. Provide sufficient time to trainees for learning so that they understand the relation between theory and practical work.

Toolbox for teachers and instructors

In the following a toolbox is outlined which the teacher/instructor should use during the training sessions.

TOOL 1: INDIVIDUAL OR GROUP WORK - PRESENTATION

Explanation: The teacher/instructor will present the trainee or a group of trainees a **well defined theoretical task**. The trainees are divided into 3 or 4 groups. The time to solve the problem is specified and should be within the current training session. Each group will present its solution of the problem in an appropriate way, be it on flip chart, a short presentation or result of work

Define theoretical task, not more than 4 lines
Individual / Group result/presentation:

TOOL 2: PRACTICAL ASSIGNMENT / PROJECT

Explanation: The teacher will present the trainees a well defined assignment which requires practical work. The assignment is done individually or in groups. The time to solve the problem is specified and could be within the training session, but could also stretch over a week at the maximum. The result will be presented individually or as per group.

Note: Such an assignment could be also used as a formative assessment.

Define practical assignment, not more than 4 lines
Group result/presentation:

TOOL 3: PRACTICAL DEMONSTRATION

The most powerful tool for any technical training is the demonstration of works processes and the practicing of the trainees. However, a well executed demonstration must be well designed and prepared:

1. Read the procedure mentioned in the Learner Guide for the relevant Learning Unit before demonstration.
2. Arrange all tools, equipment and consumable material which are required for demonstration of a skill.
3. Explain how the skill relates with the skills already learnt, describe the expected results and show the objects to trainees.
4. Carry out demonstration in a way that it can be seen by all trainees.
5. Identify critical or complex steps, or steps that involve safety precautions to be followed.
6. Explain theoretical knowledge where applicable and ask questions to trainees to test their understanding.
7. Allow the trainees to repeat the demonstration, either individually or in groups
8. Walk around and provide hints and support to the trainees.
9. Repeat critical steps in demonstration, if required.
10. Let the trainees summarize what they have learnt.

TOOL 4: DAILY LESSON PLAN

The daily lesson plan is the most powerful tool to prepare and structure efficient learning. The lesson plan needs to be completed by the teacher for every lesson. The teacher/instructor needs to plan their lessons right in advance and come to the class fully prepared to implement the session in a professional way:

1. Introduce yourself and the Learning Unit, and state the Learning Outcomes of the session clearly to activate attention of learners.
2. State the Learning Objectives of the lesson. This allows the trainees to organize their thoughts on what they will learn and to perform. Also state some questions to recall prior knowledge of trainees to arouse their interest and motivation.
3. In the main part of the lesson present the new information or material to be learned. Perform demonstrations and use relevant media including handouts, power-point slides, flip chard and white board.
4. At the end and in conclusion of the session summarize and review the lesson delivered. Ask probing question to verify, if a transfer of knowledge and skill has been achieved.

Name teacher/instructor:	
Date:	
Subject, course title:	
Learning Unit No.	
Learning Outcome No.	
Recommended Visual Aids:	
Learning Outcome:	

Activity 1: Revision of Previous Lesson

Activity 2: Today's Lecture

The instructor will explain the following points in detail:

1.
2.
3.

Activity 3: Practical Work

The instructor will perform a demonstration and ask the trainees to do the following practical work.

1.
2.
3.

Activity 4: Presentation/Assignment/group activity

Give the following projects or assignments to student

1.
2.
3.

Activity 5: Analysis of absorption of the taught lesson

Ask a probing question to verify if a transfer of knowledge and skill has been achieved.

TOOL 5: WEEKLY EVALUATION

A simple tool to capture the learning progress and to identify potential problems is a feedback form with smileys. At the end of each week (or a specific day) the teacher should use the evaluation form below to receive anonymous feedback for the week. The teacher must summarize all forms on one sheet, analyze the results and draw conclusions. If other facilitators are involved in the delivery of the training, the results should be shared with them.

Weekly Evaluation

Class: ______________

Subject: _____________

Date: __________________

Method of Evaluation	☺	😐	☹
1-Did you learn any new thing during the week?			
2-Did you learn something new today?			
3-Was it easy to understand the lesson?			
4-Was the practical work well demonstrated?			
5-Did you learn from others during group work?			

Any other opinion or comments:

____
____

TOOL 6: SELF-ASSESSMENT AT THE END OF A LU

The self-assessment at the end of each Learning Unit must be simple questions (without answers!!!!) and with a max of 10 questions. Questions must be in relation with the content of the LU. The self-assessment is not checked and cannot be used as formative assessment.

Question (simple)	**Answer by trainee**

Learning Unit 1: Types of Maintenance

Topic 1: General Maintenance

Maintenance includes all actions necessary to retain the MHP in the desired operation.

Objectives of maintenance in a MHP system are:

- Maximize operation time and energy production
- Minimize operation costs
- Organize operation cost and downtime by spare part management
- Optimize lifetime of equipment
- Optimize economic benefit of the equipment

The main group of maintenance is, if the maintenance is planned or scheduled (proactive) maintenance or unplanned (reactive) maintenance.

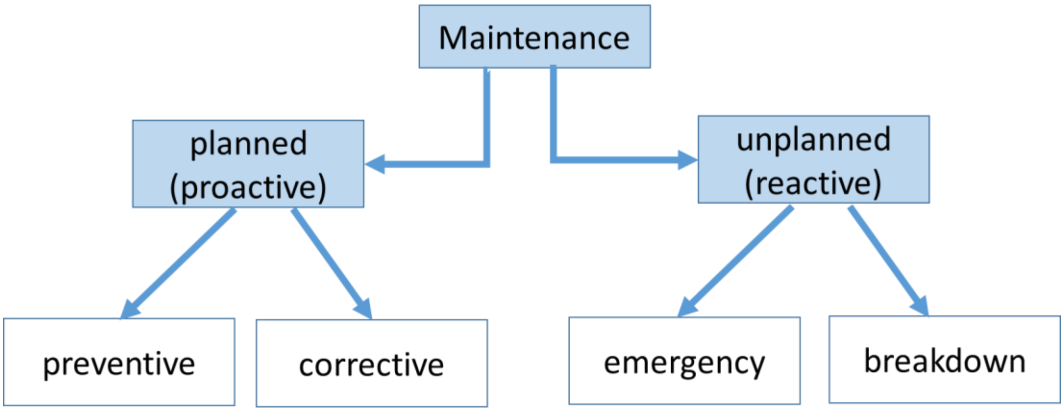


Figure 1 Categories of maintenance

Maintainability:

A clear understanding of the concept of maintainability is the basis for developing a realistic and appropriate maintenance plan.

A system (e.g. MHP) should be designed in such a way that it can be maintained efficiently and at least cost to the operator. Impacts on the environment must also be minimized. Maintainability is a major and important design parameter. Operation and maintenance should be carefully considered for all components at design stage.

Maintainability requires the consideration of many factors. These include:

- Mean time between maintenance (MTBM)
- Mean time between replacement (MTBR)
- Maintenance down time (MDT)
- Turnaround time = time to fix a problem which is affecting the operation TAT)
- Maintenance working hours / operating hour
- Maintenance / operating hour

Pre-requisites for maintenance:

It is essential that an “operation and maintenance” logbook is completed for the MHP. Operators MUST be trained to do this and understand why it is so important to do this. In the chapters below we describe which actions the operator has to take to maintain the power plant in good condition and operational. Often operators receive only a short training during commissioning and handing over of the equipment. This training should be repeated periodically to ensure the operators are up to date regarding operating procedures. Obviously where operators change, the new personnel must be trained accordingly. One important aspect is that the operators are aware of their limits and understand under which circumstances they require external assistance. This could be from the suppliers of the respective equipment or simply from someone with the specific technical expertise required (for e.g. a qualified electrician for electrical problems). A troubleshooting checklist provides valuable information to the operator for analyzing and solving of problems.

System life cycle:

This time includes design, construction, operation, retirement (retirement means the re-naturalisation of the MHP at the end of its lifetime. It can as well be a reconstruction or refurbishment). Initial investment costs of a properly designed MHP may be relatively high, however, such schemes are more likely to have good maintainability, operate reliably and have long system life cycles. Economizing on initial investment is rarely a cost effective approach for MHP projects. Having to correct mistakes made during initial design and / or having to suffer the implications of the sub standard function of certain components is far more expensive in the long term. Reliability is achieved when the MHP performs satisfactorily for a given time period. Maintainability and maintenance determine the reliability.

Origin of problems:

As a basis for establishing a comprehensive and appropriate maintenance schedule the main problems commonly surfacing within MHP projects must first be analyzed. The “fish bone” diagram below illustrates the main factors responsible for O&M problems in a MHP.

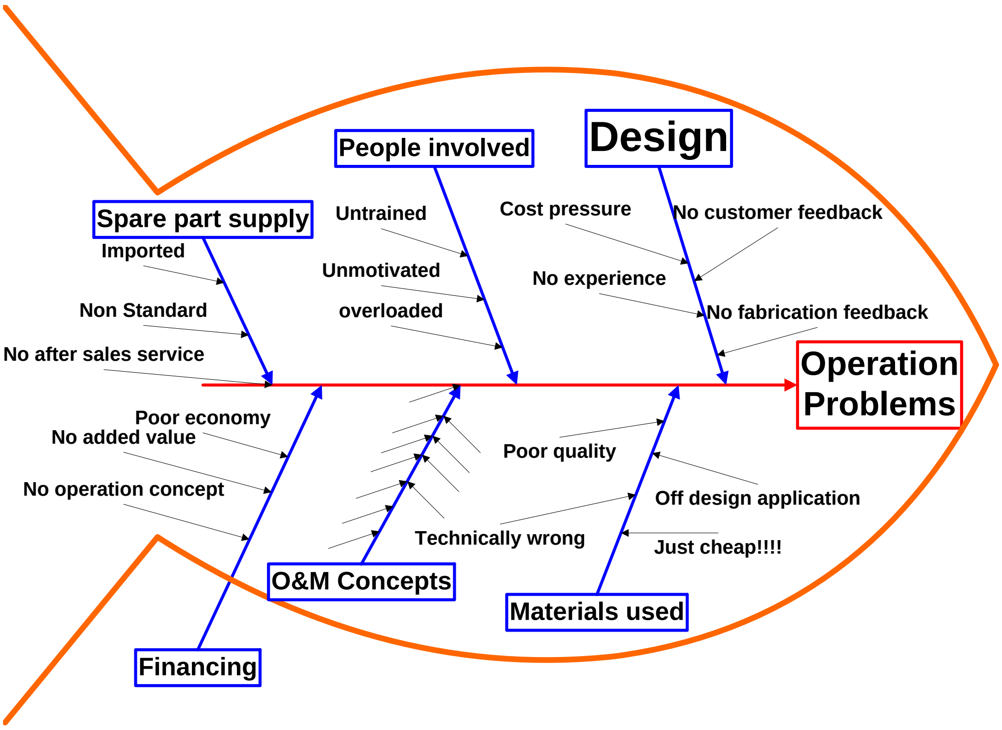


Figure 2: Fish bone diagram illustrating O&M problems

Financial aspects of maintenance

The MHP owner and the operators have to be aware of the importance of proper and well organised maintenance and the implications this has on the financial sustainability of the scheme. This is critical for stand alone schemes where in most cases they are operated as a fully independant entity meaning they receive no outside financial support. In this situation having a realistic estimate of what the annual operating costs will be is essential information for determining consumer tariffs and management and operator wages.

