Department of Mechanical Engineering,
Pulchowk campus, Institute of Engineering,
Tribhuvan University

Sustainable Energy Technologies
(Session 8)

Micro-hydro Power Technologies

Dr. Shree Raj Shakya
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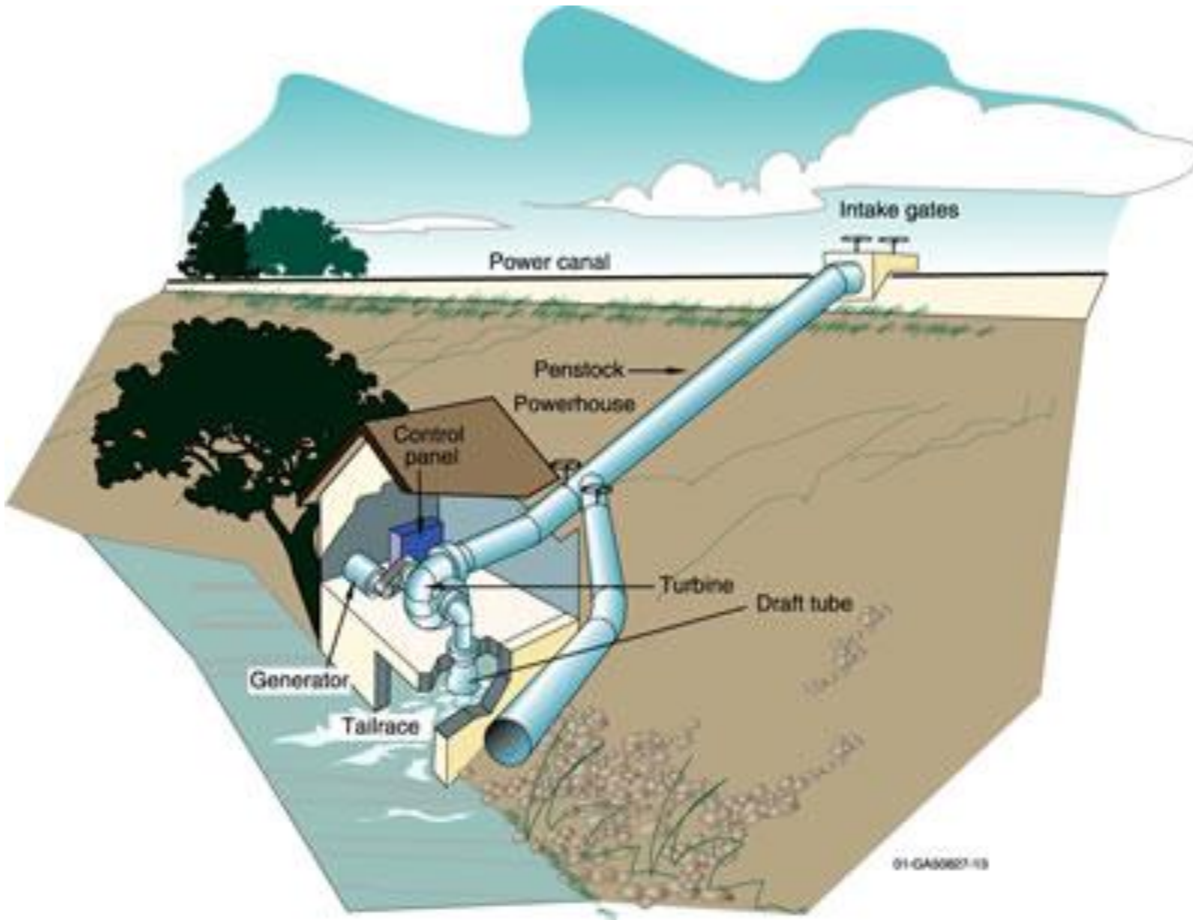
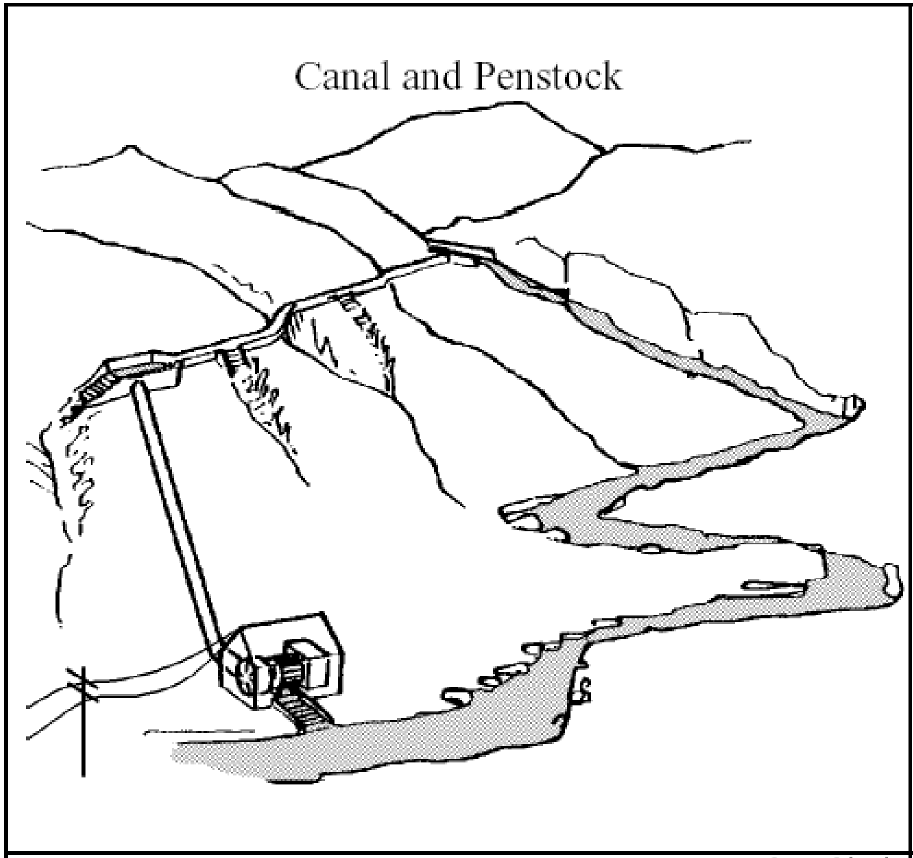
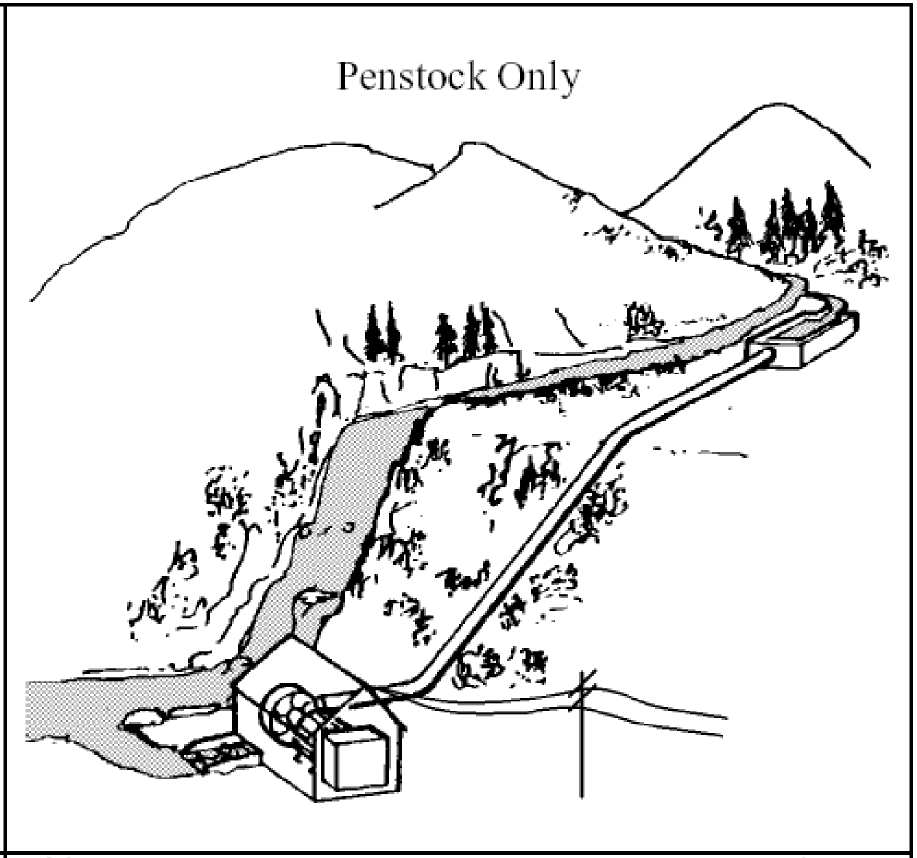
MICRO-HYDRO POWER



COMMON LAYOUT OF MHP





INTRODUCTION

- Nepal has potential of **83,000 MW** of power from the running river and 43,000 MW is considered economically viable.
- Only about **787 MW** (~1%) of this potential has been harnessed till now.
- Micro-hydro power potential is about **100 MW** at different altitudes.
- Installed capacity of MHP is about **23 MW** (23%) only.

INTRODUCTION (continued)

- What is MHP?
- Benefits of decentralized rural electrification: Education, health care, std of living, communication and transport etc.
- Spectrum of MHP technology
- Selection chart of MHP for different applications

HISTORY OF MHP IN NEPAL

- First modern MHP plant was installed in 1962 for milling purpose (~ 4 decades ago)
- Add-on & stand-alone plants for generating electric lighting were installed over last 2 decades
- Promoters of MHP in Nepal:
  - ADB/N [Agri. Development Bank/Nepal] since 1985
  - AEPC [Alternative Energy Promotion Centre] since 1997
  - IREF [Interim Rural Energy Fund] since 2000

ORGANISATIONS INVOLVED IN MHP
(1962 – Mid-July 2001)

- AEPC:
  - Energy Sector Assistance Programme (ESAP-DANIDA)
- UNDP: [Non-peltric + Peltric + Mechanical schemes]
  - Rural Energy Development Programme (REDP) [60+9+0]
- HMG/N:
  - Remote Area Development Committee (RADC) [24+3+0]
- NGOS & INGOS:
  - Annapurna Conservation Area Project (ACAP) [15+0+0]
  - Canadian Centre for International Studies (CECI) [5+0+1]

TECHNICAL ASPECTS OF MHP

- Main components of MHP system
- Potential power from water
- Suitable conditions for MHP
- Turbine: impulse and reaction
- Load factor
- Load control g
- Operation and maintenance

Steep rivers flowing all year round

Small head but

Impulse: Pelton, Turgo, Multijet, Cross-flow

Reaction: Francis, PAT, Propeller, Kaplan

Power used / Power available

Mechanical governer, ELC

Skilled and trained technician

Good operation and maintenance practice

SUITABLE CONDITIONS FOR MHP

- Steep rivers flowing all year round
- Small head but sufficient flow
- High head and low flow rate
- Data collection from Department of Hydrology and Meteorology

POTENTIAL POWER FROM WATER

- **Power calculation**:

  $P[kW] = 5xQ[m^3/s]xH[m]$ Or

  $P[W] = 5xQ[l/s]xH[m]$

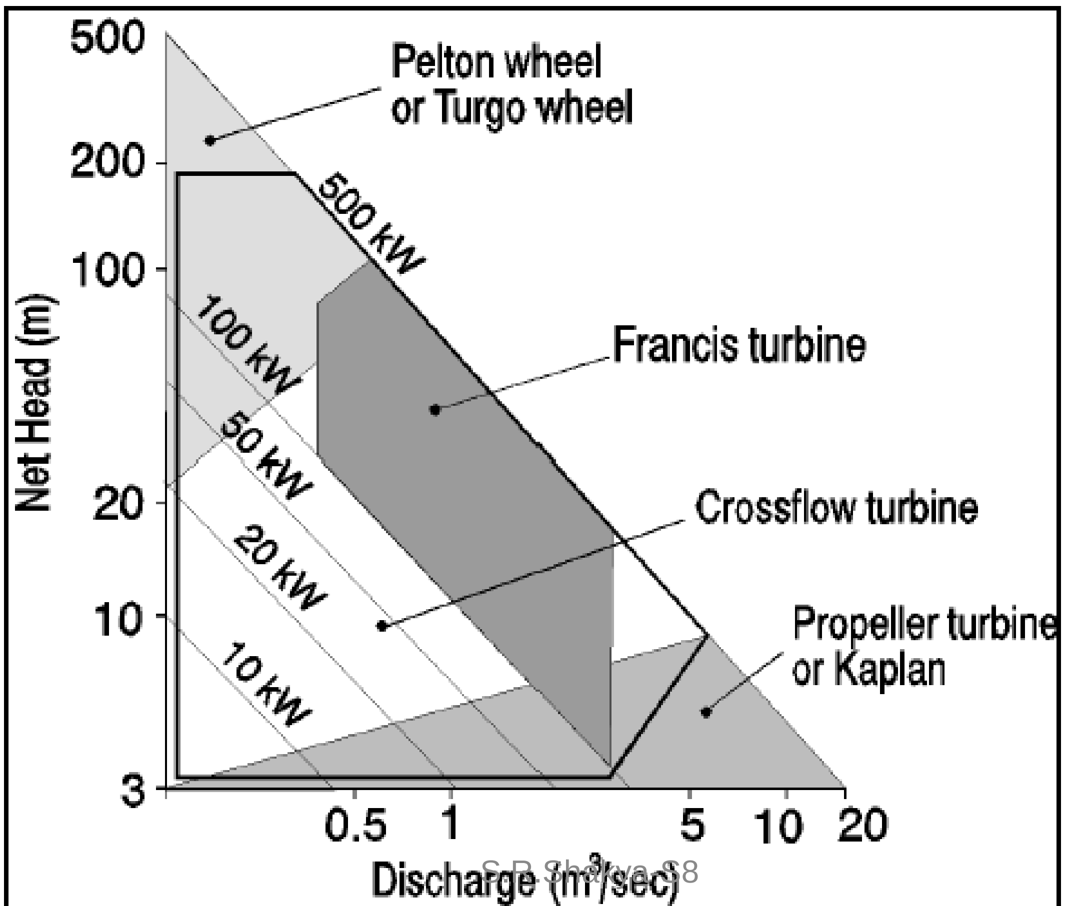
- **Other important aspects to be considered**:
  - Power requirements for lighting =

    No. of households x 100 watts
  - The demand for agro-processing services & other enterprises
  - Willingness to pay for lighting by the people
  - Track record of community for community organization and leadership

TYPES OF TURBINE USED FOR MHP

Turbine Runner	High Head Pressure (H > 50m)	Medium Head Pressure (H = 10-50m)	Low Head Pressure (H<10m)
Impulse	Pelton Turgo Multi-jet Pelton	Cross-flow Turgo Multi-jet Pelton	Cross-flow
Reaction		Francis Pump-as-turbine (PAT)	Propeller Kaplan

HEAD-FLOW RANGES OF SMALL HYDRO TURBINES



GENERATORS

Selection of Generator Type			
Type of scheme	Very small schemes up to 10 kW	Small schemes, 10 kW to 20 kW	Medium to large schemes, over 20 kW
Type of generator	Induction, single or 3 phase. 2nd choice: synchronous	Synchronous, 3 phase only. 2nd choice: induction, 3 phase only	Synchronous, 3 phase only.

SINGLE PHASE VS 3 PHASE

- Advantages of single phase
  - Simple wiring
  - Cheaper ELC
  - Load balance not considered

- Advantages of three phase
  - Saving of conductor and machine costs
  - Cheaper above 5 kW
  - Less weight/size ratio

SELECTION OF GENERATOR TYPE

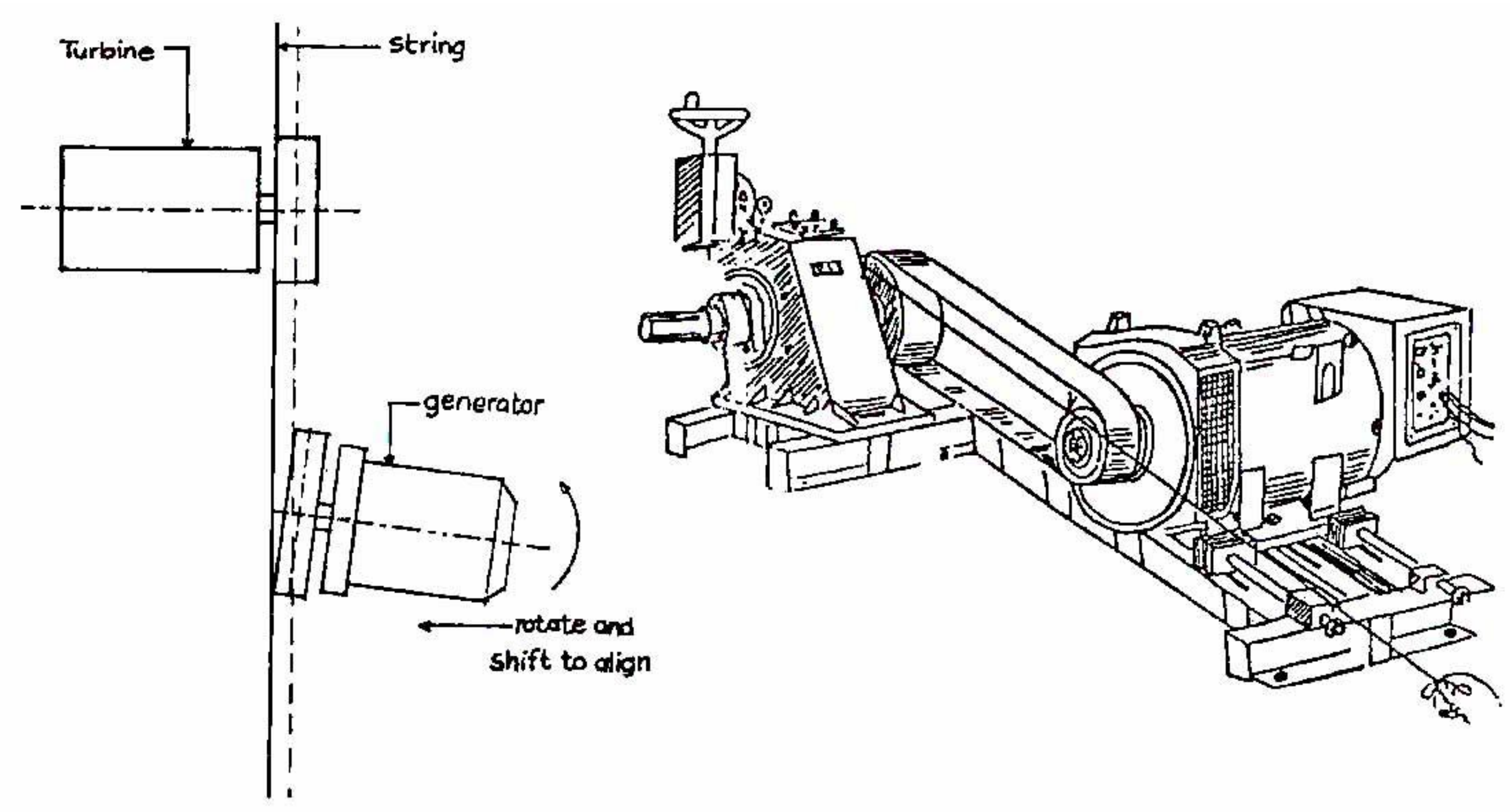
Size of scheme	Up to 10 kW	10 to 15 kW	More than 15 kW
Generator	Synchronous/ Induction	Synchronous/ Induction	Synchronous
Phase	Single or Three phase	Three phase	Three phase

INDUCTION VS SYNCHRONOUS GENERATORS

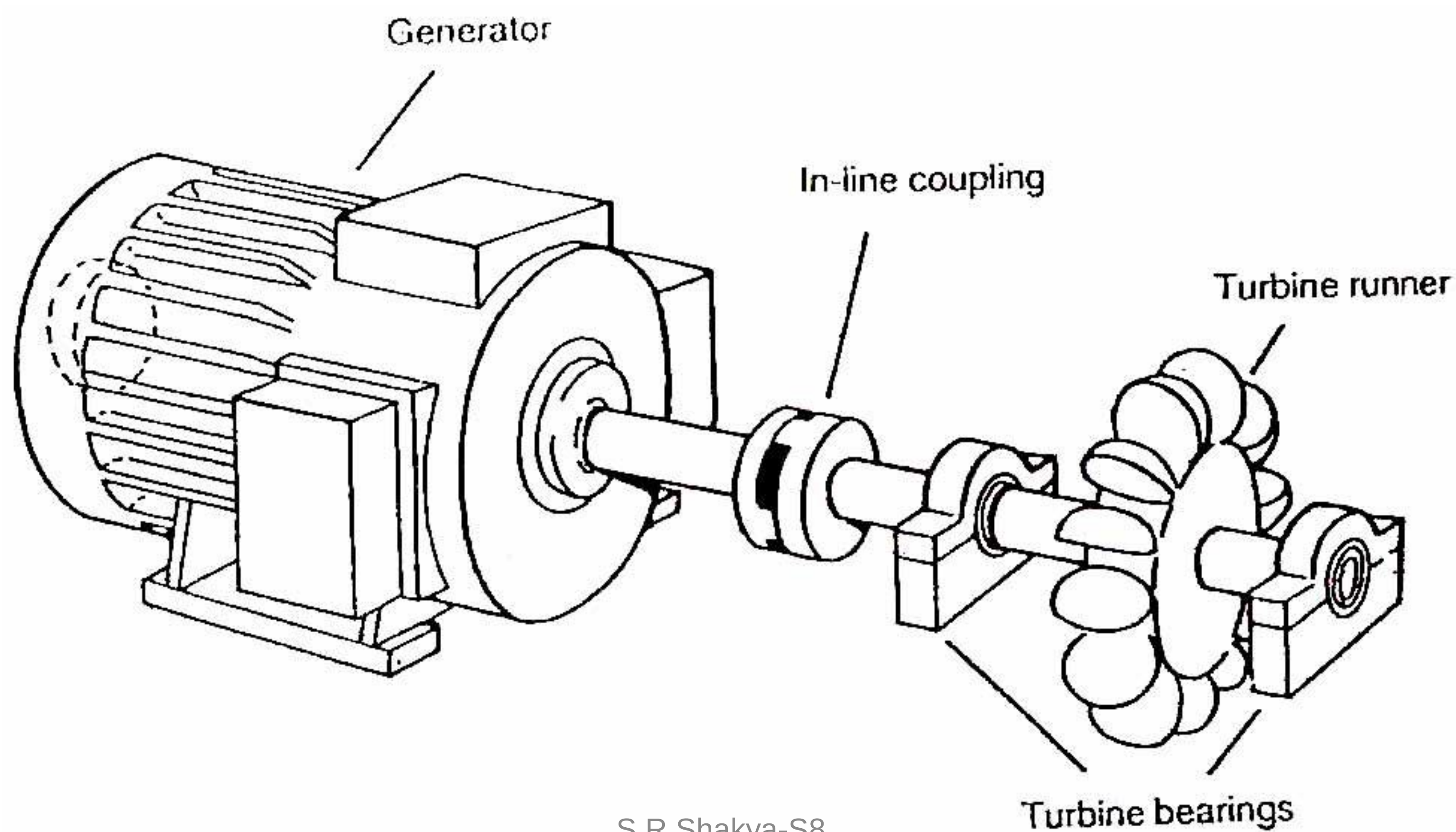
- Advantages of IG
  - Availability
  - Cheap, rugged and simple in construction
  - Minimum maintenance
- Disadvantages of IG
  - Problem supplying large inductive loads
  - Less durability of the capacitor bank
  - Poor voltage regulation compared to synchronous

