Myanmar Off-Grid Renewable Energy Demonstration Project (ADB TA 8657 MYA)

Microhydro training

1 – 4 Nov, 2016
Taunggyi, Shan State, Myanmar
Day 1: civil, mechanical and electrical systems in micro-hydropower mini-grids

- Initial site survey
- Intake design
- Power canal (power canal sizing)
- Forebay
- Penstock and anchors (penstock sizing, materials)
- Q&A
Day 2: system design, metering, tariffs, monitoring and evaluation, and business models, grid interconnection

• Turbine options
  • Reaction (Francis, propeller, etc) and impulse turbines (Pelton, Turgo, etc.)
  • Head and flow curves

• Generator types
  • Synchronous
  • Induction
  • Permanent magnet

• Load calculations (use spreadsheet to aggregate individual load data and create load curve).

• Load controllers

• GridShare

• Interconnecting with the main grid

• Q&A
Day 3: Field visit to existing micro-hydropower project: Mya Ze Di and Niang

- **Mya Ze Di village micro-hydropower**
  - Depart 7am from DRD
  - Visit site to see intake, weir, canal, forebay, turbine, generator, distribution network, etc.
  - Measurement of head and flow at site.
  - Discussion of system design choices, grid arrival
  - Lunch

- **Maing village micro-hydropower**
  - Visit site
  - Discussion of system design choices. Options.
  - Return to Taunggyi
Day 4: field visits to manufacturers, NEP micro-hydro program, wrap up

- Meet at DRD office
- Analysis of head and flow data collected in day 3
- Field visit to manufacturer #1
- Field visit to manufacturer #2
  LUNCH in DRD office (?), Taunggyi
- Discussion of DRD mini-grid support program
- Wrap up
Micro-hydro system overview
Micro-hydroelectricity

- forebay
- power canal
- intake
- penstock
- powerhouse
- tailrace
- dam or weir
Example installations
Mya Ze Di village hydro,
Shan State
Mae Kam Pong village, Chiang Mai, Thailand
20 kW x 2
Built 1983
20 kW -- Indonesia
LUMAMA hydropower project

- 300 kW – remote mini-grid
- Target 1400 customers
- Mawengi village, Njombe, Tanzania
Mwenga 4 MW hydro
800 households in 15 villages (expanding to 4000) & sells to the grid
Tanzania
3MW installed capacity (3 x 1MW) at Nam Khun outside of Kyaing Tong.
Athureliya village micro-hydro, Sri Lanka

21 kW

Was stand-alone, now grid-connected
Micro-hydro: advantages and disadvantages
Advantages compared to conventional energy

• 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
• Thanks to the small size of these schemes, impact on the environment (river ecology etc.) can be kept at a very low level.
Advantaged compared to other renewables

- Levelized cost of electricity low
- 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
- Proven, long-lasting and robust technology; systems can last for 50 years or more and can relatively easily be handled on village-level
Disadvantages

• 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 sustained effort for operation and maintenance which rural communities are not always prepared to provide (lack of organisational capacities, lack of cash: issues which have to be considered carefully during planning).
Micro-hydro attributes
Local manufacture

- Can be cheaper than imported equipment
- Service, know-how and spare parts available locally
- Local jobs
- Technical assistance can help improve efficiency & reliability
People’s participation

- Small size the projects allows the involvement of local villagers in:
  - implementation:
  - operation & maintenance
  - management.
- Public participation can reduce implementation cost and also often the level of commitment towards the project.
Accommodates mechanical power

- Instead of (or in addition to) generating electricity, micro-hydro power can be used directly as shaft power for many industrial applications:
  - milling,
  - husking and
  - water pumping.
Flexible design approaches for civil works

A wide range of designs and materials is possible for the civil works (compared to heavy concrete and steel structures used in large hydro).
Micro-hydro: classifications
Classification by design capacity
Classification by design head
Classification by design type
Classification by grid type/destination of supply
Classification by design capacity