- As a guideline / rule of thumb, the yearly operation & maintenance costs will normally be between 1.5-2.5% of the initial capital investment. They may reach 1-2USc/kWh produced.
- After approximately 10 years of operation a refurbishment / rehabilitation of the civil structures and electro-mechanical equipment will usually be necessary.The scale and cost of of this refurbishment will depend greatly on the quality of the initial civil construction, the type and quality of the E/M equipment installed and the extent to which proper maintenance has been carried out over the schemes lifetime. These costs will vary significantly. For example a very good site may have costs of <10% of initial investment whereas costs for a less optimal scheme may be > 25%.
- Not investing properly into regular maintenance results in a gradual accumulation of problems and deterioration in the condition of scheme components. This ultimately results in more serious damage emerging at some point requiring much higher cost solutions than those incurred for normal regular maintenance.

Topic 2: Unplanned (reactive) Maintenance:

Run to failure maintenance (RTF)

This is the oldest and frequently applied maintenance concept, in particular on small low cost MHP installations. Essentially zero maintenance is carried out until an event occurs serious enough to cause the plant to breakdown. In this situation commonly there existsno available budget to finance the repair due to a basic lack of proper managment of the scheme. This happens where a village MHP is handed over to the community without any maintenance and operation concept being introduced. The initial operation lifetime in this case depends fully on the quality of the MHP structures and equipment. Due to the lack of proper financial management, when breakdowns occur there is no available budget for repair. Consequently such schemes are repaired with temporary makeshift solutions resulting in perpetual technical problems over the lifetime of the scheme.

This situation tends to arise on schemes that have been built without any financial and / or in kind contribution from the villagers. When something happens that requires a financial input, the owners simply wait for somebody else to takeresponsibility for the situation (quite often this is the responsible governent department if the scheme was financed through a government rurual electrification program). The best case scenario is that the village are willing and able to mobilize the funds required to finance the necessary repairs and the scheme can continue to operate. The worst case scenario is that the scheme simply falls into a worse and worse state of disrepair until it is finally abandoned therefore ending its lifespan.

Although the RTF approach is not generally recommended, there are some environments where RTF maintenance is acceptable. For example most modern electronic devices do not require any maintenance (besides careful handling) and often cannot be repaired. If they fail it is cheaper to buy a new (up to date) replacement instead of making any attempt to repair.

In a complex system such as a MHP scheme, however, if the RTF approach is applied it will often have very expensive consequences. Lengthy down times and high subsequent repair costs will be incurred. Downtime costs are a result of lost revenue during downtime and should not be underestimated. Whilst these may not be so critical on a community based scheme, for commercial projects down time is a serious consideration in calculating overall financial viability of a scheme.

The following are a number of examples of where on a MHP scheme a RTF maintenance approach is acceptable and not acceptable:

Acceptable

- Generator AVR (if stock available)
- Controller main board or controller SCR (if stock available)
- Ballast load (if stock is available)

Not acceptable:

- Bearing brake down if overheating or noise are ignored
- Bearing brake down due to neglected lubrication (especially plain bearings)
- Oil hydraulic breakdown due to neglected oil level control
- Runner wear resulting in degreasing power and damage of turbine
- Short circuit because trees touching or falling onto the power line

An MHP is a long-term investment and requires planned (proactive) maintenance to operate reliably over a normal lifespan that should normally be able to exceed 20 years (see topic 2 and 3).

Emergency maintenance

Emergency situations may occur when operating an MHP. The operator should be trained to adopt a standard operation procedure when dealing with emergency maintenance. Suitable equipment (e.g. fire extinguisher, first aid kit, etc.) should be at site.

Below are a number of examples of typical emergency situations sometimes encountered by stand-alone MHP schemes are as follows:

- During a storm a tree or tree branch falling on the power line. It is required to immediately close down the power plant and disconnect the power line. After the storm has passed the tree / obstacle must be removed.
- Cracks or leaks emerge within the hydraulic structures (headrace, forebay - for example could be the result of an earthquake). The hydraulic system must closed off until adequate repair is carried out.
- The electro-mechanical equipment goes into runaway speed due to a failure of the control system. The turbine must be closed down immediately to avoid damage to the generator.

Figure 3: Example of a storm damaged distribution line. A tree has fallen onto the MV transmission line.

Figure 4: Cracked forebay tank as a result of an earthquake.

Topic 3: Planned Maintenance

Preventive maintenance

Preventive maintenance is made according to a defined time schedule to reduce the risk of failures. For example lubrication is made based on a defined lubrication schedule (hours of operation) or based on clear indicators such as oil level indicator of filter condition displays. Preventive maintenance also includes the exchange of components (e.g. bearings based on calculated lifetime) before they reach their potential maximum lifetime. These can also be replaced based on first indications that they are worn and are approaching the end of their lifespan (e.g. bearing noise or vibration, seal leakages, etc.).

On the civil works for example, stabilizing unstable ground within the vicinity of the civil structures (e.g. powerhouse, headrace channel etc.) to avoid landslides taking place is an example of preventive maintenance.

Corrective Maintenance

Corrective maintenance is made after a failure in the system occurs, which was not avoided through the preventive maintenance measures. For example on the electro-mechanical equipment temperature and vibration increases must be analyzed to identify the reasons behind them. These may require early corrective maintenance to avoid subsequent fatal damage occurring. However, not all corrective maintenance is a result of poor preventive maintenance. Some corrective maintenance is simply necessary due to the gradual deterioration of a specific component due to age and normal wear.

One very important element of corrective maintenance is post repair analysis of the root cause of the failure. As mentioned above, it may be that it was simply a result of normal wear and tear and therefore no special post repair measures are required. It could, however, indicate a floor or shortfall in the design or maintenance schedule of the component in which case careful analysis of how the floor can be eliminated is necessary to avoid future re-occurrences of the problem.

Examples of preventive and corrective maintenance

Example 1: Poor preventive maintenance resulting in corrective maintenance

Delaying and avoiding the exchange of worn components can lead to both more critical damage occurring at a later time and / or the loss of performance of the power plant. This in turn results in financial loss through the loss of potential revenue.

Figure 5: A very badly worn cross flow turbine runner.

Figure 6: Severley damanged achor block. If not repaired this could lead to more serious damage of the penstock, powerhouse etc.

Figure 5 above shows a very badly worn cross flow turbine runner from a turbine supplying a tea estate factory and village (diesel substitution). The logbook showed that the output had been declining gradually from 150kW to only 75kW (loss of 50%) over a period of 5-10 years, however, no action was taken to identify the problem. Eventually due to excessive noise the turbine was inspected and the problem identified. It was necessary to replace the runner (preventive maintenance evolved into corrective maintenance).

What was the economic loss of this neglected preventive maintenance based on the logbook energy production records?

- Turbine efficiency dropped over the last 5years from 80% (150kW) to 40% (75kW)–according to operator and log book records
- cost of new runner: 8000 USD
- cost of new turbine 120,000 USD
- lost energy production over 5 years = 3,285,000 kWh
- cost of non produced electricity being replaced with diesl generated energy calaculated @ 15 UScent/kWh = US$ 492,750

This means that the cost of not replacing the runner when it was already showing signs of wear is approximately 61 times the price of a new runner! Moreover an annual replacement of the entire imported turbine would still have been cheaper than the lost revenue / avoided costs incurred as a result of the poor performance of the turbine!

Clearly this was a serious management mistake not to have in place a strict maintenance schedule enabling the early identification of such problems enabling a timely preventive solution.

Example 2: Poor preventive maintenance resulting in corrective maintenance

Figures 7 shows a damaged bearing that requires corrective maintenance (replacement) as a result of poor preventive maintenance being carried out i.e.no lubrication. Figure 8 shows and how the bearing should look when properly lubricated.

Figure7: Total bearing failure with expensive consequences. Signs of vibration were ignored resulting in total failure and a blocked runner.

Figure 8: Properly lubricated and maintained bearing. Improvement of maintenance by installing vibration and temperature sensors.

Ideally once the damage is repaired, improvements to avoid repeat failure in the future should be implemented. This could be for example the installation of temperature or vibration sensors to provide early indication to the operator when the bearings require attention. On a more simple level, the maintenance schedule could be revised requiring more strict inspection time frames and reporting to avoid re-occurrence of the problem.

Example 3: Proper preventive maintenance on the civil works of a MHP

Figure 9 shows a common occurrence on MHP schemes namely the blocking and damage of a headrace channel as a result of a landslide. This usually happens following heavy rains and at places where the slope is unstable. Figure 10 shows the proper terracing / stabilizing of a slope deemed a landslide risk along a headrace channel.

Figure9: A headrace channel blocked due to a landslide.

Figure 10: Construction of a retaining wall along a section of the headrace has stabilized and reduced risk of landslide on this headrace channel.

In general there is relatively little maintenance necessary on the civil structures beyond regular observation and vigilance of erosion and scouring / undermining. Nevertheless the early identification of potential problems and subsequent preventive measures is important to avoid more serious and costly problems emerging at a later time. For civil structures, properly functioning preventive maintenance regime will reduce maintenance costs significantly in the long term.

Modern power plants are often operated without permanent staff present and therefore rely more and more on remote display of alarms whereby a specific operating condition triggers either an alarm or warning sign. Monitoring of these warnings enables the operator to carry out the necessary corrective measures.

For small-scale rural electrification projects such technology is rarely appropriate therefore these projects rely much more on a properly functioning operation and management system.

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present the different types of maintenance relevant in the context of a MHP project. Describe the main differences between preventive and corrective maintenance for a motorcycle making analogies with a typical MHP. Explain the difference between maintainability and maintenance providing examples of each.

PRACTICAL ASSIGNMENT / PROJECT:

Design a preventive maintenance plan for a 20 kW stand alone MHP scheme supplying 150 rural households. Estimate the operational costs (operator salary) and cost for the operator and of 300kW and a plant factor of 80%. The selling price for 1 kWh is 20 PKR.

Estimate the economic loss if the plant is out of operation for 2 weeks and make a recommendation for the budget of preventive and corrective maintenance.

PRACTICAL DEMONSTRATION:

At an existing MHP site, study and analyse the operator's logbook and the maintenance plan. Inspect the entire MHP installation including civil structures.