- Advantages of SG
  - High quality electrical output
  - Higher efficiency
  - Can start larger motors
- Disadvantages of SG
  - The cost is higher than induction generator for small sizes

TURBINE AND GENERATOR COUPLED THROUGH A BELT DRIVE



DIRECT DRIVE TURBINE AND GENERATOR SYSTEM



TRANSMISSION LINES

- **Selection of underground or overhead lines**
  - Overhead lines are less expensive and easier to install than underground lines. They are also easy to repair and maintain.
- **Selection of high voltage or low voltage**
  - Low voltage transmission line: if the product of power produced and the length of transmission line is less than 54 kW.km (i.e., power output x transmission length < 54 kW.km).
  - If the installed capacity exceeds 10 kW, a three phase transmission line should be used.

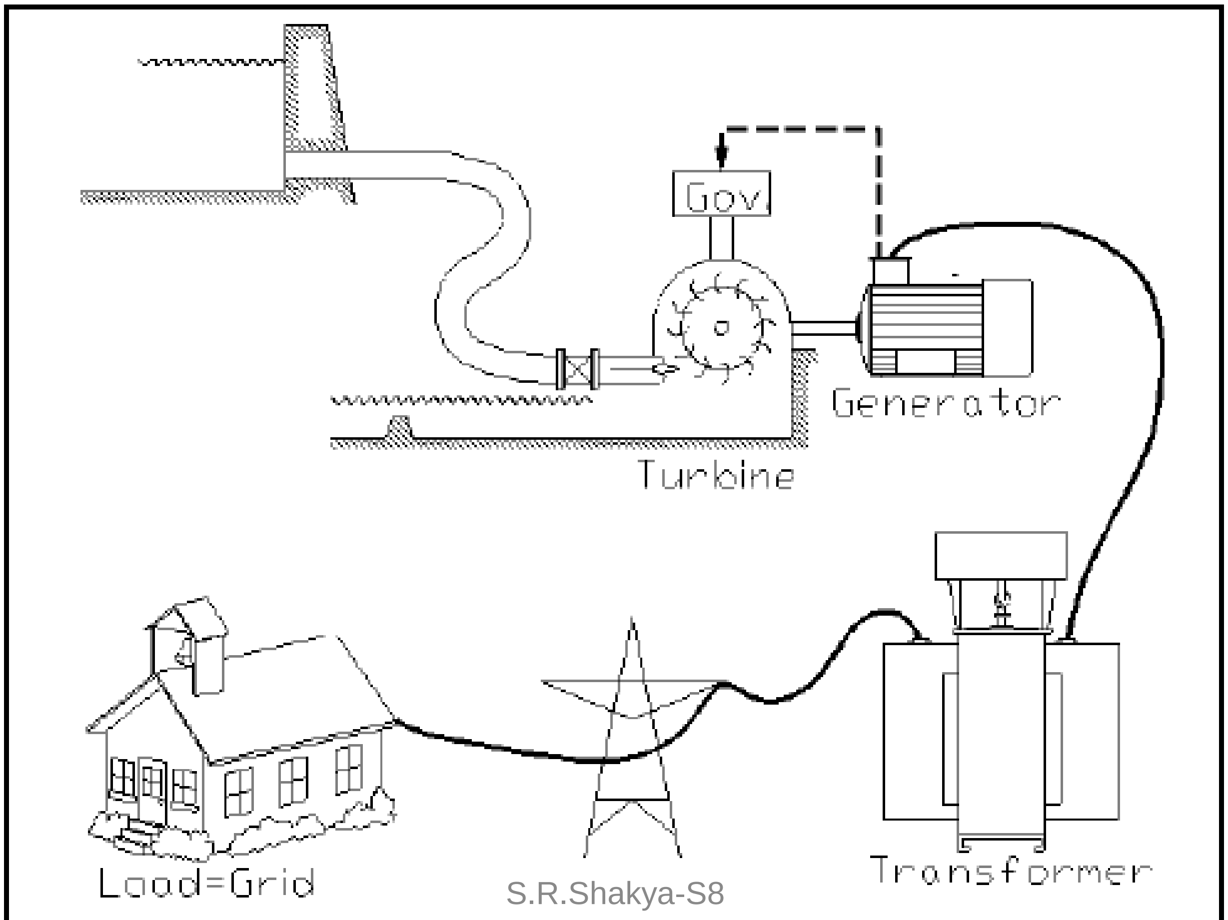
LOAD FACTOR

- Load factor = amount of power used / amount of power that is available (if the turbine were to used continuously)
- Low load factor if the turbine is only used for domestic lighting in the evening
- High factor can be achieved by using power for rural industry during day, lighting during evening and pumping water for irrigation during evening
- It is important to ensure a high plant factor for cost effective scheme during planning stage otherwise have to consider the use of a 'dump' load

LOAD CONTROL GOVERNORS

- Water turbines will vary in speed as load is applied or relieved. This speed variation will seriously affect both frequency and voltage output from a generator.
- *Hydraulic or mechanical* speed governors altered flow as the load varied.
- *Electronic load controller* prevents speed variations by continuously adding or subtracting an artificial load, so that in effect, the turbine is working permanently under full load. ELC has no moving parts and is very reliable and maintenance free.

GRID-CONNECT OR STAND-ALONE



OPERATION AND MAINTENANCE

- Only a trained and skilled technician can operate and maintain a MHP plant. Provide training to would-be operators so that they can look after the plant once it is ready.
- Good operation and maintenance procedures increase the sustainability and life of the plant.

COMMISSIONING A FEASIBILITY STUDY

- Preliminaries
  - Getting professional help
  - Preliminary site assessment: weir and site for turbine, access for construction equipment, demand for electricity, land ownership etc.
- Feasibility
  - Hydrological survey: flow duration curve (flow data, catchment geology and soil types)
  - System design: civil works, the generating equipment, grid connection
  - System costing: civil costs, cost of grid-connection, cost of electro-mechanical equipment, engineering and project management fees
  - Estimate of energy output and annual revenue
- Environment
  - The environmental statement: Environmental impact assessment
  - Fisheries

ENVIRONMENTAL ASPECTS

- Seepage of water from the canal, forebay, or penstock can cause damage to downstream lands or houses, or lead to soil erosion and landslides.
- Breaching of canal could cause more serious damage to land or crops in short time.
- Need to cut trees for the construction of powerhouse, civil structure and transmission lines.
- Original stream may become very low or dry up completely for a short distance making inconvenient to people who use it for drinking and washing.

FINANCIAL ASPECTS

- **Investment costs**
  - Machinery: turbine, gearbox or drive belts, generator, water inlet control valve
  - Civil works: intake, forebay tank and screen, channel/pipeline, turbine house, machinery foundations, tailrace channel to return water to river
  - Electrical works: control panel & control system, wiring within the turbine house, connection cost
  - External cost: engineering services of professionals
- **Running costs**
  - Leasing: annual rent
  - Salary
  - Maintenance and servicing
  - Insurance
- **Revenue**: tariff
- **Financial assistance**: Grant, bank loan, tax breaks, subsidy etc.

FINANCIAL ASPECTS

- The capital cost of decentralized rural electrification is best met in the medium term from a mixture of local equity capital (community or private), and a loan component from a bank or other conventional credit organization, at commercial rates backed if necessary by loan guarantee funds. Subsidies should ideally only be used where there is a possibility of their being phased out.

- Cost reduction
  - Material: use of local materials and technology
  - Tariffs: community can set tariff rates, willing to pay by the people

FINANCIAL ASPECTS (Continued)

- ***Types of MHPs that Qualify for Subsidy***
  - All new MHP projects of capacity up to 5 kW (mainly Peltric sets).
  - All new MHP projects of capacity above 5 kW to 100kW.
  - Add on electricity generation from improved water mill (ghatta).
  - Existing micro hydro schemes that need rehabilitation.

FINANCIAL ASPECTS (Continued)

1. A subsidy amount of NPR 8,000 per household will be provided for new MHP project up to 5 kW capacities. But the subsidy will not be more than NPR 65,000 per installed kW.
2. A subsidy amount of NPR 10,000 per household will be provided for new MHP project from above 5 kW to 500 kW. But the subsidy will not be more than NPR 85,000 per installed kW.
3. A subsidy amount of NPR 4,000 per household will be provided for to the add-on MHP project (Improved Water Mill), if it is for electrifying villages. But the subsidy will not be more than NPR 40,000 per installed kW.

FINANCIAL ASPECTS (Continued)

4. In respect of rehabilitation of MHP project of more than 5 kW capacities, a subsidy of NPR 10,000 will be provided per additional households if it is served by MHP as a result of rehabilitation But the subsidy will not be more than NPR 85,000 per incremental kW due to rehabilitation.
5. An additional subsidy will also be provided for the transportation of equipment and materials of the MHP project. The transportation subsidy will be given based on distance from the nearest road head to project site. The MHP projects will be categorized for transport subsidy as shown below: Rehabilitation projects, as mentioned in 4, will receive 50 percent of transport subsidy specified below:

FINANCIAL ASPECTS (Continued)

Category	Location of MHP projects	Subsidy in NRs per kW installed capacity
A	All projects in Karnali and adjoining specified districts* and projects that are located at the distance of more than 50 km walking distance from nearest road head	3000
B	Projects located at a distance of 25 km to 50 km walking distance from nearest road head.	1200
C	Project located at a distance of less than 25 km walking from nearest road head	No subsidy

* Humla, Jumla, Kalikot, Dolpa, Mugu, Rolpa, Rukum, Jajarkot, Bajhang, Bajura, Achham, Dailekh, Darchula

INSTITUTIONAL SUPPORTS

- ***National level (AEPC/ESAP)***
  - Formulation of policy and plans for rural development provides the legal and regulatory framework.
- ***Local level***
  - Suitable owners may be community based
  - organizations, electrification co-operatives supported by local NGOs, or branches of national NGOs.
- ***Intermediate level (NGOs,Government bodies)***
  - provides an integrating link between the national and local levels, ensuring that plans and policies
  - match the needs of consumers, owners and suppliers.

