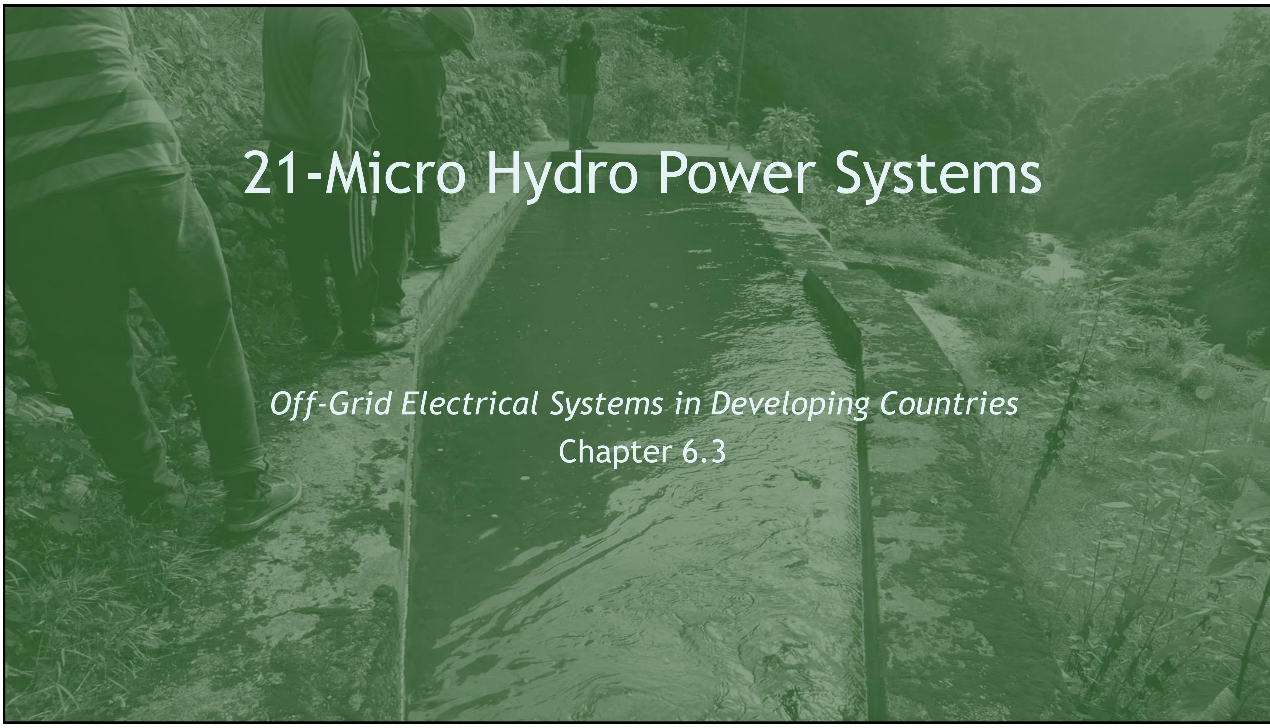


21-Micro Hydro Power Systems

Off-Grid Electrical Systems in Developing Countries

Chapter 6.3

1

Learning Outcomes

At the end of this lecture, you will be able to:

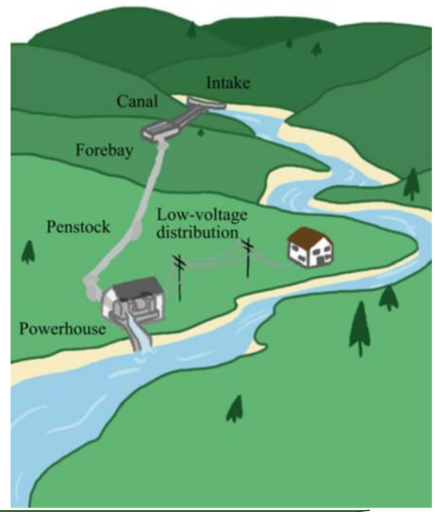
- ✓understand the basic operating principles of microhydro power systems
- ✓identify and describe the components of a MHP system
- ✓estimate the power potential of a hydro resource