Check if tools and spare parts are available and in which condition they are. Make an assessment of whether they are they sufficient for carrying out the preventive and corrective maintenance tasks? On the basis of these inspections make an overall assessment of how well the MHP scheme is maintained classifying it as either:

Good – Average – Poor

Provide reasons for your decision.

Learning Unit Self Assessment:

Question (simple)	Answer by trainee
What are 2 main types of maintenance?	
Give 2 examples of preventive maintenance?	
Give 2 examples of corrective maintenance?	
If maintenance is ignored how can this affect the financial situation of the MHP?	
Give an example of how a natural disaster can impact maintenance?	
Give an example of a typical emergency situation?	
What should be done to the power plant in the event of an emergency event?	
If no maintenance plan and finance exists for a MHP what will likely happen when a breakdown occurs?	

Learning Unit 2: Maintenance Tasks & Schedule for Civil Structures

The level of maintenance of the civil structures required is defined by the specific design rather than by default. The specific design of the scheme will largely dictate the operation and maintenance procedures and sequencing.

Preventive maintenance is highly important to micro hydropower schemes. Adopting a strict approach to routine and preventive maintenance of the key components will avoid the majority of problems and breakdowns before they occur. This is hugely preferable to incurring the much higher costs of corrective maintenance as preventive repairs are generally cheaper and also avoid excessive downtimes of the scheme. In particular civil structures exposed to river flow and flood and the natural elements are susceptible to damage. When problems occur the severity can escalate rapidly sometimes with catastrophic consequences, e.g. if water conveyance structures such as channels or pipes completely fail. The power of water and its potentially destructive nature, if not handled correctly, MUST NOT be underestimated.

Simple, appropriate and proven technologies should be applied when developing a micro hydropower scheme. By doing so this enables operators, usually not having an engineering background or extensive experience, to understand the functions more easily and to carry out required maintenance tasks. The design should focus on achieving satisfactory functionality of the system whilst easing operation and minimizing required efforts for maintenance.

Topic 1: Intake and Diversion Weir

An intake should function with minimum operational and maintenance requirements. The main objective of the weir is to control the upstream water level, divert water towards the intake and to ensure a constant flow at the intake area.

The designer has to provide a **weir regulation scheme** that defines how the weir must be operated at different flows, especially during floods

➔Operation follows the design

Transport of silt and sediment occurs mostly during high flows, often only a few days per year, and also depends on the general amount and size of the material. The river section upstream of the weir has to be cleaned (flushed) regularly from bed-load, silt and debris. The interval in which such measures are carried out cannot be strictly defined, but depends on the specific characteristics of the river and its sediment load. Commonly such procedures are required if certain levels of sedimentation are reached.

To allow flushing of the upstream section weirs should always be equipped with sluice gates adjacent to the intake. By opening this gate the accumulated debris can be flushed downstream through the gate. Regular cleaning of the intake area ensures that sediments and bed load are not carried into the intake. Flow velocities remain low, allowing sand particles to settle in the area upstream of the intake thus reducing sedimentation in the water conveyance structures.

Besides flushing, the only other routine maintenance task is the lubrication of the gates. Normally there will be a flushing sluice gate positioned adjacent to the weir and an intake isolation gate positioned at a point behind the intake orifice. These will normally be conventional fabricated gates adjusted with a coarse threaded central shaft. Regular greasing of the shaft is required to ensure easy opening and closing of the gates.

Periodic checking of the overall intake structure for cracks and damage should be conducted as required. This is particularly important following heavy flood flows where large objects such as logs and boulders can inflict damage on the weir / intake structure.

During extreme flood flows the intake gates are often shut (i.e. the complete plant is shut down) for safety reasons to prevent the following structures (i.e. headrace, forebay etc.) from overflow and damage. At the same time the flushing gate should be opened to avoid excessive siltation, allow safe passage of larger rocks and boulders and to reduce the overall hydraulic force on the structures by lowering the water level upstream of the weir.

Figure 11: Picture of flood flow at weir

Figure 12: High flow going over weir

Maintenance Activity and Frequency:

Task:	Frequency:
Flush intake	Weekly / as required
Grease spindles of gates settling tank (use water-resistant grease)	Monthly
Inspect overall structure for damages, fractures and cracks. Watch for changes of existing fractures.	Monthly and after every flood event (OBSERVATION OF SUCH EVENTS REQUIRE IMMEDIATE EVALUATION BY AN ENGINEER)
Watch seepage flows, especially watch for increasing seepage flows as this is a signal for possible failure.	
Watch for erosion downstream of weir, spillway or stilling basin and erosion behind wing walls.	

Topic 2: Settling Basin

To allow proper operation, i.e. to ensure that sediments are settled as per design of the basin, it is crucial that the required and defined water level in the basin is maintained at all times. A lower than required water level would result in increased flow velocities, which would prevent suspended sediments from settling on the bottom of the basin.

The settling basin requires regular flushing to ensure its effective volume is maintained[1]. The exact time required between flushing will depend on the amount of waterborne debris settling in the basin. This will change depending on the seasons. During the rainy season more sand and silt will be transported by the river, therefore more frequent flushing of the basin will be required. The maximum permissible height of accumulated silt will depend on the specific design of the basin. During flushing, less or no water flows to powerhouse. Flushing should therefore be intense and rapid. If flushing does not remove all sediments, remove sediments manually.

At some MHPs (more frequently at SHPs and large hydropower plants) sand traps with two or more parallel basins are provided. The designer must clarify how such sediment traps should be operated at low and high flows and for flushing.

Periodic removal of mould, moss or any other growth developing on the structure should also be carried out. The trash rack where fitted has to be cleaned from leaves and debris daily. The steel structures (trash rack, gates, etc.) have to be painted with tar epoxy paint as required.

Figure 13: Settling basin being flushed

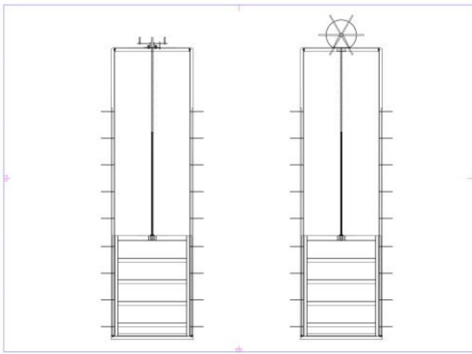


Figure 14: Typical flushing gate design

Maintenance Activity and Frequency:

Task:	Frequency:
Clean trash rack thoroughly	Daily
Flush the settling basin	Weekly / as required
Remove mould and algae from walls (not with a wire brush as this will damage the concrete)	Monthly
Grease spindles of gates settling tank (use water-resistant grease)	Monthly
Cut grass and bush around the intake structures	Monthly
Tighten flushing gate seals if leakage becomes excessive	As required

[1]As the settling basin fills with sediment, its volume reduces resulting in an increase of flow velocity. This in turn reduces the amount settling that can take place for a given flow of water therefore reducing its effectiveness.

Repaint steel structures (racks and stop log grooves) with tar epoxy paint (see next section for specification)	Annually
Inspect overall structure for damages, fractures and cracks. Watch for changes of existing fractures.	Monthly and after every flood event (OBSERVATION OF SUCH EVENTS REQUIRE IMMEDIATE EVALUATION BY AN ENGINEER)
Watch seepage flows, especially watch for increasing seepage flows as this is a signal for possible failure.	
Watch for erosion downstream of spillway and / or flushing gate.	

Topic 3: Headrace Channel

The headrace channel is one of the most critical civil components and is very susceptible to damage. It often traverses relatively steep slopes therefore is exposed to the risk of landslides. Leakage from the headrace will cause erosion and can over time result in the headrace slipping off the slope with catastrophic consequences. Blockages of the channel as a result of landslips above the channel will result in over spilling with similarly catastrophic results.

Regular (daily) walks along the headrace must be conducted to check for fallen trees, possible landslides or scouring due to rainwater or channel leakage.

In order to ensure proper operation and to maintain the conveyance capacity, there should be no obstacles or sediment depositions in the headrace. Obstacles can be objects in the headrace but also growth of vegetation. If the flow velocities are too small, e.g. after long periods of low flows, or following floods, there can be sediment depositions which must be flushed or removed manually. Excessive vegetation in earth channels must be removed. Both, obstacles or sediment depositions can reduce flow velocities and increase water levels that can cause dangerous spill over the channel side walls.

Figure 15: Damage of an unlined earth channel.

Figure 16: Properly maintained and functioning above ground stone masonry headrace channel.

Maintenance Activity and Frequency:

Task:	Frequency:
Watch for leaks and seepage flows, especially watch for increasing seepage flows as this is a signal for possible failure.	Weekly
Check for landslides and erosion along the headrace route and clear and repair where necessary	Weekly
Watch stability of earth channels (erosion, slope stability) and structural integrity of concrete channels (cracks, leaks)	Weekly
Cut back growth of plants / grass along the access foot path between the intake and the forebay	Monthly
When empty, check closely condition of channel and repair with cement / stone masonry as appropriate	6 monthly
Inspect overall structure for damages, fractures and cracks. Watch for changes of existing fractures.	Weekly and after every flood event (OBSERVATION OF SUCH EVENTS REQUIRE IMMEDIATE EVALUATION BY AN ENGINEER)

Topic 4: Forebay

The transitional function of the forebay connecting the headrace channel to the penstock means its efficient function is critical to the overall operation of the scheme. Maintaining the correct water level in the forebay is important to ensure that sufficient water reaches the turbine, that the operating head is satisfactorily maintained and that entry of air into the penstock is avoided. Regular monitoring and inspection of the trash rack is required to ensure it maintains its correct dimensions and providing the correct level of protection to the turbine. The condition of the flushing gate and in particular of the seal have to be inspected regularly to ensure that there are no water leaks[2].

The forebay is often positioned relatively close to the edge of a slope in order to facilitate effective dimensioning and design of the penstock. Given this and the weight and pressure of water it has to support, regular close inspection of the forebay structure is necessary. In particular it is important to monitor the area around the penstock exit as this is the most common area where leakage is likely to appear. If leakage develops this must be repaired immediately, e.g. thorough grouting and re-cementing of the source of the leak. Any scouring, be it due to leaking from the basin or due to improper drainage, can cause the failure of the basin with catastrophic and fatal consequences.

[2]It is essential to avoid conveying flow from the intake to the forebay only for it to leak away through the flushing gate.