Classification by design head
Classification by design type
Classification by grid type/destination of supply
<table>
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<tr>
<th>Term</th>
<th>Power output</th>
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<tr>
<td>Pico hydropower</td>
<td>&lt; 500 W</td>
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<td>Micro hydropower</td>
<td>0.5 - 100 kW</td>
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<tr>
<td>Mini hydropower (MHP)</td>
<td>100 – 1 000 kW (=1 MW)</td>
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<td>Small hydropower (SHP)</td>
<td>1 MW - 10 MW</td>
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<tr>
<td>Full scale (large) hydropower</td>
<td>&gt; 10 MW</td>
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Pico Hydro Power: < 500 W

- Power supply for single or few households
- Only suitable for isolated operation
- Depending on type of installation usually very maintenance intense
Micro Hydro Power: 0.5 - 100 kW

- Power supply for several hundred households
- Mostly used for isolated micro grids in the context of rural electrification
- Grid connection possible
Mini Hydro Power: 100 – 1,000 kW

- Power supply for up several thousand households
- Promising potential on smaller rivers
- Can substantially contribute to stabilization of grid, especially at end-points
- Larger-scale productive use possible (e.g. tea factories)
Small Hydro Power: 1 MW - 10 MW

- Power supply for up to several ten thousand households
- Promising potential on medium sized rivers
- Can contribute to stabilization of grid
Large Hydro Power: > 10 MW

Power supply for municipalities of large cities and supply to national grids
Classification by design capacity
Classification by design head
Classification by design type
Classification by grid type/destination of supply
Classification by head

Most literature recommends the following general limits:

- low-head plants \( H < 15m \)
- medium-head plants \( H = 15 \) to 50m
- high-head plants \( H > 50m \)
Low head: $H < 15\text{m}$

Low head with diversion channel
High head: $H > 50m$

High head with no headrace channel
High head

High head with headrace channel/pipeline
Classification by design capacity
Classification by design head
**Classification by design type**
Classification by grid type/destination of supply
Run-of-the-river type

- Most common type in the context of mini and micro hydropower
- The diversion weir installed in the river causes a minimum impact to the river as it has no impact on the seasonal flow pattern downstream of this structure.
- In some cases an enlarged forebay serves as daily storage to cover daily peak demands.
Storage system type

- Not commonly used in the context of MHP (complex design and expensive to implement)
- Causes a large accumulation of water by flooding the valley upstream of it (large impact on the river ecology)
- Seasonal storage and flood prevention (regulation of the river flow).
- A common problem with large dams is the accumulation of silt.
Classification by design capacity
Classification by design head
Classification by design type
Classification by grid type/destination of supply
On-/Off-Grid

**Off-grid**
The MHP supplies to an island grid, not interconnected with the national grid.

**On-grid**
The MHP directly supplies electricity to (usually) the national utility.
Estimating power available
Micro-hydroelectricity: Estimating the power available (metric units)

Power = 9.8 \times \text{efficiency} \times \text{height} \times \text{flow}

Micro-hydroelectricity: Estimating the power available (feet/gallons)

Power = 0.18 x efficiency x height x flow

Watts

feet

gallons per minute

Micro-hydro power estimation
Example (metric units)

Head: 30 meters
Flow: 200 liters/second
Efficiency: 70%

Power (W) = 9.8 \times 0.7 \times 30 \times 200
= 41,000 \text{ watts}
= 41 \text{ kW}
Micro-hydro power estimation

Example (metric units)

Head: 90 ft
Flow: 3000 gpm
Efficiency: 70%

Power (W) = 0.18 \times 0.7 \times 90 \times 3000

= 34,000 \text{ watts}

= 34 \text{ kW}
Measuring height drop (head)
Measuring height drop (head)

Laser height/distance (e.g. Leica Disto)
Site level
Abney level
Water-filled clear tube
Pressure gauge
Measuring head – Leica Disto
Measuring head: Abney level

\[ \Delta h = SD \times \sin(\alpha) \]
\[ \Delta h = 32.5 \times \sin(18) \]
\[ \Delta h = 32.5 \times 0.309 \]
\[ \Delta h = 10.043 \text{ m} \]

SD = slope distance
\( \Delta h \) = height difference
1. Height of level is head for each leg.
2. Repeat multiple legs from turbine location to intake location.
3. Multiply the height of level times the number of legs to determine total head.