2

2

Micro Hydro Power (MHP)

- Turbines convert energy in water into mechanical energy to power a turbine
- Mature technology
- Requires suitable water resource and terrain
- Can be AC-coupled or DC-coupled
- Civil works are required



Hydro Resource

- Power potential of a hydro resource depends on:
  - Head (m)
  - Flow rate (m^3/s)
  - Conveyance system loss estimate
- Desirable characteristics
  - Steep surrounding terrain (reduces penstock length and losses)
  - Water intake at high elevation compared to powerhouse location
  - Consistent, predictable seasonal flow

Bernoulli's Equation

- From Bernoulli, the energy in a volume of water depends on its
  - Velocity
  - Elevation (above reference plane)
  - Pressure
- Energy from pressure and velocity usually ignored

$$\frac{1}{2}\rho_{wa}v_{wa}^2 + \rho_{wa}gz + p_{wa} = K$$

ρ_{wa}: density of water, ~1000 kg/m^3
v_{wa}: velocity of water, m/s
g: gravitational constant, 9.81 m/s^2
z: elevation, m
P_{wa}: pressure, Pa
K: constant, J/m^3

Bernoulli's Equation

As water flows down a slope in open air, assuming no friction losses and ignoring the small change in atmospheric pressure, the velocity increases and the elevation decreases so that K remains unchanged

$$\frac{1}{2}\rho_{wa}v_{wa}^2 + \rho_{wa}gz + p_{wa} = K$$

Bernoulli's Equation

What happens if water is flowing through a pipe, and a valve is closed so that the velocity suddenly drops to zero?

$$\frac{1}{2}\rho_{wa}v_{wa}^{2}+\rho_{wa}gz+p_{wa}=K$$

Total Head

Divide Bernoulli's equation by ρ_{wa} and g to yield:

$$\frac{1}{2}\rho_{wa}v_{wa}^{2}+\rho_{wa}gz+p_{wa}=K$$

$$\frac{1}{2g}v_{wa}^{2}+z+\frac{p_{wa}}{\rho_{wa}g}=H_{t}$$

Units of each term are meters

Velocity Head

Elevation Head

Pressure Head

Total Head

Total Head

- We can conceptually replace a water resource with certain velocity, elevation and pressure and volume with an equivalent volume of water at no pressure, no velocity at an elevation equal to the total head
- This makes energy calculations and comparisons easier
- A water resource with greater total head has greater energy density than one with a lower total head

9

Energy in Water

- Recall that potential energy of an elevated mass is:

$$E = m \times g \times h = (\rho \times V) \times g \times z$$

- The total energy in water with volume V_{wa} is:

$$E_{wa,total} = \rho_{wa} \times V_{wa} \times g \times H_t$$

m: mass, kg
ρ: density, kg/m^3
V_{wa}: volume, m^3

Don't confuse this with velocity

10

Example

Compute the total head and energy of two cubic meters of water whose velocity is 1 m/s and is located 38 meters above the reference plane. Assume the water is exposed to atmospheric pressure (101.325 kPa)

11

11

Example

Compute the total head and energy of two cubic meters of water whose velocity is 1 m/s and is located 38 meters above the reference plane. Assume the water is exposed to atmospheric pressure (101.325 kPa)

$$H_t = \frac{1}{2g} v_{wa}^2 + z + \frac{p}{\rho g} = \frac{1}{2 \times 9.8} 1^2 + 38 + \frac{101{,}325}{1000 \times 9.8} = 0.05 + 38 + 10.33 = 48.39\text{m}$$