Maintenance Activity and Frequency:

Task:	Frequency:
Clean trash rack thoroughly	Twice daily (or as required)
Flush the forebay if sediment is more than a few centimetres. The turbine must be stopped for this activity.	Weekly
Clean the drainage channels around the forebay using a shovel or a spade.	Weekly
Check for leaks from the forebay (especially from the drainage pipe and flushing valve discharging into the spillway)	Monthly
Clean breather head / air inlet from cobwebs and insect nests.	Monthly
Cut grass around the forebay area	Monthly
Repaint steel structures (breather head and pipe, level sensor protection pipe and brackets, ladder) with tar epoxy paint.	Annually
When empty, check closely condition of forebay and repair with cement / stone masonry as appropriate.	6 monthly

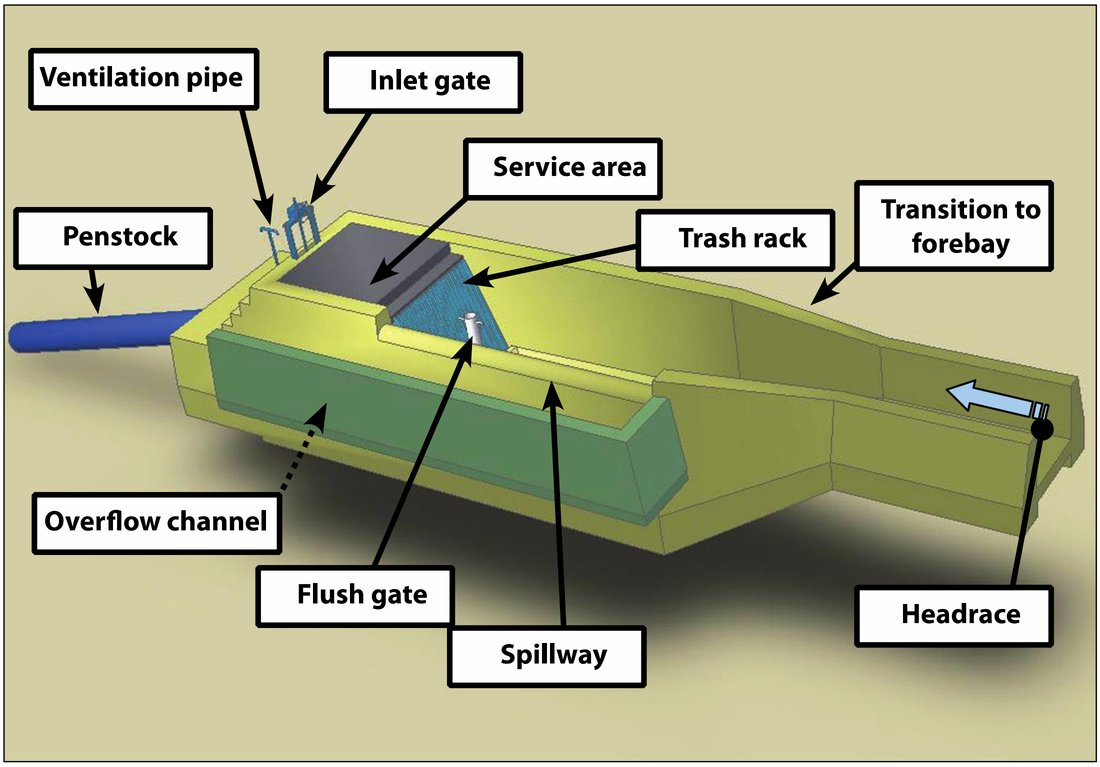


Figure 17: Typical forebay and component terminology

Topic 5: Penstock

Where steel pipes are used for the penstock (most common), corrosion protection is the main area of maintenance required to assure the durability and long life of the penstock. Effective anti-corrosion treatment is a 2 stage process. This comprises firstly of ‘rust removal’ and secondly ‘surface treatment and painting’. This treatment should be carried out both prior to installation in a suitable workshop and on site after welding. Annual or bi-annual repainting is necessary to prolong penstock life.

Checking the penstock for leakages must be carried out regularly and remedial measures undertaken immediately if water leakage exists.

It is important to ensure that satisfactory dewatering / drainage along the headrace route exists to avoid any scouring of anchor and sliding blocks as these will undermine the stability of the penstock potentially resulting a breakdown of the pipe.

Figure 18: Poorly maintained penstock pipe. Over time lack of protection and contact with soil / vegetation will lead to corrosion.

Figure 19: A properly maintained penstock kept free from contact with other elements and regularly painted.

Vegetation of grass, trees and bushes close to the penstock should also be controlled. Above ground penstock pipes should be kept free from any contact with earth and vegetation to minimize the probability of corrosion taking place.

Maintenance Activity and Frequency:

Task:	**Frequency:**
Keep access path and drainage channels along the penstock clear. Cut grass and bush.	Weekly or more frequently if required (e.g. after heavy rainfall)
Keep steel structures of pipe bridges and supports clean from dirt and leaves (esp. around the abutments) to prevent corrosion.	Weekly or more frequently if required (e.g. after heavy rainfall)
Check for leaks from the penstock; if you observe any leaks, stop the plant and report to responsible persons.	Monthly
Check for deformations, settlement or movement of anchor blocks.	Monthly
Check for landslides and erosion along the penstock route and repair particularly around the anchor blocks and penstock supports and	After heavy rainfall

repair as required.	
Buried penstocks: check for deformations or wash out of the bedding material.	Monthly or more frequently if required (e.g. after heavy rainfall)

Topic 6: Powerhouse& Tailrace

The powerhouse shall protect the generating and control equipment from adverse weather conditions and prevent access by unauthorized persons. Checking the housed equipment for leakages and keeping everything clean are the tasks to execute regularly. Repainting equipment and building has to be done if required.

Maintenance Activity and Frequency:

Task:	**Frequency:**
Maintain adequate ventilation to evacuate heat from generator	Always
Clean drainage channels and culvert around powerhouse	Weekly
Thoroughly clean powerhouse walls, roofs, doors and windows	Weekly
Cut grass and bush around powerhouse.	Monthly
Clean and repaint powerhouse walls and timber structures	Yearly or Bi-yearly
Sweep powerhouse floor and terraces.	Daily
Clean tailrace stilling basins and channels	Weekly
Check river bank protection at powerhouse and tailrace.	Monthly and after flood events

Figure 20: Powerhouse of a 15kW MHP.

Figure 21: Example of a properly maintained powerhouse.

Topic 7: Civil Structure Materials

Most of the civil structures are carried out in stone or brick masonry or concrete. Additional materials are steel (reinforcement, pipes and support structures) soil, all kind of prefabricated pipes and wood.

Stone Masonry

Stone masonry is the usually the foremost utilized material, used for the weir, intake, headrace channel, forebay, for anchors and sliding blocks along the penstock, foundations and in some circumstances for the powerhouse. The principal reasons for this is the lower cost if constructing with stone masonry due to reduced need for cement and steel (reinforcement) compared to concrete, the main alternative material.

Depending on the specific exposure and function of the construction, different mixtures of mortar are used. For many components mortar 1:4 (cement: sand by volume) is sufficient. Structures facing floating water should be plastered (mortar 1:3), pointed (mortar 1:2) or carried out in mortar 1:3.

While carrying out stone masonry works the quality of the stones must be supervised. In most cases river stones have a very good hardness and are available in applicable sizes. Before laying the stones they must be cleaned from sand and dirt to ensure a proper binding to the mortar.

The mortar has to be mixed in a clean and watertight platform or wheelbarrow or with a machine. Approximately 23 litres of water have to be added per bag (50 kg) of Portland cement, assuming that the sand is dry. The mortar has to be mixed thoroughly and should have an easy to apply consistence. As the ready mortar has to be used within 30 minutes the quantity mixed each time should be determined accordingly.

Curing is done by keeping the masonry wet a minimum of five days by covering with a wet burlap or other saturated material or by sprinkling with water.

Brick Masonry

Brick Masonry is almost only used for the erection of the powerhouse, as bricks are mostly more expensive than widely found river stones. In fact the usage of bricks or stones is an economic consideration, as the prices vary regionally according to the availability.

Almost always the bricks are laid in mortar 1:3. A good, constant quality of the bricks must be ensured; before laying them they have to be watered to prevent the masonry from drying too early in tropical climate, which would cause low quality mortar bedding. Curing has to be provided in the same way as for stone masonry.

Concrete

In some cases concrete is used for the heavy-duty structures (for example weir and intake). Due to the larger expenditure for cement, the usage is not very common. However, for some details, like operation platforms, bridges and foundations, the application of concrete is easier and longer lasting than that of masonry.

Concrete is composed of cement, sand, gravel and water. Usually 300 kg of Portland cement (Type I) and 1.2 m^3 well proportioned sand and gravel will yield about 1 m^3 of quality concrete. The 1.2 m^3 sand and gravel should have a ratio of 65% gravel and 35% sand. This is about a 1:2:4 (cement: sand: gravel) volume proportion.

The water/cement ratio is a critical factor in quality concrete. Lowering the water content will result in stronger concrete, but the amount of water must be enough to produce a workable mix. Excessive water will cause shrinking cracks and a weak porous concrete. The water/cement ratio is the ratio of the weight of water in the mix (including the water in the sand and the gravel) to the weight of cement in the mix. The water/cement ratio for a quality concrete should be 0.45. To maintain this ratio, limit water to 20-25 l/bag (50 kg) of cement for dry sand and gravel and 15-20 l of water when wet sand and gravel is used.

The mortar has to be mixed thoroughly. If the concrete is hand-mixed it must be done on a clean watertight platform or wheelbarrow. The amount should be limited to 0.1 m^3, mixing and placing should be completed within 10 minutes. Cement and sand should be first mixed while dry until the mixture is thoroughly blended and uniform in colour. Then the gravel is added and mixed before adding the water. Mixing should be continued until the concrete is of a uniform colour. After placing the concrete has to be cured to prevent from rapid evaporation of water, which causes cracking, shrinking and low quality concrete. Protect the concrete from rapid drying for five days after placement. Submerging in water, applying membrane curing, or covering with moist burlap, canvas, straw, plastic or soil may accomplish this.

Stone masonry vs. concrete

Use of stone masonry permits savings by reducing the quantity of cement required compared to concrete. One m3 of plastered stone masonry requires approximately 0.25 m3 of mortar or 0.07 m3 of cement (100 kg). This is about one-third of the amount of cement required for poured concrete. Aggregate for concrete usually has to be purchased or produced from larger stones on site, whereby river stones, usually used for stone masonry, can be found in the close vicinity to most sites. If structures can be "slimmed down" by the use of reinforced concrete, the cost of 80 to 120 kg of reinforcement bars per m3the additional cost for formwork has to be considered.

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present the main civil components of a conventional MHP describing their main maintenance requirements and frequency. Explain what the consequences could be if the maintenance is not properly carried out.

PRACTICAL ASSIGNMENT / PROJECT:

For a conventional stand alone MHP, create a maintenance schedule for the entire civil component. This should indicate whether the tasks should be carried out weekly, monthly or at a longer period.