LEGAL PROVISIONS ON MICRO HYDRO DEVELOPMENT IN NEPAL

- No license is required for conducting surveys or for building and operating plants.
- No royalty is imposed on the electricity power generated
- Exemption from income tax
- The private producers may fix the selling price of electricity

CONTRACTING A SCHEME

- Development options
  - Turnkey contracts
  - DIY
- Suppliers
- Installers
- Commissioning and handover
- Operating the scheme

OWNERSHIP & MANAGEMENT

- **Ownership**
  - Private
  - Community
  - Public
- **Local participation**
  - Community participation in planning for electrification is likely to lead to more successful and sustainable schemes. Careful preparation is needed and locally appropriate guidelines prepared, and an external facilitator is recommended.

ENERGY MANAGEMENT

- ***Demand limiters***: Electronic cut-outs which limit the power demand of each consumer, combined with a fixed monthly tariff, according to the maximum demand.
- ***Time diversity for high load* uses** (e.g. welding only during afternoon in Peru; off-peak water heating for bathing or cooking)
- ***Pre-payment metering:*** reduces meter reading costs and permits pay-as-you-go.
- ***Heat storage cookers***: Low power cookers that store the heat over several hours (in hot rocks or water) and make it available at high intensity for short cooking periods.

STANDARD FOR QUALITY CONTROL

- The setting of appropriate technical standards is an important aspect of quality control. Without such standards the lowest capital cost is likely to dominate, with unacceptable compromises in safety and reliability.
- Availability of quality spare parts
- Qualified technicians for repair and maintenance works for technical support

MARKET ASPECTS

- Agro-processing
- Battery charging
- Lighting houses
- Small scale industries
  - Making handmade papers and noodles
  - Running photo studios, photocopiers etc.
  - Hot showers to tourists etc.

FAILURES OF MHP

- Insufficient site studies, poor estimation of hydrology, poor installation, faulty equipment
- Plants affected by floods and landslides
- Uneconomic canal length, bad canal design
- Lack of operating capability
- Inability of owner to replace generator after breakdown
- Insufficient structures for service & repair
- Inability to pay tariffs by targeted population

SUSTAINABILITY OF MHP

- Technically feasible
  - Flow
  - Head
  - Site (location)
- Socially acceptable
  - Community management
- Financially viable
  - Private entrepreneur (profit oriented)
  - Community owned (service oriented)

ENVIRONMENTAL BENEFITS

- Large hydro-power uses dam to store water and direct water. Flooding and displacement of human settlement may take place.
- Pollution free electricity (e.g. replaces fossil fuels for lighting and cooking)
- In fact, by reducing the need to cut down trees for firewood and increasing farming efficiency, micro-hydro has a positive effect on the local environment.
- Slope stabilisation
  - Retaining structures
  - Bio-engineering works: planting grass & shrubs; fast growing, deep rooted & dense cover type of vegetation at 3m away from the canal

CONCLUSIONS

- MHP is introduced where national grid is not available in general.
- Community people are benefited by doing income generating activities.
- People will have access to mass media; such as TV, radio etc.
- Children will have better education including access to computer.
- Proper site selection, continuous income generating activities and regular maintenance and repair etc. are very important for the sustainability of MHP.

CONCLUSIONS

- The components of MH can be locally manufactured & the schemes can be locally built;
- MH Plants are comparatively simple in its construction;
- The scheme can be locally managed, operated and maintained with training input to the local.

CLASSIFICATION OF HP BY SIZE

HP Types	***Installed Capacity***
Large-hydro	> 100 MW
Medium-hydro	15-100 MW
Small-hydro	1-15 MW
Mini-hydro	> 100 kW < 1 MW
Micro-hydro	Up to 100 kW

CLASSIFICATION OF MHP

MHP Types	***Size***
Very small	Up to 8 kW
Small	8 - 20 kW
Medium	20 - 50 kW
Large	50 - 100 kW

Potential of MHP in Nepal > 50 MW

BENEFITS OF RURAL ELECTRIFICATION

Electrification

- Reduces drudgery of women
- Helps children to study
- Reduces deforestation
- Encourages small entrepreneurs to generate income by creating employment
- Promotes cooking on low-wattage cookers
- Promotes transportation of goods by ropeways
- Promotes small scale industries: handmade papers, noodles; running photo studios etc.
- Preserve vaccines and other medicines in refrigerator.

MICRO-HYDRO POWER CATEGORY

MHP by application

- Mechanical installations (agro-processing)
- Add-on electrification
  - mechanical power: (during daytime)
  - Electricity (at night)
- Stand-alone installations
  - Single phase: up to 20 kW
  - Three phase: > 20 kW (to reduce transmission losses)

DISTRIBUTION OF MHP BY SCHEME

(1962 - Mid-July 2003)

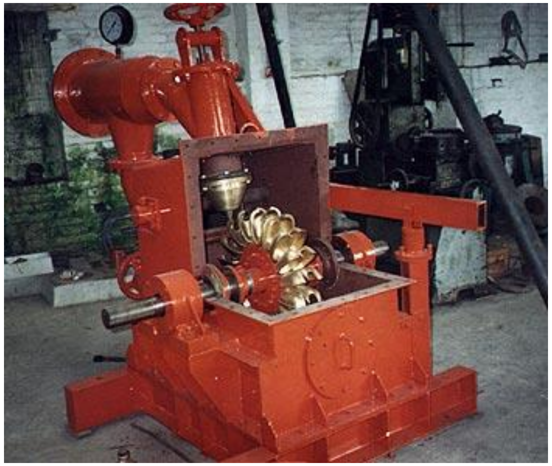
Scheme	**Number**	**kW**
Non-peltric scheme	429 *[20%]*	5833.9 *[40%]*
Peltric scheme	942 *[43%]*	1637.9 *[11%]*
Mechanical scheme	804 *[37%]*	7106.9 *[49%]*
Total	***2175***	***14578.6***

DISTRIBUTION OF MHP BY DEVELOPMENT REGION
(1962 - Mid-July 2003)

Development Region	**No. of schemes**	**Installed capacity**
Far-Western Region	88	961.0 kW
Mid-Western Region	274	2066.5 kW
Western Region	665	5983.9 kW
Central Region	417	3218.9 kW
Eastern Region	722	2295.3 kW
Not known	9	53.0 kW
TOTAL	***2175***	***14578.6 kW***

MHP SELECTION CHART FOR DIFFERENT APPLICATIONS

S. N.	Service Required	No. of households served	Best Choice	Power (kW)	Head (m)	Flow (lps)	Approx. cost range (thousand Rs)	No. installed in Nepal	Availability of subsidy (Nepal)	Remarks
1	Flour milling	20-30	Traditional ghatta	0.2-0.5	3-7	40-100	8-12	25000	Not required	Indigenous technology; local blacksmiths build
2	Flour milling	30-150	Improved ghatta	0.5-3.0	2-7	30-100	16-150	736	Rs. 27,000/kW; for electricity generation only	A few installations have electricity generation and a small huller; the rest are for milling only
3	Flour milling, rice de-husking, oil expelling	200-600	Turbine mill	5-15	Low	Medium to high	Up to 90/kW	799	None	Because of subsidy for electric MHP, demand for mill is almost nil. Some mills generate electricity with small alternator.
4	Lighting	Up to 30 houses	Peltric set	0.5-3.0	20-200	1-5	100-150 per kW	810	Rs. 55,000/kW	
5	Electrification of large area	30-500 or more households	MHP up to 100 kW	3-100	Wide range	Wide range	100-150 per kW	347	Rs. 70,000/kW	Transport subsidy Rs. 8,750-21,000 based on distance from nearest road head
6	Lighting and milling	More than 60 houses	Pico power pack	0.5-5	High range	Low flow	Over 100 per kW	1	Yes	First pilot project installed at Kushadevi, Kavre in 1998
7	Lighting	4-10 houses	Family hydro	0.2-1.0	2-5	30-85	30-100	5	Under consideration	A number of demonstration plants installed