Note that the total head is independent of the volume

Most of the total head is due to the elevation head

12

12

Example

Compute the total head and energy of two cubic meters of water whose velocity is 1 m/s and is located 38 meters above the reference plane. Assume the water is exposed to atmospheric pressure (101.325 kPa)

$$E_{\text{wa,total}} = \rho_{\text{wa}} \times V_{\text{wa}} \times g \times H_{\text{t}} = 1000 \times 2 \times 9.8 \times 48.39 = 0.95 \text{ MJ}$$

Effective Head

- Effective Head: the head available to a hydro turbine for energy conversion
  - Effective Head < Total Head
- Difference between effective and total head arise from:
  - friction and conveyance system losses
  - velocity head is usually low compared to the elevation head and assumed unavailable to the turbine
  - water at the turbine outlet is at atmospheric pressure, so this energy is not available to the turbine

Effective Head

- If we ignore the losses in the conveyance system, then the effective head is

$$\cancel{\frac{1}{2g}v_{\mathrm{wa}}^2} + z + \cancel{\frac{p_{\mathrm{wa}}}{\rho_{\mathrm{wa}} g}} = H$$

The effective head is equal to the elevation head

- Including losses:

$$H = z - H_f = z\eta_{\mathrm{convey}}$$

H: effective head, m
η_{convey}: conveyance system efficiency

Hydro Resource

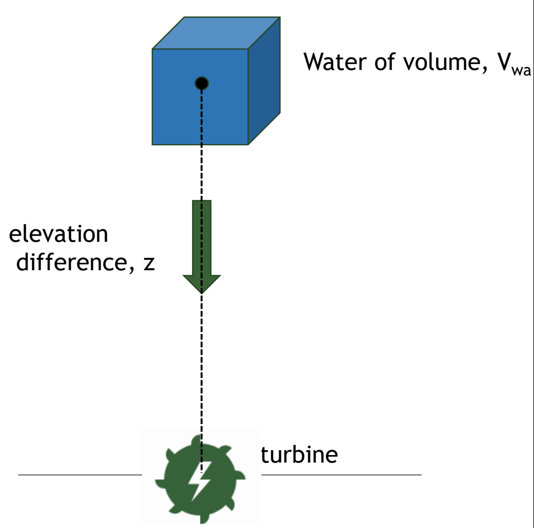
- Useable energy in a volume of water

$$\mathrm{E_{wa}} = \mathrm{g} \times \mathrm{H} \times \mathrm{m_{wa}} = \mathrm{g} \times \mathrm{H} \times \rho_{\mathrm{wa}} \times \mathrm{V_{wa}}$$

- Power in falling water

$$\mathrm{P_{wa}} = \frac{\mathrm{dE_{wa}}}{\mathrm{dt}} = \rho_{\mathrm{wa}} \times \mathrm{g} \times \mathrm{H} \times \mathrm{Q}$$

g: gravitational constant, 9.8 m/s^2
H: effective head, m
m_{wa}: mass of water, kg
V: volume of water, m^3
ρ_{wa}: density of water, 1000 kg/m^3
Q: water flow rate, m^3/s



Exercise

The water resource for a MHP scheme has an effective head of 38 m. The flow rate is 0.005 m^3/s (5 liters per second). Compute power available to the input of the turbine.

Exercise

The water resource for a MHP scheme has an effective head of 38 m. The flow rate is 0.005 m^3/s (5 liters per second). Compute power available to the input of the turbine.

$$P_{wa} = \rho_{wa} \times g \times H \times Q$$
$$P_{wa} = 1000 \times 9.8 \times 38 \times 0.005 = 1862 \text{ W}$$

Power Extracted by Turbine

Hydro turbines, if properly designed and operated, are highly efficient, but the losses should be considered.