Note: If the final leg is not an even increment, subtract the height of the sighting on the assistant from height of level to determine the head of that leg.
Measuring head: Hose & Pressure Gauge

Accurate and simple method.
Bubbles in hose cause errors.
Gauge must have suitable scale and be calibrated.

meters = PSI x 0.7032
feet = PSI x 2.307
Measuring head: Plastic tube filled with water
Measuring flow
Measuring flow: Bucket Method

\[ \text{Flow} = \frac{\text{bucket volume (liters)}}{\text{time to fill (seconds)}} \]

Tips:
- Use large bucket
- Do several trials and average
- If parallel waterfalls, calculate each separately.
Measuring flow: Float Method

Flow = area \times \text{average stream velocity}
Measuring flow: Salt Dilution Method

A known volume of salt solution is added to a turbulent stretch of the river, and the increase in electrical conductivity is measured downstream, after the salt is well mixed into the flow. The more the salt is diluted, the higher the flow.
Salt dilution method example – Shan State

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\[
Q = \frac{M_{\text{salt}} \cdot k^{-1}}{\text{Area under curve}}
\]
Hydrology and design flow
Hydrographs

Flow [m$^3$/s]

Day
**Flow duration curve: stand-alone hydro**

For stand-alone hydro, design flow is dry-season minimum minus ecological flow.
Flow duration curve: grid-connected hydro

For grid-connected, ideally choose design flow to maximize total energy production.
Estimating flow at un-gauged sites using the correlation method
Micro-hydropower: key components
Civil Works – some golden rules

- Think floods, landslides
- Think dry-season.
- Try to remove sediment
- Maximize head, minimize penstock
  - “wire is cheaper than pipe”
The purpose of a dam or weir is to raise / control the water level in the stream so that sufficient quantities of water can be diverted into the intake of the hydropower plant.
Intake

The purpose of the water intake is to take water from a river or a pond and deliver it to a canal, penstock or storage basin.

The main challenge is that intakes must operate under a full range of flows from low to flood, sometimes handle large quantities of silt, sand and gravel or floating debris ranging from full grown trees to leaves and weed.
Weir, intake & canal
**Water intake: Design**

- Most importantly, design has to be good to allow diversion of required amounts of water into canal or penstock with minimum possible headloss.

- Trash and floating debris should be kept away and sediment should be kept from entering the headrace
  - Submerged wall
  - Floating bar
  - Coarse trash rack
  - Sluice gate
Location and design intake

As a basic principle, intakes should always be located on the outer side of a river bend to minimize sediment in headrace.

Sluice gates in the intake are provided to allow flushing of deposited sediments from the intake.
Coanda (or Tyrolean) screen

- Flow over weir crest
- Debris excluded from extracted water
- Screen
- Coanda sump
- Screened flow to powerplant
- Debris, silt and excess flow continues downriver
Typical layout of a Coanda (Tyrolean) Weir
The purpose of desilting structures is to trap and eliminate sand and silt from the diverted water.

If heavy sand and silt-laden water is admitted to the turbine, hard particles may cause damage to runners, seals and bearings. Silt might also settle in the water conveyance system and obstruct flow.

The traditional method of excluding sand and silt is to reduce the velocity of the flowing water - in a specifically designed basin - to such an extent that the particles of a certain size settle out at the bottom of the structure from where they can be flushed back to the river (gravity sluicing).
Desilting basin: Design

- Desilting basin must be a longish structure, i.e. about **eight times longer than wide**. If the basin is too wide, water will tend to meander through the basin and areas of high velocity or even reverse flow will occur and settling of particles is limited.

- The desilting basin needs to have a **gutter shaped bottom** in order that accumulated sediments can be flushed out.

- **Sediment removal from desilting basins** through intermittent or continuous flushing without causing significant interruptions of the operation of the hydropower plant is the most difficult part of desilting.
Typical layout of a desilting basin
Desilting basin: Monitoring and maintenance

- Check if sediment trap works during high sediment concentrations, take water samples after sediment trap and watch if particles larger than 0.2 mm are removed efficiently. Allowed size and concentration depends on turbine and is provided by manufacturer.