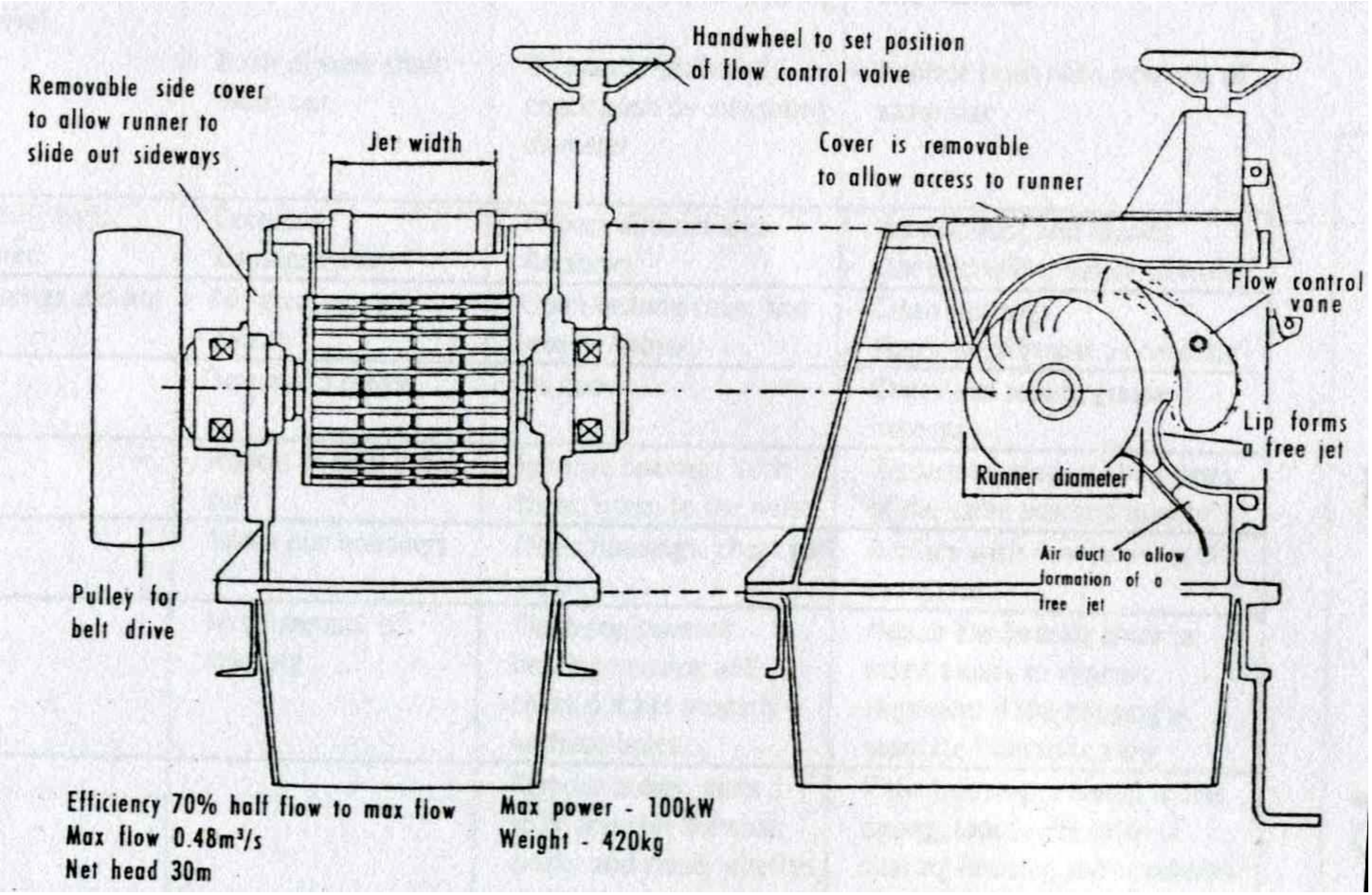


PELTON

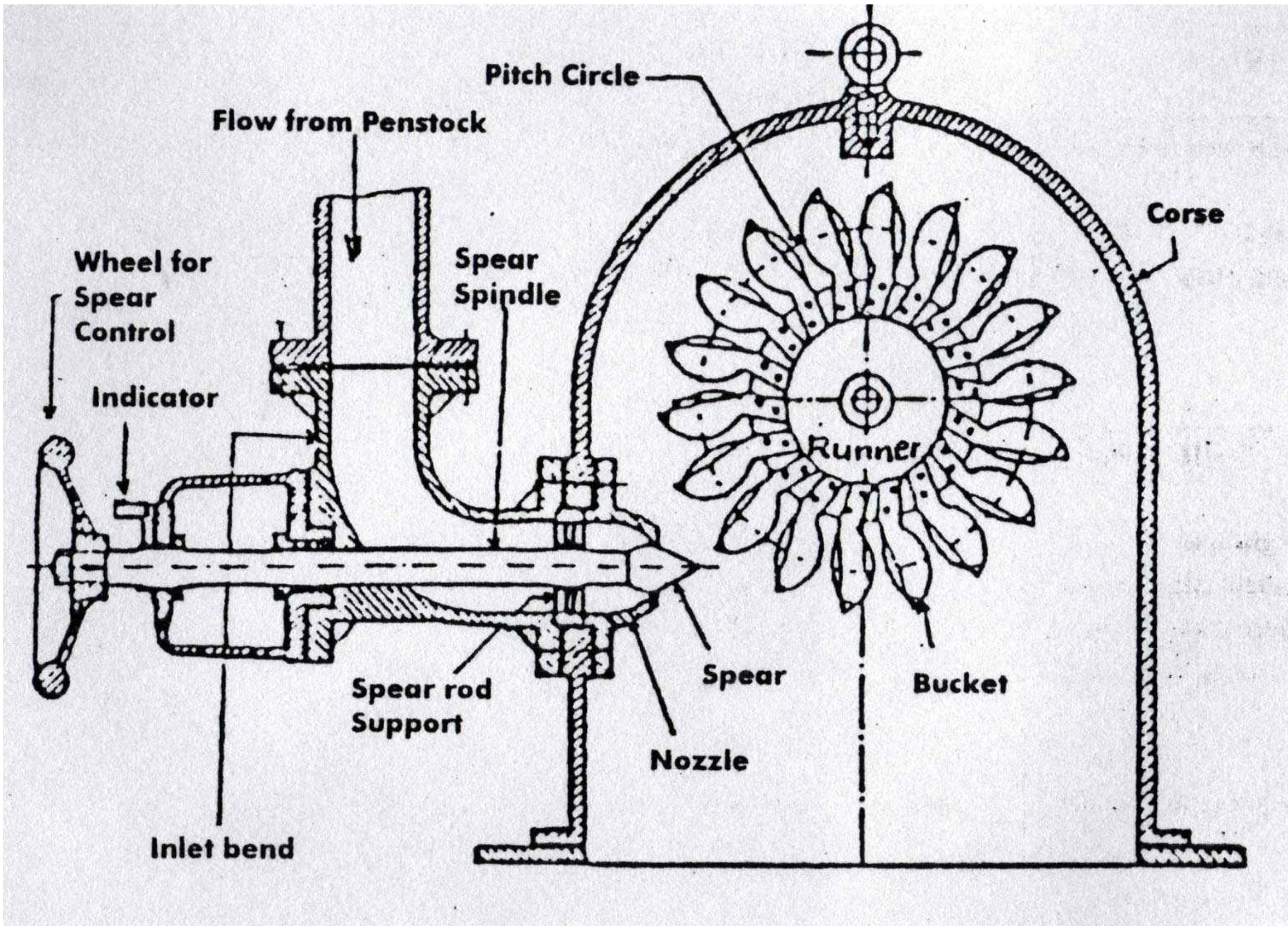
TURGO

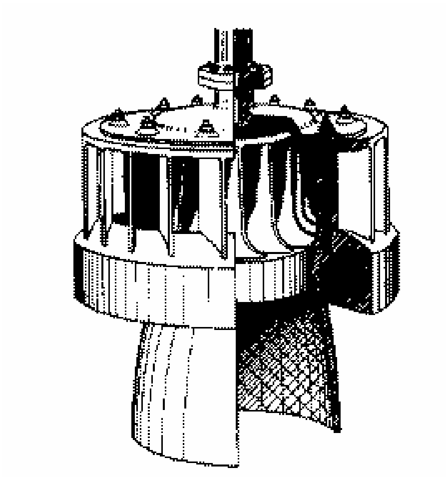
CROSS-FLOW

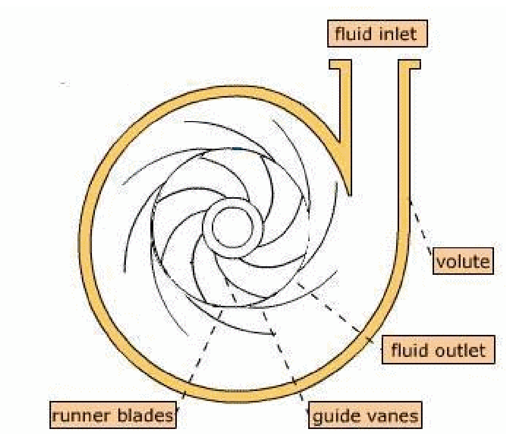
CROSS-FLOW TURBINE



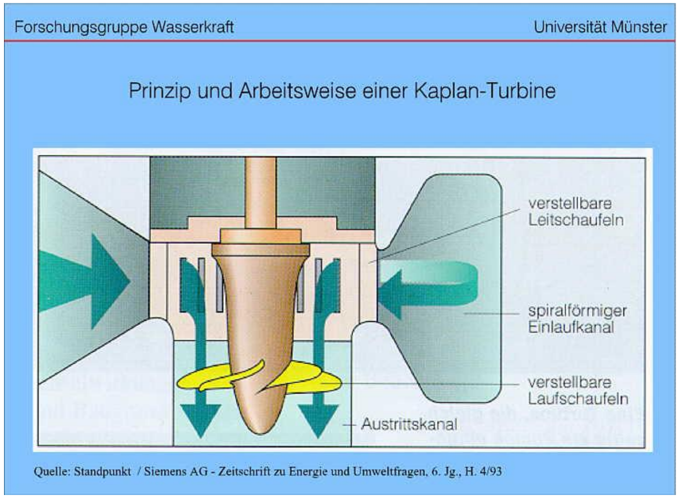
PELTON TURBINE



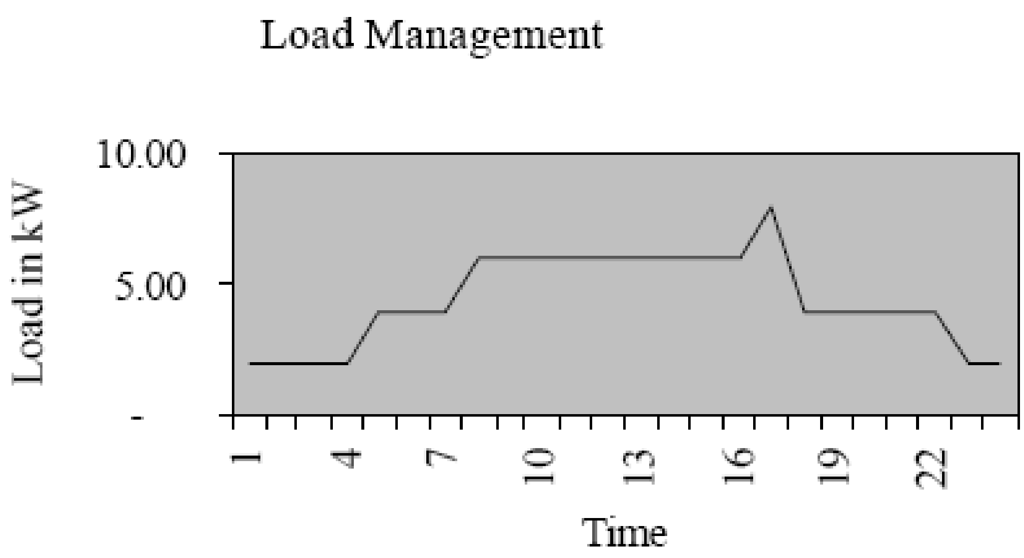




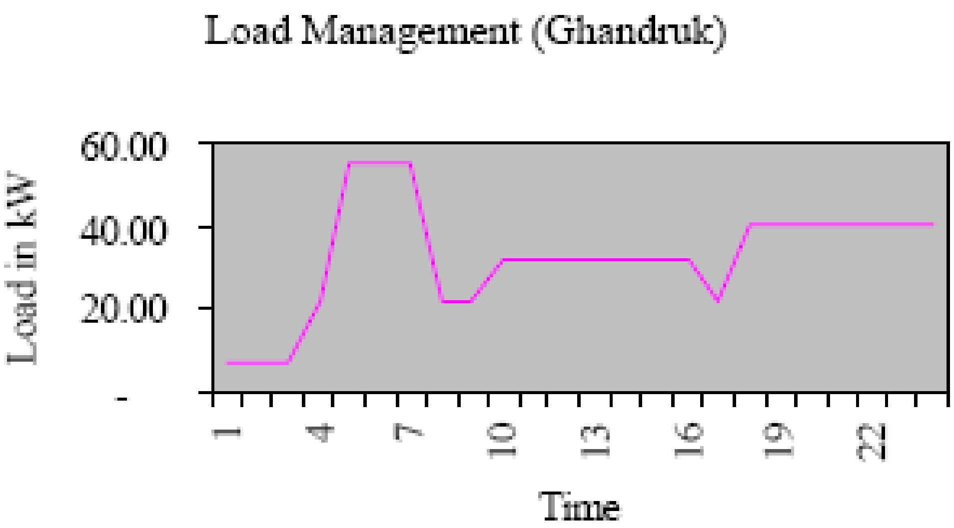
FRANCIS



PROPELLER



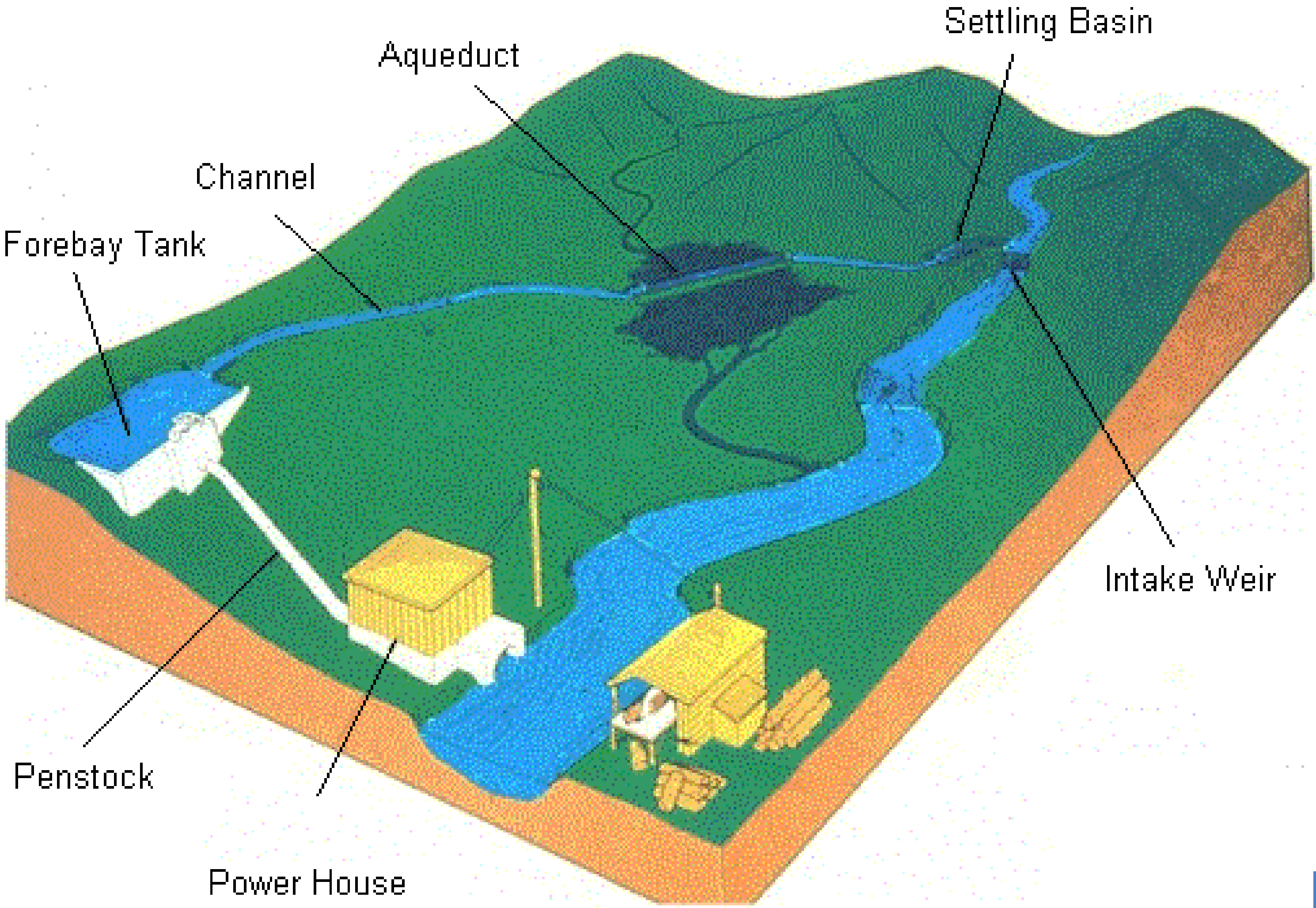
Gorkhe, Illam



WHAT IS MICRO-HYDRO POWER?

- Water can be harnessed on a small scale to large scale to generate power