The mechanical power extracted (developed) by the turbine is:

$$P_{\text{d,turbine}} = P_{\text{wa}} - P_{\text{outlet}} = \eta_{\text{turbine}} P_{\text{wa}}$$

19

19

Water Intake

Only a portion of the stream is diverted for MHP use

(courtesy Joe Butchers)

(courtesy Joe Butchers)

(courtesy Joe Butchers)

www.drhenrylouie.com

20

20

Intake

Removeable boards to clear silt/debris

Water passes through grate into penstock (not visible)

21

Penstock

- Conveys water from intake to turbine
- Above- or below-ground pipe
- Should be straight and short

(courtesy Joe Butchers)

(courtesy Joe Butchers)

(courtesy Joe Butchers)

22

Turbine Types

Pelton

Francis

Crossflow

Turgo

Turbine coupled to generator

(courtesy Joe Butchers)

(courtesy Joe Butchers)

Turbine Selection

- Several types of hydro turbines
- Most water resources for MHP are high head or medium head

High Head	Medium Head	Low Head
Pelton	Crossflow	Crossflow
Pelton (Multi-jet)	Turgo	Propeller
Turgo	Pelton (Multi-jet), Francis	Kaplan

www.drhenrylouie.com

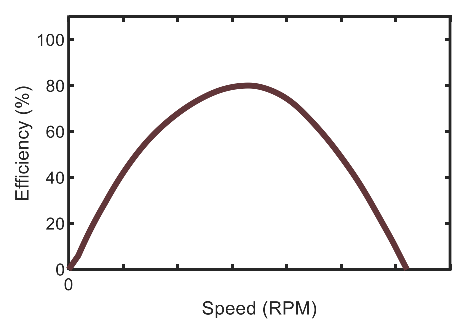
25

25

Turbine Selection

- Select turbine that will operate most efficiently given the power and rotational speed requirements, and the water resource speed and head
  - Turbine Application Chart
  - Calculate using "specific speed"

Illustrative efficiency curve for Pelton Turbine



www.drhenrylouie.com

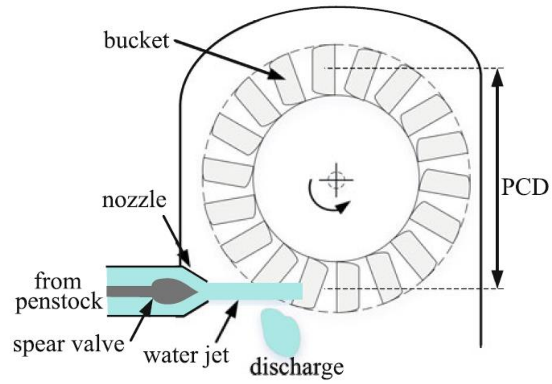
26

26

Speed Matters

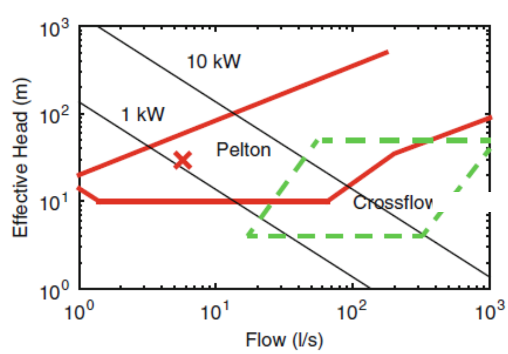
- Velocity of water jet depends on head
- Efficiency is maximized when water jet speed is 1/2 the tangential speed of the bucket
- Bucket must rotate at certain RPM to produce desired voltage frequency
- Mismatch of resource and turbine lowers efficiency

Pelton Turbine



27

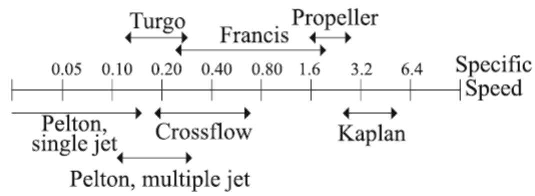
Turbine Application Chart



28

Specific Speed (Dimensionless)

$$S = \frac{\omega_m \sqrt{Q}}{(gH)^{3/4}} = \frac{\omega_m \sqrt{P_{\mathrm{d,turbine}} / \rho_{\mathrm{wa}}}}{(gH)^{5/4}}$$



ω_m: rotational speed of turbine, rad/s
g: gravitational constant, m/s^2
H: effective head, m
Q: water flow rate, m^3/s

Caution: several other "dimensioned" specific speeds are used and reported by turbine manufacturers.