PRACTICAL DEMONSTRATION:

At an existing MHP carry out the following tasks:

- Flush the sandtrap and / or forebay tank
- Clean the trash rack
- Flush the intake

With the system full of water, conduct a detailed inspection of the entire headrace and penstock starting at the intake through to the powerhouse formulating a detailed report on its condition and indicating where it attention / improvement is required.

Learning Unit Self Assessment:

Question (simple)	Answer by trainee
What is singularly the biggest danger posed to an intake?	
Why is it necessary to have a sandtrap?	
How is flow normally conveyed from intake to the forebay tank?	
What will happen to the operating head if the trash rack is blocked?	
Approximately how often should the sandtrap be flushed?	
What is the purpose of the spillway and how large does it need to be?	
When will the spillway have water flowing over it?	
What happens if the forebay water level is too low?	

Learning Unit 3: Maintenance Tasks & Schedule for Electro-Mechanical Equipment

As with any other industrial machine, the moving parts of a MHP project namely the electro-mechanical equipment have a defined lifetime. Consequently maintenance of the different components must adhere to a pre-defined time schedule. As is common with industrial machines, the lifetime of the individual components are measured in hours of work. This implies that as a pre-requisite for implementing a controlled and disciplined maintenance program, operating time MUST be measured and recorded. This requires that an hour meter must be installed in the electrical control panel to record the exact number of operational hours. Similarly all maintenance work carried out on the plant must be recorded by the operator. This is usually done manually with entries being made into the logbook located within the powerhouse. The logbook MUST be diligently kept up to date enabling accurate referencing of previous maintenance work carried out.

Topic 1: Turbine

The type of maintenance required for the turbine will depend very much on the type of turbine installed. This manual will focus on the normal maintenance requirements for cross flow, pelton and propeller turbines as these are deemed the most commonly used in the context of village rural electrification projects. The majority of information provided is general and applies to all types of turbine mentioned. Where the information is specific to a particular type of turbine this will be mentioned.

Properly manufactured good quality turbines require surprisingly little maintenance. The following text presents the main areas where periodic checks and maintenance will be required.

Bearings

The main runner shaft bearings must be greased in accordance with the bearing manufacturer's specifications and importantly using the correct grade of grease. The runner bearings for cross flow and pelton turbines will be of the spherical roller type mounted either directly on the side of the turbine housing mounted on a sub frame if housed in a plummer block housing. For propeller turbines, the exact type of bearing depends on the specific type of propeller turbine.

Figure 22: Sidewall mounted runner shaft bearing housing on a cross flow turbine. The grease nipple is visible on the top of the housing.

Figure 23: Spherical roller bearing of the type commonly used for turbine runner shaft bearings.

It is important not to over grease the bearings as this result in them overheating. The bearings do NOT require daily greasing! As mentioned earlier it is important to follow the manufacturer's instructions regarding the frequency and volume of grease to be applied[3].

The advantage of the plummer block bearing is that it is possible to periodically remove the top cover and inspect the bearing from inside. If required the old grease can be removed and replaced with new. For inspection of sidewall mounted bearings it is necessary to remove the outer cover providing visual access to the outer side of the bearing only.

Figure 24: View of plummer block bearing with the top cover removed.

Figure 25: Inspection of a sidewall mounted bearing of a T15 crossflow turbine.

To accurately measure the temperature of the bearings when operating, a special digital thermometer should be placed on the bearing housing. In normal practice, however, touching the housing with ones hand is sufficient. A rule of thumb is that if one can bear ones hand on the housing then the bearing is not overheating. If, however, the housing is too hot to bear, this indicates the bearing is running too hot and further exploratory measures into the reason for this should be carried out. Overheating of the bearing could be due to too much or too little grease, false alignment, wrong adjustment or simply that the bearing is badly worn and requires replacement.

Guide vane / spear valve assembly

Besides the runner, the only other moving part of a turbine is the guide vane assembly sometimes also referred to as the flow valve. For manually controlled cross flow turbines this will require periodic greasing of the thread bar mechanism. Over time the thread will wear resulting in a loosening / increase play movement in the mechanism. If this becomes too loose the mechanism will need replacing. Normally however, this mechanism will have a relatively long lifespan.

On pelton turbines, flow is controlled by a spear valve adjusted with an adjuster wheel. This adjuster will require periodic greasing similar to the cross flow guide vane adjuster. The pelton is primarily a high head turbine therefore relatively high pressures are acting on the turbine. Depending on the quality of water and the operating head, the spear valve will over time wear resulting in pitting and roughening of its surface. The spear valves on a pelton should therefore be

[3]There is a tendency amongst operators to think "more the better" and subsequently squeeze grease into the bearings almost on a daily basis – this is not the correct approach. This will have detrimental effect on the lifetime of the bearing and is a waste of grease.

periodically checked and repaired when necessary. Repair is done by rebuilding the hard surface with special hardened welding before machining back to the original dimensions. Similar rebuilding and machining is carried out on the actual pelton turbine buckets. Visual checking will normally require the full removal of the spear valve and turbine housing covers.

Figure 26: View of the guide vane adjusting mechanism on a cross flow turbine.

Figure 27: Adjustable spear valve on a pelton turbine.

For simple propeller turbines, very often the guide vane is fixed with seasonal adjustable only possible by moving the guide vane and / or runner blade position manually to a fixed set of positions[4].

Figure 28: Open flume propeller turbines under construction. The guide vane (yellow) and vertical adjusting mechanism is visible to the side of the runner shaft casing.

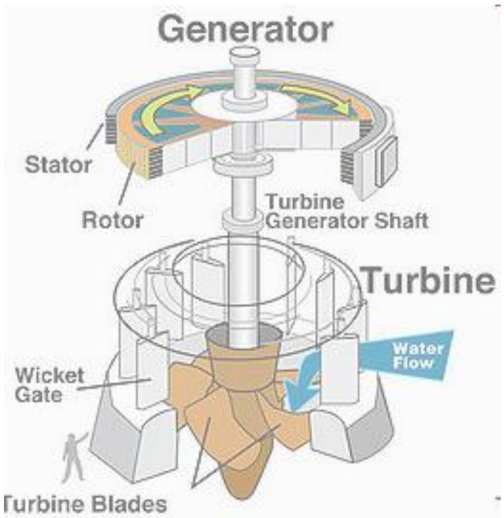


Figure 29: Schematic illustration of guide vane adjusting mechanism on a propeller turbine.

Runner

Besides the bearings and guide vane assembly, the main component of the turbine that will require periodic inspection is the runner. If the settling basin and trash rack

[4]In order to accommodate different seasonal flow conditions, a number of fixed settings are often made facilitating seasonal adjustment.

are functioning properly the turbine runner should not be subjected to high levels of erosive material such as sand / grit. However, low cost schemes are often forced to compromise to some extent on the size and sophistication of settling basins therefore waterborne sediments can never be eliminated entirely meaning some degree of erosion is bound to take place within the turbine over time.

To facilitate easy inspection of the runner, cross flow turbines are normally fitted with an inspection access point on the top of the turbine. Alternatively if the headrace is large enough access from the tailrace and viewing from beneath the turbine offers an alternative method. A similar approach applies for pelton turbines. Inspection should identify any signs of erosion and cavitation. On cross flow turbines the condition of the runner blades should be inspected to ensure there are no bends or damage as a result of foreign objects passing through the turbine. Signs of wear after a number of years operation is normal, however, provided the runner is not showing any serious signs of erosion or damage that will cause significant under performance there is no need to carry out any repairs. Many turbines can run for years and decades before requiring runner overhaul. This will be a very site-specific issue and depend very much on both the quality of flow (how clean and free from silt is the water) and equipment (material of the runner).

Inspection of a propeller runner is more difficult and will require dismantling of the turbine. Given the relative difficulty of inspection, beyond periodic overhaul schedules (10 – 15 years), inspection of the runner is only normally carried out if a problem arises.

Figure 30: Crossflow runner viewed from below turbine. Still in good operational condition after 10 years continuous operation.

Figure 31: Final polishing of a pelton bucket after rebuilding work.

General

Besides the checks and maintenance of the turbine moving parts, it is also necessary to conduct regular general checks. This includes checking the tightness of all bolts including those securing the turbine to the base frame as these can gradually loosen over time as a result of vibration. Vibration of the turbine should be monitored closely. Any increase in the normal level of vibration is usually the first indication of a problem with the turbine.

The condition of the static head pressure gauge usually positioned in the turbine-penstock adaptor should be checked for proper operation and replaced if necessary.

Maintenance Activity and Frequency:

Task:	Frequency:
Grease runner bearings in accordance with manufacturers specifications	As per instructions (usually monthly)
Clean turbine-generator unit and related equipment from accumulated dust and dirt	Weekly
Check valves for leaks; tighten stuffing boxes when excessive leaks occur (more than one drop per second). Replace stuffing box / packing rings when the gland can no longer be tightened.	Weekly / Monthly
Grease spindle of turbine shut-off valve using water resistant grease	Bi-monthly
Internal inspection of runner & flow valve	Annually

Topic 2: Mechanical transmission

The mechanical transmission from turbine to generator is the most maintenance intensive component of the electro-mechanical equipment. Depending on whether the arrangement is a direct drive or step-up belt drive transmission the system will contain different components and require different levels of attention.

The simplest form of direct drive will simply be a coupling joining the turbine shaft with the generator shaft. This arrangement is common for small schemes where the stresses on the turbine shaft do not demand a separate intermediate shaft be added.

Where direct linking of the shafts is not possible, an intermediary shaft arrangement is required. This will be suspended by plummer block bearings secured to a base frame. This arrangement will require two flexible couplings fitted at both ends of the secondary shaft.

Similarly with step-up transmissions, pulleys can be fitted directly onto the turbine & generator shafts where forces are not too high. Where the forces are too great then the addition of a drive layshaft is necessary. The level of sophistication of the transmission will determine the maintenance requirements.

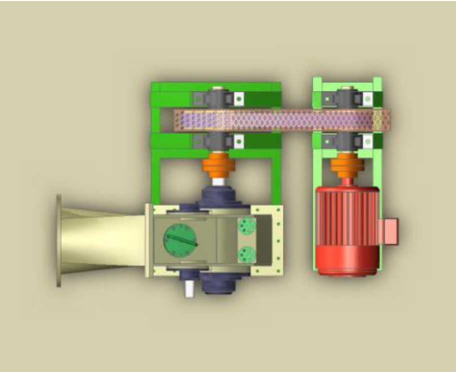


Figure 32: Schematic view of step up transmission.

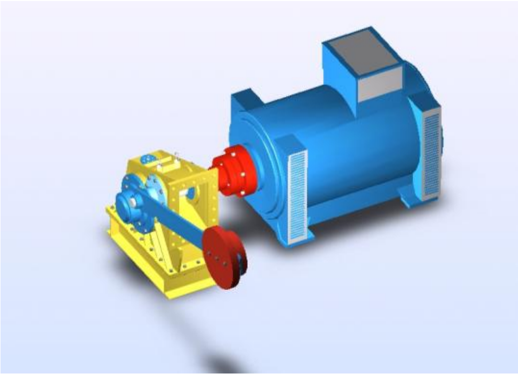


Figure 33: Schematic view of direct drive.