- Hydropower is the generation of power (mechanical and/or electrical) using the fall of water
- Micro-hydro power is the small scale harnessing of energy from falling water. (e.g; harnessing enough water from a local river to power a small factory or village)

MAIN COMPONENTS OF MHP



Selection of Turbine

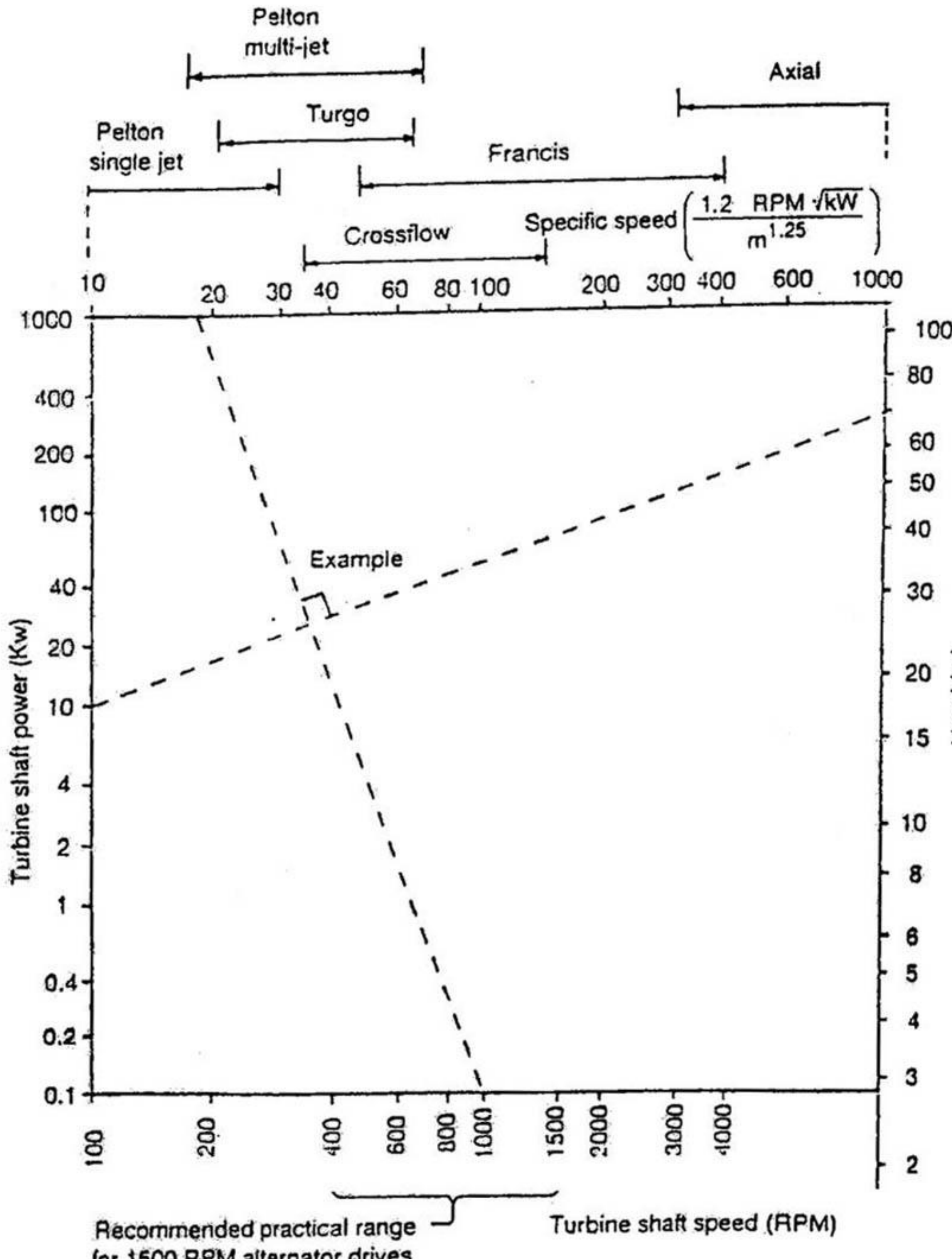
Nomogram

Turbine selection using Nomogram

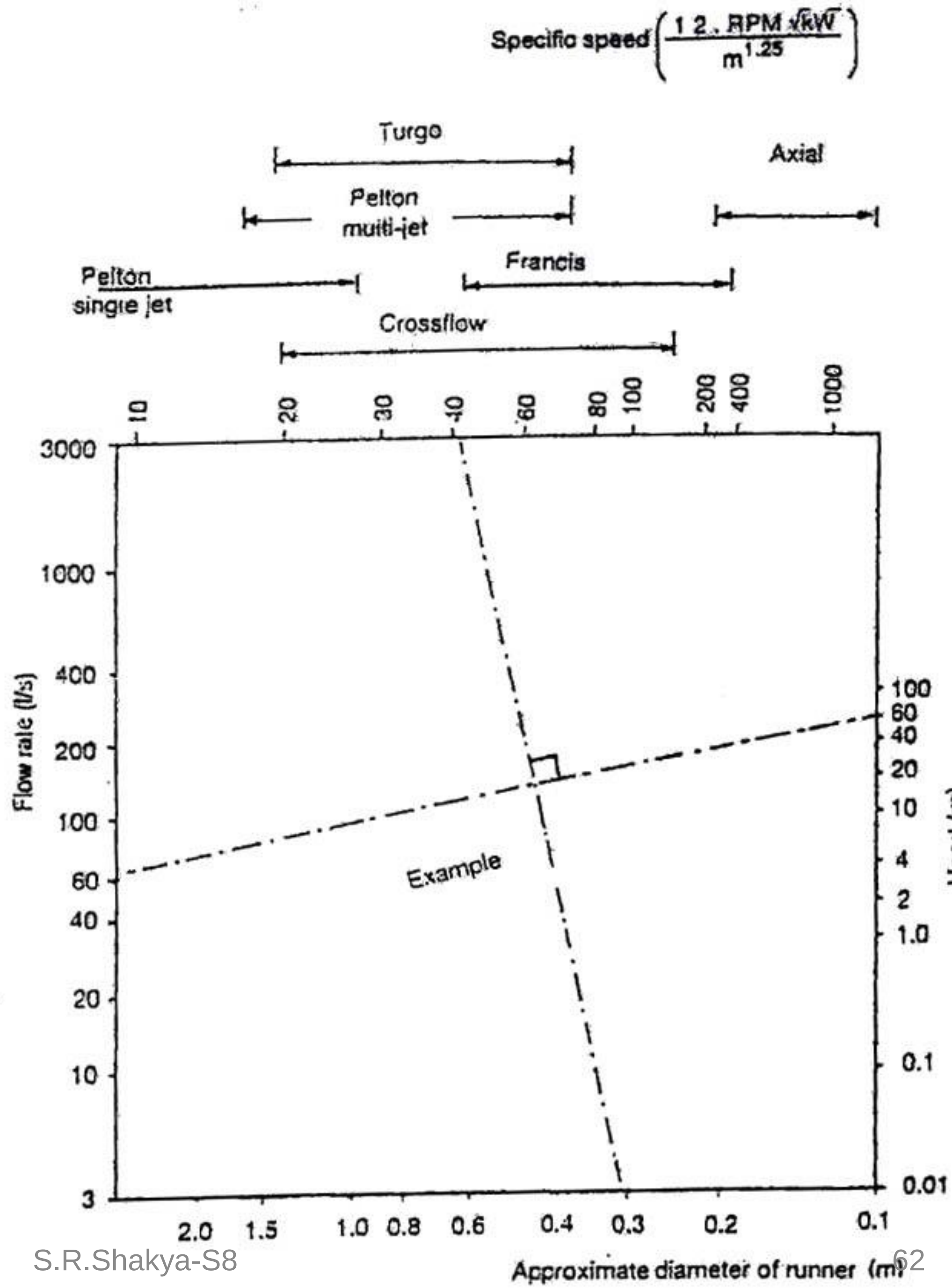
•Mark head available, calculate turbine output power and rule line across

•Choose desired turbine running speed and draw a line from this point which is at right angle to the head-power line.