- If flushing does not remove all sediments, remove sediments manually.

- Often 2 parallel basins are provided. Designer must clarify how sediment trap should be operated at low/high flows and for flushing.

- Check structure and gates similarly like weir or dam.
Headrace

The headrace conveys the water from the intake / desilting basin to the forebay. A headrace can have any length from zero (if penstock starts at desilting basin) to several kilometers.

The most cost effective headrace is an open channel because these can be constructed with low gradients (longitudinal slopes) but large cross-sections and hence introduce low head losses to the scheme.
Earth channels are the lowest cost options. However, problems associated with unlined open channels are: high maintenance requirements, water losses, landslides triggered by seepage water from unlined canal, requires stable and relatively flat cross slopes.
## Headrace: Lining

<table>
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<tr>
<th>Type of lining</th>
<th>Remarks</th>
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<tr>
<td>Stone masonry lining (trapezoidal section or flume type)</td>
<td>low cost solution if stones and inexpensive labor is available</td>
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<tr>
<td>Concrete lining (plain concrete, non-reinforced)</td>
<td>thickness of lining 50 to 100 mm, common problems with joints and poor subsoil (embankment situations)</td>
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<tr>
<td>Ferro-cement lining</td>
<td>requires skilled workers</td>
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<tr>
<td>Buried membrane linings (PE, PVC or butyl liners)</td>
<td>side slopes of canals must be flat to place membranes =&gt; canal requires large space</td>
</tr>
<tr>
<td>pre-fabricated canal sections (sheet metal, concrete, etc.)</td>
<td>only for small flow rates</td>
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</table>
Headrace

- If open channel headrace is not possible (e.g. crossings, unstable or steep ground) pipelines should be used.
Channel dimensioning

Discharge calculation for a straight trapezoid channel in natural stone masonwork or rough concrete (roughness coefficient 60)
# Channel dimensioning

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<th>height [m]</th>
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</table>

ADB Myanmar Off-Grid Renewable Energy Demonstration Project
Low pressure headrace pipes

- Availability of large diameter, light-weight pipes (e.g. PE, PVC, glass fiber, reinforced polyester, asbestos cement) on the market allows economic piping of headrace.

- Piped headrace can be of advantage in terms of reduced maintenance costs and land use as compared to on open canal.

- Concrete pipes have also been used but these may impose problems of transport to remote sites due to their weight.

- Steel pipes may be too expensive and need to be protected against corrosion.

- Wood stave pipes are suitable at locations where changes in humidity are not too frequent and significant.
Forebay / Storage pond
Forebay Tank
Forebay

The forebay serves as a final settling basin for suspended matter in the water, provides submergence for the penstock inlet (to avoid air entrainment) and has:

- fine trash rack to remove debris
- overflow spillway to spill water in case of load rejection
- sluice gate to remove deposited silt

The size of the forebay is usually determined from turbine governing requirements. The forebay must have a minimum storage volume to accommodate rapid changes of turbine flow without excessively lowering forebay water levels and introducing surge waves into the headrace. In acts as surge tank. The required storage volume typically corresponds to 30 seconds of turbine design flow.
It may be of advantage in certain cases to introduce additional storage volume in the forebay for the purpose of transferring energy on a daily cycle from off-peak to peak demand times.

In stand-alone systems storing water makes sense if the available stream flow in the river is at times (dry season) insufficient to cover peak demand.

In grid connected systems daily storage is only meaningful if electricity fed into the grid is valued differently during system peak and off-peak periods.
Forebay: control and maintenance

- Check forebay for leakage from seepage
- Check for cracks in concrete
- Check for deformations of structure
- Regularly make sure gates are movable (sluice gate and shut-off for penstock)
Trash Rack
Trash racks

- Trash racks/strainers should be fabricated in a way that it is possible to detach these from the concrete/masonry structure for maintenance.
- Trash racks/strainers shall be corrosion protected by sandblasting and applying primer and appropriate protection coat or by galvanising.
- The rack should be constructed to allow easy cleaning with a rake, i.e. vertical bars should be welded behind the vertical bars.
Penstock
Penstock