Belt drives

Maintenance of belts is essentially the same regardless of whether the pulleys are fitted directly on the turbine and generator shafts of suspended independently via a layshaft arrangement. Maintenance comprises monitoring the tension and correct alignment of the drive belts and replacement when necessary. This applies equally for both flat and V belt drives. Drive belts have a defined lifetime and should be replaced in accordance with the manufacturer's recommendations. If worn out belts are not replaced, their performance will deteriorate resulting in reduced output of the scheme. Where the pulleys are fitted directly onto the turbine and generator shafts, the supporting bearings must be closely monitored for wear and replaced when necessary. This arrangement is normally only applicable for low power outputs where the radial forces on the shafts is within acceptable limits.

Figure 34: V belt step-up transmission with pulleys fixed directly on generator / turbine shafts.

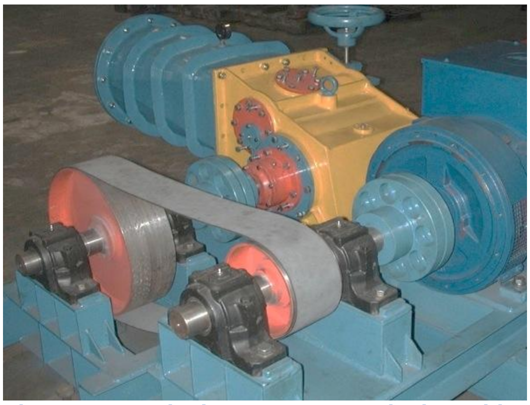


Figure 35: Typical step-up transmission with layshaft arrangement showing plummer block bearings and flexible couplings.

Alignment tolerance for V belt drives is much greater than for high efficiency flat belts. Tensioning of the flat belt drives is also more critical and must follow exactly supplier's guidelines to ensure accurate and correct tension of the belt is achieved. Failure to do this will result in sub standard performance and may result in the belt slipping off the pulley and incurring irreparable damage.

Similarly tensioning of V belts is less critical than flat belts, nevertheless effort should be made to ensure that V belts are aligned and tensioned properly as this will extend their lifetime considerably.

Pulleys and Coupling

Pulleys under normal operating conditions do not require any special maintenance beyond general observation that there are no stress related cracks or deformations. It is important to ensure that no grease or oil finds its way onto the pulleys as this will detrimentally impact performance and damage the drive belts.

The most common couplings used for transmitting power are flexible rubber couplings. These come in a range of different quality levels. The removable rubbers will require periodic replacement. The time period between rubber replacement will depend both on the quality of the product and importantly the accuracy of alignment of the two coupling halves (see below). Regular monitoring of the wear of these rubbers is required and prompt replacement when excessive free movement or visible wear is apparent.

Figure 36: Flat belt transmission arrangement showing turbine, pulley, plummer block bearings and flexible coupling with guard.

Figure 37: Checking the free movement of the rubbers of a flexible drive coupling.

The most critical factor determining the lifetime of the flexible coupling rubbers is the accuracy of the vertical and horizontal alignment. Consequently great attention should be paid to ensuring that as close to perfect alignment is achieved when initially installing replacement rubbers or when reassembling the coupling after maintenance to other components. The required level of accuracy can only be achieved by the use of a number of dial test indicators in combination as shown below.

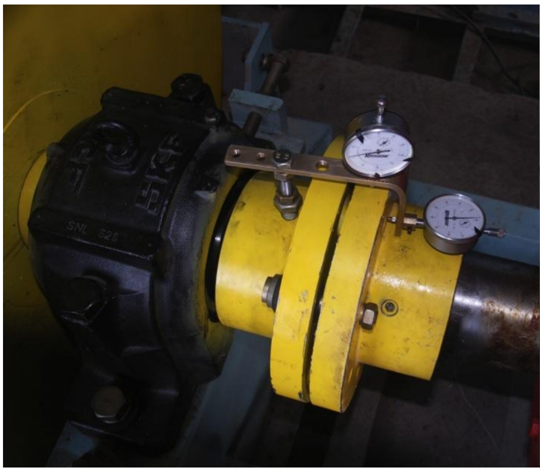


Figure 38: Checking alignment of the flexible coupling using 2 dial test indicators in combination.

Figure 39: Checking alignment of the flexible coupling on a flat belt drive transmission driven with a crossflow turbine.

Maintenance Activity and Frequency:

Task:	Frequency:
Check tension of drive belts and adjust where necessary	Weekly
Grease layshaft plummer block bearings	As per instructions (usually monthly)
Inspect inside plummer block bearings (removal of top cover and visual inspection)	Annually
Check free movement wear of the rubbers of flexible couplings and replace as required	Monthly
Replacement of drive belts	In accordance with manufacturers specifications or when worn

Topic 3: Generator

The types of generator used for MHP projects fall into 2 main categories:

1. Asynchronous
2. Synchronous

The general maintenance requirements for modern day generators are very small. In most cases if there is a fault with the generator then this falls beyond the capacity of the operator to analyse and undertake any repair. Major repairs to the generator must be carried out by specialist repair companies.

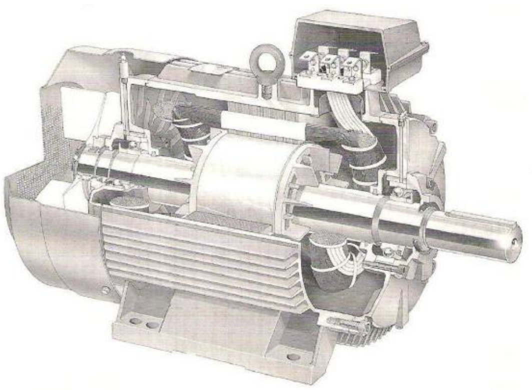


Figure 40: Cut away view of an asynchronous generator.

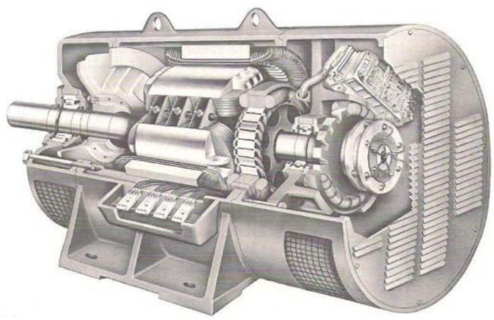


Figure 41: Cut away view of a synchronous generator.

Asynchronous (including IMAG)

This type of motor / generator is extremely robust consequently there is virtually no maintenance required beyond periodic checking of bearings particularly if the drive pulley is fitted directly on the generator shaft.

Brushless synchronous generator:

Similarly with the asynchronous generator, there is virtually no maintenance required beyond periodic checking of bearings particularly if the drive pulley is fitted directly on the generator shaft. The AVR is a relatively sensitive component and therefore good protection of the AVR must be ensured to avoid it coming into contact with dirt and damp. All guards and ventilation ducts should be checked that they are properly fixed and free from obstruction.

Brush type synchronous generator:

Brushless generators are by far the most maintenance intensive type of generator used on MHP projects. Their mass production (mostly from China) and low cost means they are still widely used particularly on very small low cost installations. Regular monitoring of the condition of the brushes is essential and relatively regular replacement will be necessary. In addition to the brushes, the slip rings upon which the brushes run will also wear. These will require refurbishment on a periodic basis.

It is important that a spare set of brushes is always available on site ready for immediate fitting if required.

Figure 42: Low cost brush type synchronous generator on a 5 kW MHP

Figure 43: Brushless synchronous generator driven by a cross flow turbine.

Maintenance Activity and Frequency:

Task:	Frequency:
Clean external housing and check removable terminal covers / ducts to make sure insects cannot enter.	Weekly
Check conditions of brushes. Replace before they are fully worn out.	Monthly (as required)
Remove old grease and lubricate the bearings as described by manufacturer with the specified grease quantity.	As specified (usually 30gr. every 4500h).
Temperature of bearings and stator are indicators for overload or other problems. Check sensor display or feel by hand.	Daily
Ensure the power house is properly ventilated and the temperature is below 35 degree Celsius	Weekly
Generator and the base frame/ foundation should be kept dry. Ensure any leakage (e.g. from stuffing box) C or condensation is properly drained away from the generator and base frame.	As observed
If the generator is not operated for a prolonged period, it should be protected from humidity (e.g. heating) to avoid problems with the insulation.	If applicable
Check automatic voltage control to ensure voltage is correct in isolated operation for standalone schemes and that cosPHI is correct for grid connected operation	Daily

Topic 4: Controller& Ballast Load

The controller for sites up to 100kW is normally an Electronic Load Controller (ELC).

The power output of the turbine is set by adjusting the flow valve / guide vane hand wheel. If the consumer load is smaller than the generated power, all excess power is diverted to the ballast load. This diversion process is handled by the ELC.

In the event that the available water flow is not sufficient (e.g. in dry season) to supply the load, then the load must be reduced to match the available power. This means no power is diverted to the ballast.

Electronic controllers are sensitive components and must be carefully installed and looked after. Humidity, insects and small animals can detrimentally affect the controller's function if they enter the controller. If permitted, mice will eat the cable insulation causing short-circuiting with fatal consequences.

Keeping the powerhouse and the controller cubicle clean and secure from entry of foreign elements is important. Frequently mice or insects like the safe cubicle box to make their nest. The heat generated within the cubicle attracts mice and insects to establish nests there, therefore it is important to ensure the cubicle door is always kept firmly closed and then any ventilation holes are secured with the correct gauge wire mesh.

When the power plant is off, periodic cleaning inside the cubicle is required to remove any insects and general build up of small debris (e.g. cobwebs) that may have entered the cubicle.

As with the generator, there is actually relatively little maintenance required for an ELC beyond keeping it clean and periodically checking the tightness of the main power cables.

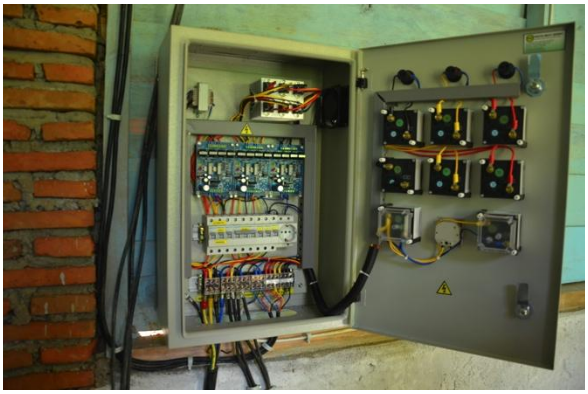


Figure 44: Inside a clean and well maintained wall mounted ELC cubicle.