•Choose a turbine shaft speed of 1500 rpm for direct drive between turbine and generator

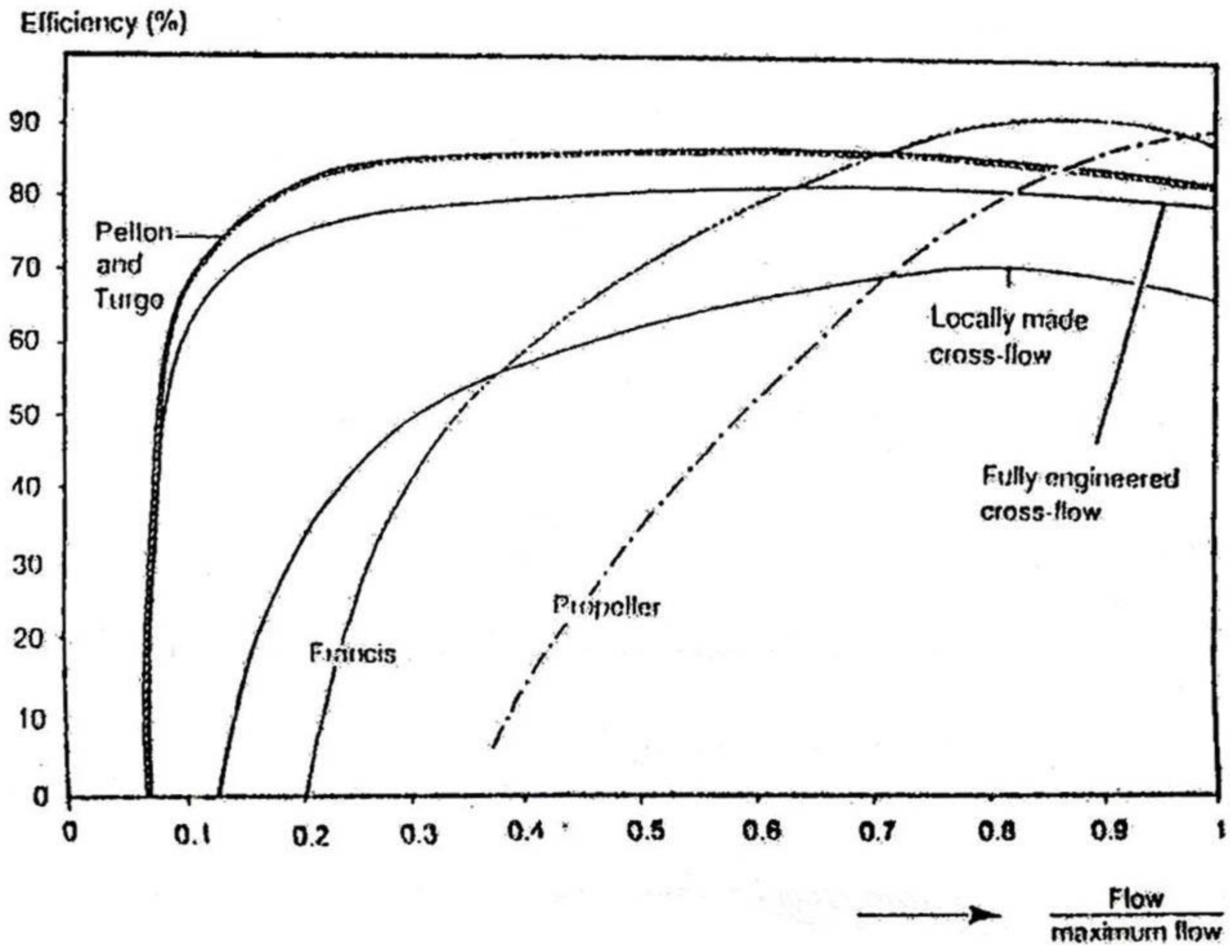


Estimate of appropriate runner diameter

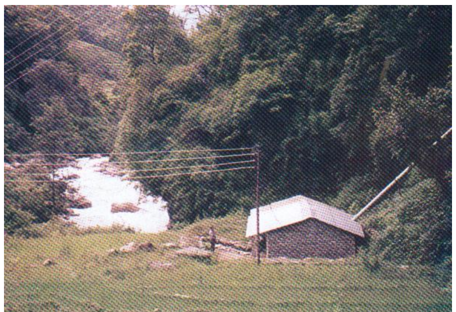


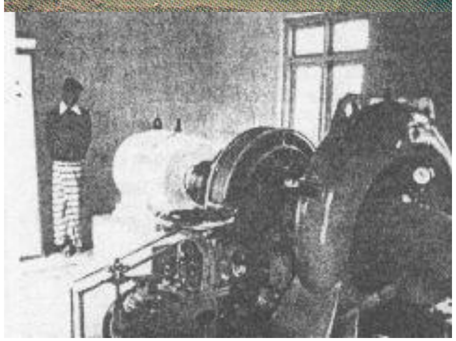
Part flow efficiency of various turbines

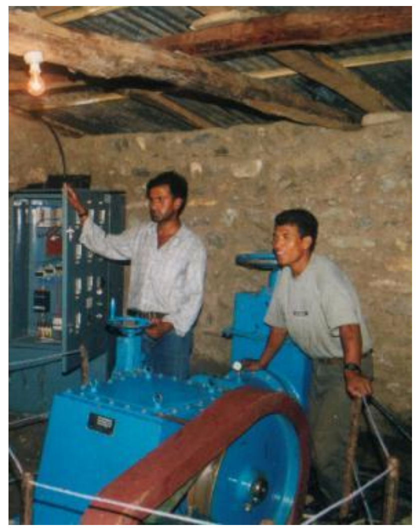
These curves assume turbines which have facilities for varying water flow rate at constant head



Selection of Micro-hydro Turbines







Turbine selection parameter

- Head
- Specific speed [$Ns = N[P^{1/2}/H^{5/4}]$
- Rotational speed
- Efficiency
- Part load condition
- Disposition of turbine shaft
- Local Fabrication Facility
- Ease of Operation and Maintenance

The selection of the best turbine depends on

- Site characteristics
  - HEAD available
  - FLOW RATE available
  - POWER required
- desired RUNNING SPEED of the:
  - Generator (1500 RPM)
  - Agro processing and other mechanical devices loading the turbine
- power production under part-flow conditions
- Cost of the turbine

Selection by Head & Operation principle

Turbine Runner	High Head	Medium Head	Low Head
Impulse Turbine	1. Pelton 2. Turgo 3. Multi-jet Pelton	1. Cross Flow 2. Turgo 3. Multi-jet Pelton	1. Cross Flow
Reaction Turbine		1. Francis 2. Pump as Turbine (PAT)	1. Propeller 2. Kaplan

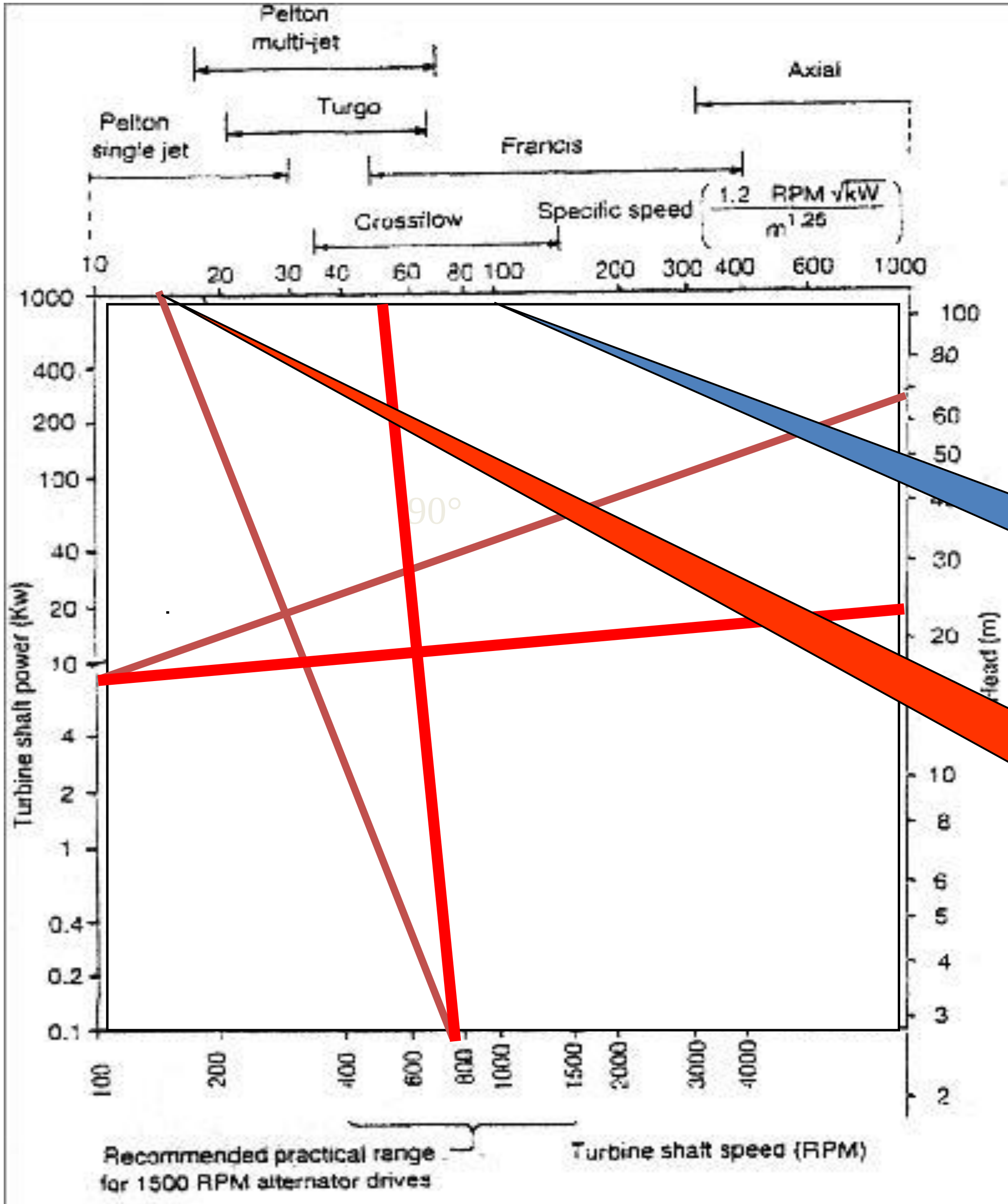
Suitable MHP turbine types for different conditions