- A vent prevents vacuum collapse of the penstock.
- Valves that close slowly prevent water hammer.
- Anchor block – prevents penstock from moving
Penstocks: failure mechanisms

- Structural failure due to settlements and deformation of anchor blocks, slope stability problems
- Failure due to excessive positive or negative pressures in penstock caused by water hammers
## Penstock materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Max. head</th>
<th>Typical diameter</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>&gt; 400 m</td>
<td>80 to 2500 mm</td>
<td>special attention to internal and external corrosion protection</td>
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<tr>
<td>Ductile iron</td>
<td>400 m</td>
<td>80 to 1200 mm</td>
<td>corrosion protection</td>
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<tr>
<td>Fibre cement (formerly asbestos cement) pipes</td>
<td>160 m</td>
<td>80 to 600 mm</td>
<td>poor resistance against mechanical impact and external loading</td>
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<tr>
<td>High density poly-ethylene (HDPE)</td>
<td>160 m</td>
<td>80 to 1000 mm</td>
<td>large diameters are expensive</td>
</tr>
<tr>
<td>PVC</td>
<td>160 m</td>
<td>75 to 600 mm</td>
<td>large diameters are expensive</td>
</tr>
<tr>
<td>Wood stave</td>
<td>40 m</td>
<td>80 to 3000 mm</td>
<td>requires special skills</td>
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</table>
Penstock diameter

Hazen-Williams friction loss equation:

\[ h_f = \frac{10.67 \ L \ Q^{1.85}}{C^{1.85} \ d^{4.87}} \]

where:

- \( h_f \) = pressure loss over a length of pipe, m (head pressure)
- \( L \) = length of pipe, m (meters)
- \( Q \) = volumetric flow rate, \( m^3/s \) (cubic meters per second)
- \( d \) = inside pipe diameter, m (meters)
- \( C \) = roughness coefficient

<table>
<thead>
<tr>
<th>Material</th>
<th>C Factor low</th>
<th>C Factor high</th>
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<td>Cast iron</td>
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<tr>
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<tr>
<td>Fibre-reinforced plastic (FRP)</td>
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</table>
Penstock: Anchor and Thrust Blocks
Locating the Powerhouse

- Power house must be above flood height.
- Locate powerhouse on inside of stream bends.
- Use natural features for protection.
Powerhouse

The following points should be checked in any powerhouse:

• Maintain adequate ventilation to evacuate heat from generator

• Keep chain block / hoist to lift turbine, generator and valves in good working condition

• Keep sufficient space inside as a working bay for repair of equipment in orderly and clean state.

• Maintain adequate drainage trench or recess for penstock so that water leaks do not inundate the whole powerhouse.

• Maintain building in good condition
Tailrace

• Tailrace large enough to safely evacuate water from the turbines
• Remove obstacles from tailrace
• River bank protection and adequate elevation of the powerhouse above maximum flood level of river.
• Watch for erosion and deposition in tailrace, erosion can be dangerous for stability of building, deposition causes backwater effect on turbines and reduces power generation
MICROHYDRO DESIGN AIDS © 2004 for Microsoft Excel XP
Small Hydropower Promotion Project (SHPP)/GTZ
Mini-Grid Support Programme (AEPC)

Micro Hydropower Project Model

Worksheets
- Conductivity
- Hydrology
- Side Intake
- Bottom Intake
- Headrace Canal
- Headrace Pipe
- Sealing basin
- Penstock & Power
- Turbine
- Electrical
- Transmission Line
- Costing & Financial Analyses
- Utilities
- List of Reference

Collaboration Partners
- SHPP
  - shpp@gtz.org.np
  - www.shpp.org.np
- AEPC
  - energy@aepc.wlink.com.np
  - www.aepc.nepal.org

Feedback
- Pushpa Chitrakar
  - pushpa.chitrakar@gtz.org.np

Help
- Online Manual
- Drawings
Thank you!

Contact information
Chris Greacen, Micro-hydro consultant, (chrisgreacen@gmail.com)
Tin Myint Deputy Team Leader (Yangon) (tinmyint@suntactechnologies.com)