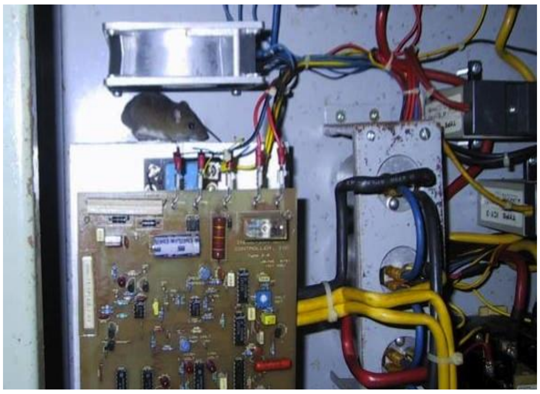


Figure 45: Mice and other small animals as seen here are attracted to the cubicle heat. They must be kept out to avoid them eating cables.

The condition of the various meters should also be monitored and if there is any indication of malfunction should be replaced immediately. This is important to ensure correct monitoring of the plant when operating. Of the highest importance is the hour meter that measures the operational time of the plant. This MUST be working at all times and if damaged must be immediately replaced. Most maintenance tasks are defined by hours of operation therefore it is of paramount importance that this clock functions properly.

The most maintenance intensive component of the control system is usually the ballast or dummy load. This is usually a water or air heater ballast load. Water heater elements that form the ballast must be constantly submerged in water therefore require a secure and constant water supply. If they are operated with insufficient water they will overheat and burn out resulting in failure of the control system. This is a main disadvantage of water heaters over air heaters. Because of this they are increasingly less commonly used compared with air heaters unless there is a requirement for warm water[5].

Air heaters ballasts are relatively simple to install and maintain. They can be located either in or outside the powerhouse, however, must be kept out of reach of children and have to be properly ventilated to facilitate efficient cooling. They should also be mounted with the elements a safe distance from timber or other inflammable material to avoid creating a fire hazard.

Figure 46: Air heater ballast load suspended in the powerhouse with proper ventilation.

Figure 47: Externally installed air ballast.

The lifespan of the ballast load will depend on how much work it undertakes. In most schemes high load to ballast is only experienced during start up therefore overall workload of the ballast is relatively small resulting in a long lifespan of the elements.

Regular monitoring of the condition of the ballast load must be carried out. Irregular behaviour of the ELC usually indicates a problem with the ballast load. If any heater elements are identified as faulty they MUST be replaced immediately. Continuing to operate the scheme with a damaged ballast load can result in much more serious and expensive damage of the ELC and or generator. Failure of the ballast load can potentially lead to the turbine and generator going into runaway condition. Runaway condition not only places enormous stress on the entire electro-mechanical equipment but also can create high voltages posing a serious safety hazard. Runaway speed condition MUST be avoided!

[5]For example in the mountainous regions of India, Nepal, Pakistan, Afghanistan etc. where temperatures in Winter are very low and heated water is required

Maintenance Activity and Frequency:

Task:	Frequency:
Clean inside of cubicle / panel clean and keep free from insects or animals (mice, rats, wasps…). Ensure any possible entry points are covered with suitable mesh.	Weekly
Check condition of all meters and indicator lamps	Weekly
Check that the hour meter is working	Daily
Check condition of ballast load and replace elements as and when necessary.	Weekly
Check the ventilator of the panel is working and cables or controller items are not over-heating	Daily
Check all grounding connections in the power house and their function	Monthly

Topic 5: Powerhouse, Tools & Consumables

Powerhouse

The condition and cleanness in a powerhouse often reflects on how the entire scheme is maintained. If the powerhouse is tidy and clean there is a good chance the entire power plant is maintained to the same standard – and visa versa!

The powerhouse has a very important function. First and foremost it houses the electro-mechanical equipment therefore must provide a secure and safe environment for this equipment. Secondly it provides shelter for numerous other items and in some cases can also incorporate a small office, basic workshop and sleeping quarters for the operators. The extent of the facilities that are incorporated into the powerhouse will depend on the size of the power plant and also the proximity and accessibility of the powerhouse to the load centre.

Figure 48: A poorly kept powerhouse & E/M equipment. This indicates a poorly maintained scheme overall.

Figure 49: A well managed powerhouse. Clean and tidy after 10 years of operation!

The maintenance requirements of the powerhouse are as follows:

- Must be kept clean and dry at all times.
- Tools and spare parts should be properly stored in the powerhouse, ideally in a cabinet.
- The operator's logbook should be kept in a clean and safe place within the powerhouse. Copies of the records should be archived at a different location on a monthly basis.
- A copy of all handbooks describing the components of the powerhouse should be kept either in the powerhouse or in alternative secure environment (i.e. with the management).
- No animals should be allowed to enter the powerhouse (chickens, mice, rats, insects) and the powerhouse should be kept free of any obstacles. It should not become a village storeroom!
- It should be properly ventilated at all times.
- It should be adequately protected from floods or water entering during heavy rains.

Tools & Consumables

To enable the operator to undertake his/her task properly it is essential the MHP scheme is adequately equipped with an adequate tool kit and the necessary consumables.

The tool kit must contain the tools necessary to carry out basic maintenance work on the electrical and mechanical components. Spanners and sockets covering all the bolt sizes of the turbine and a full range of screwdrivers enabling tightening of all types of screws are essential. Additionally hammers, pliers, wrenches and other tools as required must be included. An electrical multi meter for carrying out basic electrical test should also be included. The suppliers of the electro-mechanical equipment should provide the essential tools required for basic maintenance tasks.

Nevertheless, the more comprehensive the tool kit is, the easier it is for the operator to carry out proper maintenance therefore priority should be given to equipping the operator team with a comprehensive set of equipment. All tools should be listed and kept under lock and key in a tool cabinet provided specifically for the task. The operator should be made fully responsible for maintaining the condition and completeness of tool kit.

Equipment for maintenance of the distribution lines and house installations such as ladders, cable cutters, wood saws etc. must also be made available to the operator

To ensure timely and disciplined lubrication of moving parts and replacement of components when lifetime has expired, a stock of the following consumables must be kept permanently in stock and available to the maintenance staff (e.g. stored in the powerhouse).

- Water resistant grease (lithium-based) (e.g. Shell Alvania No. 2 or equivalent)
- Paints: Tar epoxy: (black) with Thinner (for surfaces with water contact) and brushes
- Paint for the outside as specified by the supplier (Type and RAL number)
- Packing rings for valve stuffing boxes where used.
- Seal set for turbine and inspection flange
- 1 set of coupling rubbers (if applicable)
- 1 set of belts (if applicable)
- 2 set of generator brushes (if applicable)
- Blank copy of logbook, pencils
- Torch

Figure 50: The plant logbook MUST be kept up to date on a daily basis by the operator.

Figure 51: A properly equipped and looked after tool kit is an obligatory requirement for the operator.

Maintenance Activity and Frequency:

Task:	Frequency:
Make log book entries recording all operational tasks carried out	Daily
Swept clean powerhouse floor and clean windows	Weekly
Check for any roof leaks and ensure proper ventilation of powerhouse	Weekly
Check that tool kit is complete and functioning	Monthly
Check that the required consumables are sufficient for the next 6 months of operation.	Bi-monthly
Internal cleaning and painting of powerhouse walls	Annually
External painting of powerhouse	Annually

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present for each topic included under this learning unit two of the most important maintenance tasks. Describe the frequency that these tasks must be undertaken and explain possible consequences if they are not properly carried out.

PRACTICAL ASSIGNMENT / PROJECT:

For an imaginary 15 kW stand alone MHP featuring a cross flow turbine, synchronous generator and ELC, prepare a detailed maintenance schedule detailing the weekly and monthly tasks that to be carried out by the operator.

PRACTICAL DEMONSTRATION:

At an existing MHP site conduct an analysis of the electro-mechanical equipment, powerhouse including availability of tools and consumables. Discus with the operator what are the most frequent O&M problems he/she experiences. On the basis of this analysis produce a list of 5 improvements that could be made to improve the overall standard of the MHP.

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
What happens if you over grease turbine runner bearings?	
How does the operator assess turbine runner bearing temperature?	
What is the most critical adjustment for a flexible coupling?	
What indicates a worn out belt drive?	
Name 2 types of ballast load commonly used with ELC controllers?	
Name 2 types of generator used on MHP projects?	
How is operational time of a MHP measured?	
Why is maintaining an operational logbook so important for the maintenance of a MHP?	

Learning Unit 3.1: Maintenance Tasks & Schedule for Transmission & Distribution

Transmission / distribution lines, poles and accessories

The main maintenance of the transmission and distribution lines comprises ensuring there are no obstructions as a result of overgrown trees and fallen branches interfering with the cables. The inherent isolated nature of many MHP projects means that the transmission lines frequently traverse dense vegetation. In these environments it is important that the operator regularly checks that the cables are clear of any interference.

Depending on the specific environment and the type of cables used, it may be necessary to periodically re-tension the cables to ensure they remain at a safe height above ground.

Cable posts& Accessories

The material of the cable poles will largely dictate the type and degree of maintenance required. As presented in Module 1, cable poles can be made from a variety of materials depending on the specific nature of the scheme. For all pole types it is important that regular checks are made to ensure poles are satisfactorily upright and where supporting cables are used, that these are properly tensioned.

For steel and timber poles, they need to be checked for corrosion / rot in particular at the base of the pole where they are likely to come into contact with water and dampness. Where appropriate the poles should be protected with paint or protective oil.

Regarding the cable and pole accessories, it is sufficient to conduct periodic visual checks to ensure they are still in satisfactory condition and fulfilling their tasks.

Figure 52: Erection of transmission line in densely vegetated forest. Regular cutting back of vegetation will be necessary.

Figure 53: Leaning cable pole posing a safety threat.

Step up / down transformers

The main responsibility of the operator where a transformer is present is to ensure that the protection guard is in good condition and that access to the transformer is adequately restricted. Step-up / down transformers require no regular maintenance and should not be approached by the operator. Where medium voltage is used on a scheme (unlikely for small schemes), for safety reasons, maintenance work should only be undertaken by qualified experienced personnel.

House connection

Consumer house connections including internal house wiring is normally carried out by the MHP plant management. They should commission a qualified electrician to undertake this work. The low voltage supply cable from the distribution line is connected to the consumer service board mounted on the outside of the house. The service board remains the property of the MHP scheme and the consumer must not be permitted to make any changes to any of the components or connections. The operator must periodically conduct checks of the consumer boards to ensure they are functioning properly and that the consumer has not attempted to bypass broken fuses, MCBs or the kWh meter if fitted.

The internal wiring of the houses is normally the responsibility of the consumer to ensure that it is in a safe condition. The lack of awareness of many rural communities regarding the danger of electricity means that awareness measures should be implemented by the MHP management to highlight the dangers of electricity to consumers (in particular children) if not handled correctly.