Turbine Type	Power range(kW)	Head range (m)	Flow range (l/s)	Speed range (rpm)
Cross flow	1 - 100 kW (200 kW)	4 - 50 m (88 m)	50 - 800 l/s	200 - 1000 (1500)
Pelton single jet	0.2 - 500 kW	35 - 200 m	1 - 200 l/s	300 - 1500
Pelton multi jet	0.8 - 1000kW	35 - 200 m	3 - 600 l/s	300 - 1500

Steps for using NOMOGRAMs to select the Turbine Type and Rotor Diameter

- **Use of Head (m), expected Shaft Output (kW) and expected Shaft Speed (RPM) to determine Turbine Type**
- **Use of Head (m), Flow Rate (l/s) and Turbine Type to determine Diameter of Runner of Turbine (m)**
- **Study Part Load Performance**
- **Costing**
- **Other factors**

Selection of Turbines



Turbine Shaft Power = et x 10 x Q x H (kW)
Q(m^3/s), H (m)

Low Head - Cross Flow

High Head - Pelton

Average efficiency of MHP Turbines

Turbine Type	Average Efficiency
Cross flow	65
Pelton	75
Turgo	75
Francis, Propeller	80
Pump as Turbine	60

Selection of Turbines: Specific Speed

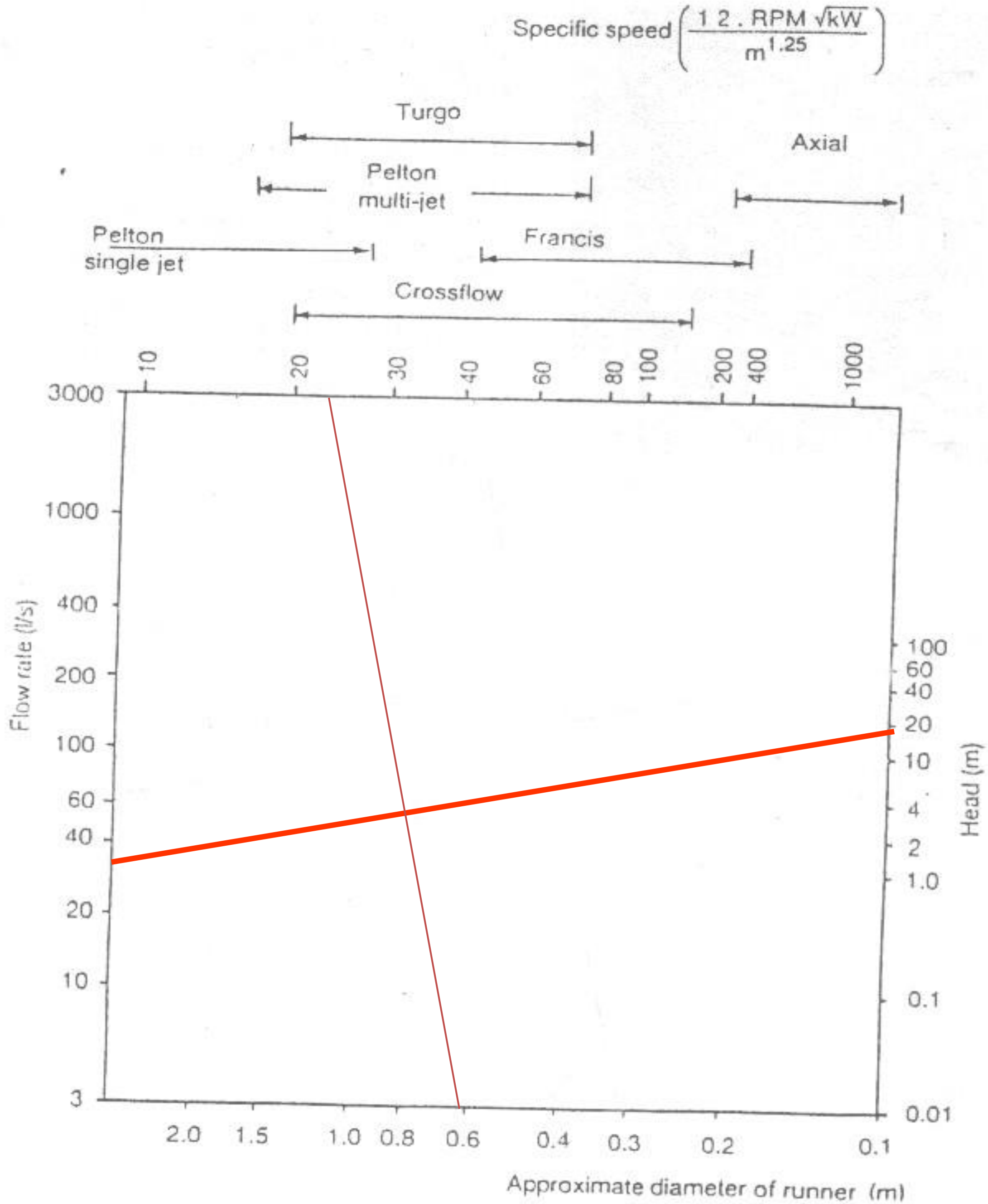
Specific Speed

$$n_s = n_{turb} \times \frac{P_0^{0,5}}{h^{1,25}}$$

P_o: shaft power of turbine [kW]
h: head [m]
n_{turb} : speed of turbine [rpm]
n_s: specific speed [rpm]

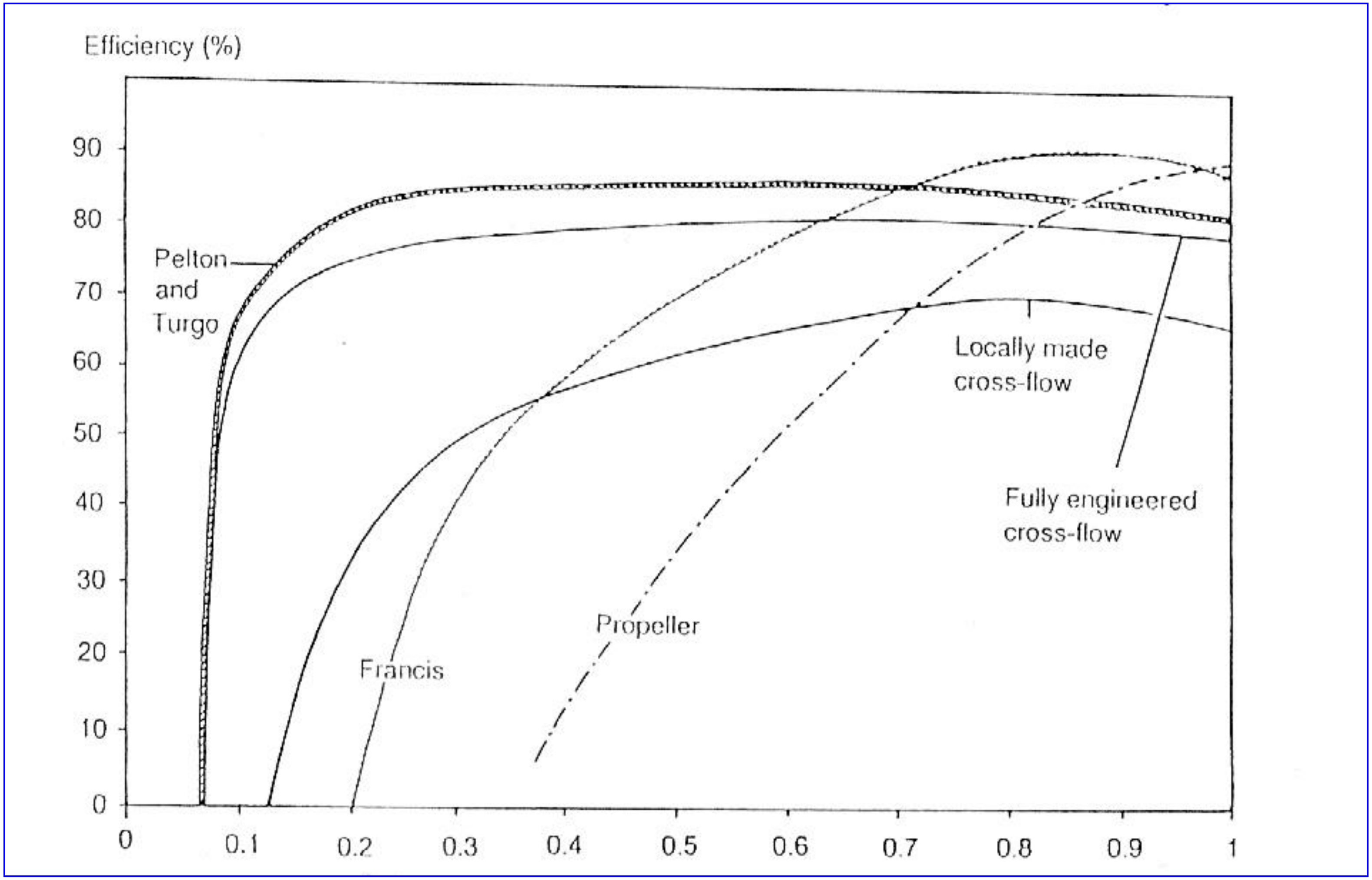
Values for n_s

Pelton turbines:	**12 - 30 rpm**
Turgo turbines:	**20 - 70 rpm**
Cross Flow turbines:	**20 - 80 rpm**
Francis turbines:	**80 - 400 rpm**
Kaplan turbines:	**340 - 1000 rpm**



Estimate of the runner diameter (appox.)

PART FLOW EFFICIENCY OF DIFFERENT TURBINE TYPES



Cost

Shaft power kW	Crossflow	Francis	Single-jet Pelton	Multi-jet Pelton	Turgo	Propeller
2	1 - 2	4 - 6	1 - 4	1 - 3	2 - 4	4 - 6
5	2 - 6	8 - 10	2 - 8	2 - 6	5 - 8	8 - 10
10	2 - 10	15 - 20	2 - 15	2 - 10	8 - 14	15 - 20
20	3 - 14	20 - 30	3 - 20	3 - 15	12 - 20	20 - 30
50	5 - 30	25 - 70	5 - 50	5 - 30	35 - 50	25 - 70
100	30 - 50	40 - 100	40 - 80	15 - 60	55 - 80	40 - 100
150	50 - 80	60 - 120	60 - 100	30 - 80	80 - 100	60 - 120

Costs of turbines in units of US $1000 excluding alternator and drive