Exercise

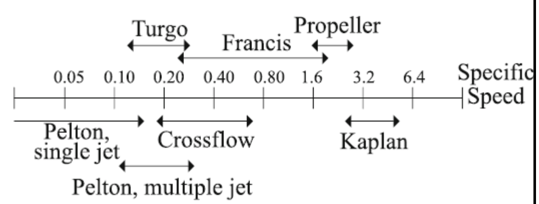
Compute the dimensionless specific speed for a water resource with an effective head of 30 m. Assume the turbine will rotate at 1500 RPM with a developed mechanical power of 1.25 kW.

$$\mathcal{S} = \frac{\omega_m \sqrt{P / \rho_{\mathrm{wa}}}}{(gH)^{5/4}} = \frac{\frac{2\pi}{60} \times 1500 \sqrt{1250 / 1000}}{(9.8 \times 30)^{5/4}} = 0.144$$

Exercise

Compute the dimensionless specific speed for a water resource with an effective head of 30 m. Assume the turbine will rotate at 1500 RPM with a developed mechanical power of 1.25 kW.

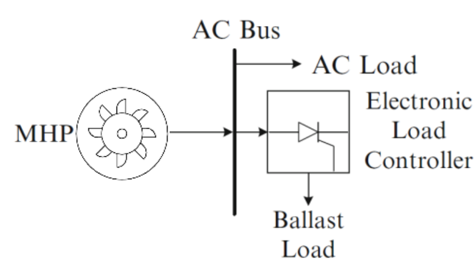
$$\mathcal{S} = \frac{\omega_{\mathrm{m}}\sqrt{P/\rho_{\mathrm{wa}}}}{(gH)^{5/4}} = \frac{\frac{2\pi}{60}\times 1500\sqrt{1250/1000}}{(9.8\times 30)^{5/4}} = 0.144$$



Here we see that either a Pelton (single or multiple jet) or Turgo is an appropriate turbine

Turbine Control

- Can be AC- or DC- coupled
- Frequency Regulation
  - Spear valve: adjust water flow to turbine
  - Electronic load controller: adjust electrical power to ballast (dummy) load to keep electrical power constant
- Voltage Regulation
  - Automatic Voltage Regulator (synchronous generator)
  - Impedance controller (self-excited induction generators)
- Do not suddenly remove load (overspeed can result)



Micro Hydro Power

- Relatively inexpensive
- Simple to operate
- No fuel costs
- Long operational life
- Consistent power production---no need for batteries
- Renewable resource
- No emissions
- Mature technology

- Adequate water resource not widely available
- High up-front costs
- Water resource characteristics (flow rate, head, and effects of seasonality) must be assessed
- Must be custom-designed
- Commercially-available turbines might not match the site characteristics
- Many stakeholders affected—permits and permissions might be required

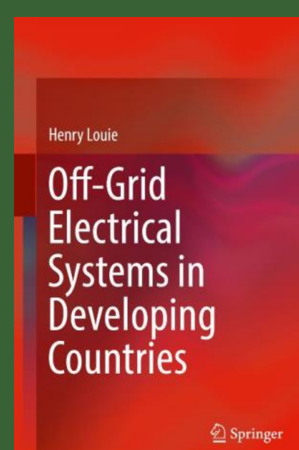
www.drhenrylouie.com

33

33

Contact Information

Henry Louie, PhD
Associate Professor
Fr. Wood Endowed Research Chair
Seattle University
@henrylouie
hlouie@ieee.org
www.drhenrylouie.com
Office: +1-206-398-4619



34

34