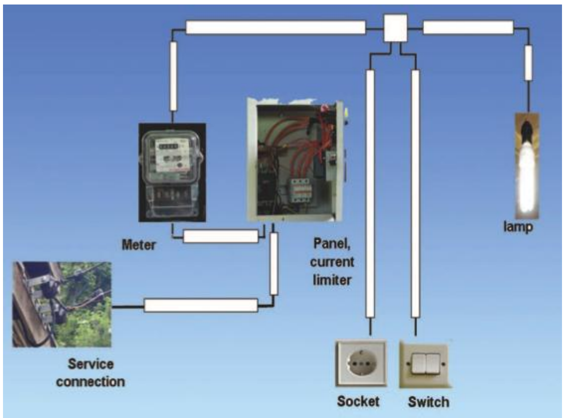


Figure 54: Schematic layout of typical house installation.

Figure 55: Proper cable connectors used to connect household from distribution line.

Maintenance Activity and Frequency:

Task:	Frequency:
Check that transmission and distribution lines are free from vegetation and fallen tree branches.	Weekly and particularly after storms
Check that all poles and support cables for uprightness.	Weekly and particularly after storms
Check condition of all cables, insulators, lightning protectors	Weekly and after heavy wind/rain
Ensure a 2m radius around the poles is free.	Monthly
Check that poles are in good condition – especially the part entering the ground.	Bi-monthly
Check condition of power line connection at the pole	Weekly and particularly after storms
Check grounding connections of the poles (if installed)	Monthly
Inspect house connection up to service Board. Check that the consumer has not tampered with any connections (bypassing kWh meter, MCB etc.)	Monthly or during meter reading
Inspect house internal connection	Monthly or during meter reading
Check that all medium voltage elements are safe from children and animals, no open cables	Weekly

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Present 3 different configurations of typical transmission & distribution networks used on MHP projects. Explain the type of materials used for the various components and explain where specific configurations are appropriate.

PRACTICAL ASSIGNMENT / PROJECT:

At an existing MHP site conduct a walk along the entire length of the network noting down any points where you think it could be improved. Record the main points of the network including length of lines, number of poles and number of consumers. On the basis of this prepare a simple maintenance schedule for the distribution network.

PRACTICAL DEMONSTRATION:

At an existing MHP using a current meter and multi meter measure the current on the main distribution line at the powerhouse. At a selected number of consumers measure their individual consumption using the current meter and the voltage and frequency using an electrical multimeter. Inspect the condition of the house connection checking that the limiting device is installed and checking that the kWh meter (if fitted) is working.

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
What maintenance is carried out on cable poles?	
What poses the main threat to transmission and distribution lines?	
Why must medium voltage lines be suspended higher than low voltage lines?	
Who should make the electrical house installation for the consumers?	
Name 2 components that form part of the consumer connection board?	

Learning Unit 3.2 Troubleshooting

What is important when solving problems is the adoption of a systematic approach. After identifying the problem, try to go to the origin of the problem to solve it. If in order to correct the problem, replacement parts or components are required then these must be procured. If it necessary to carry out remedial construction works then these must be commissioned as early as possible to avoid any further deterioration of the problem. Only in special circumstances is it acceptable to make temporary repairs in order to keep the scheme operational.

The systematic concept applied for a MHP project is essentially no different to that applied on normal everyday appliances such as motorcycles and cars. These steps are:

1. Analyse and formulate the problem.
2. Try to establish the history of the problem
3. Get advice from experienced persons
4. Read operation manuals
5. Formulate a plan of operation to correct the problem

The following presents some typical problems encountered on a MHP scheme, their likely causes and action to be taken. Obviously this list is not exhaustive and the customized nature of micro hydro means that every power plant will have its operational characteristics. On some schemes certain areas will be more than critical than others.

Civil structure

Problem Indication	Cause	Action to take
Noise and pressure fluctuations at the turbine	Air or foreign objects entering the penstock	Check water level in forebay and increase flow where necessary Check and clean trash rack
Low pressure at the turbine	Lack of flow at entering the penstock	Check trash rack for blockage and clean Check opening of intake gate and increase if necessary Check for blockages along waterway Reduce turbine flow to match available flow
Excessive flow going down spillway	Too much flow entering waterway	Check opening of intake gate
Not enough water reaching the forebay	Intake blocked	Clean intake trash rack, orifice
Flow contains excessive sand / gravel	Sandtrap is full and / or flow is excessively dirty	Clean the waterway and civil structures and flush sandtrap

Mechanical equipment (Valves, Turbine, Hydraulics)

For maintenance of the mechanical equipment, the operator must follow the instructions as per the manuals provided by the equipment supplier. The operator must be provided with a working copy of all manuals. The originals should be kept in a safe place by the management of the MHP.

Indication	Cause	Action taken
Turbine flow valve cannot be adjusted	Flow valve is blocked	Close flow into turbine and remove inspection cover to clean (crossflow) Remove spear valve and remove obstruction (pelton)
Runner shaft and / or flow valve leaking	Worn stuffing boxes Worn / broken runner seals	Adjust stuffing boxes Replace runner / flow valve shaft seals
Bearings overheating and / or noisy	Bearings do not have adequate lubrication Bearing out of alignment Bearing is worn out	Check bearing for lubrication Adjust bearing alignment Replace bearing
Coupling is vibrating and / or rubber powder is seen below coupling	Coupling worn out Coupling not properly aligned	Stop and check coupling rubbers Check coupling alignment Replace rubbers if required and re- align the coupling
Belt is not centred on pulley Belts making noise Belt comes off pulley Belt vibrates	Belt not properly aligned Belt(s) worn and / or not properly aligned	Check belt condition and alignment Check belt tension and adjust Replace belts if worn
Turbine is noisy and vibrating and has low power	Runner is damaged or blocked Air is entering penstock	Check penstock inlet and trash rack for blockage and clean Check if runner can be easily rotated Open inspection hole to check if runner is damaged or blocked. If blocked remove blockage

Electronic Load Controller (ELC)

For maintenance of the electronic control system, the operator must follow the instructions as per the manuals provided by the equipment supplier. The operator must be provided with aworking copy of all manuals. The originals should be kept in a safe place by the management of the MHP.

Indication	Cause	Action taken
Controller is hunting and unstable	Incorrect controller adjustment	Supplier should adjust or controller parameters
	Conflict with AVR	Supplier should adjust or replace AVR
	Belt is not properly tensioned and starts slipping if the controller try to correct this decreasing power	Check the belt, replace if required and tension properly
Frequency is too high	Ballast is not big enough to control frequency	Check if all ballast elements and working and if connections are ok. Replace elements where necessary
	Wrong frequency setting	Contact supplier to find out if setting can be adjusted and adjust accordingly
Frequency is too low. Consumers may be disconnected by the controller protection	System overloaded	Check the reason for the overload. Reduce consumer load where necessary

Induction Generator Controller (IGC)

For maintenance of the electronic control system, the operator must follow the instructions as per the manuals provided by the equipment supplier. The operator must be provided with aworking copy of all manuals. The originals should be kept in a safe place by the management of the MHP.

Indication	Cause	Action taken
Controller is hunting and unstable	Incorrect controller adjustment	Supplier should adjust or controller parameters
Generator does not start working at rated speed	The residual magnetic field to start the excitation in combination with the capacitors is not enough	Disconnect load for start up. Connect a battery to the stator winding for a short time to create residual magnetic field
Frequency is too high	Ballast is not big enough to control frequency	Check if all ballast elements and working and if connections are ok. Replace elements where necessary
	To low capacity of capacitors (or broken capacitors)	Contact supplier to find out the correct capacitor specifications Exchange or increase capacitor rating
Frequency is too low. Consumers may be disconnected by the controller protection	System overloaded	Check the reason for the overload. Reduce consumer load where necessary
	Capacitor rating too high	Contact supplier to find out the correct capacitor specification Reduce consumer load Exchange or decrease capacitor rating
	Consumers with low cosPHI	Check consumers in the grid: Motors and other inductive consumers need to be cosPHI compensated with a suitable capacitor

Generator

For maintenance of the electronic control system, the operator must follow the instructions as per the manuals provided by the equipment supplier. The operator must be provided with aworking copy of all manuals. The originals should be kept in a safe place by the management of the MHP.

Indication	Cause	Action taken
Generator does not start working at rated speed	Excitation not working: some generators require the residual magnetic field to start the excitation	Follow instruction of manufacturer (maybe connect a battery to the stator winding for a short time to create residual magnetic field
	AVR not properly connected or broken	Fix or replace AVR if required
	Rotating diode defect	Check and replace diode if necessary
Generator voltage fluctuating	Brushes worn out (for generator with brushes	Check and replace brushes and refurbish surface of slip ring
Voltage not correct	Wrong speed or problem of AVR	Check and correct operational speed of generator Fix or replace AVR if required
Phase voltage not symmetric	One winding is broken	Check stator winding resistance and insulation Re- wind generator
dito	Unsymmetrical consumer load	Check for problems in the distribution of re-distribute consumers symmetrically
vibrations	Unbalance	Find cause of unbalance Balance coupling, replace damaged generator ventilator
	Problems of coupling or pulley	Misalignment of coupling

Transmission and Distribution

Where problems exist on the network a normal process of systematic elimination can be applied to identify where the problem is. For example if there is a short circuit then it is necessary to isolate specific sections of the network until the problem can be identified and isolated.

Indication	Cause	Action taken
Not possible to connect the consumer load	Short circuit / problem on the transmission & distribution line	Systematic process of elimination to find the fault and repair
No supply to some sections of consumer	Damage to specific sections of distribution line	Repair distribution line

Learning Unit Assignments:

INDIVIDUAL / GROUP PRESENTATION:

Explain common 3 faults on a motorcycle and describe the trouble shooting and maintenance procedure for addressing these faults. Make an analogy of this with events / faults on a MHP.

PRACTICAL ASSIGNMENT / PROJECT:

Based on the interviews with operators at the site used for the practical demonstration, prepare a list of common faults together with a list of how the operator identifies and overcomes them. Compare this with the troubleshooting list of this module.

PRACTICAL DEMONSTRATION:

At an MHP site analyse the condition of the E&M equipment and interview the operator about his most frequent problems noting how he identifies them. Make 3 proposals for how to improve maintenance for the operator.

Learning Unit Self Assessment:

Question (simple)	**Answer by trainee**
What is the sequence of good problem solving using a troubleshooting approach?	
Provide an example of troubleshooting for the civil components of a MHP?	
Provide an example of troubleshooting for the E&M component of a MHP?	

National Vocational and Technical Training Commission (NAVTTC)

5th Floor Evacuee Trust Complex Sector F-5/1, Islamabad.

+92 51 9044 04

+92 51 9044 04

info@navttc.org

www.navttc.org