HEAD TANK (FOREBAY TANK)

- Head-tank - Pond at the top of a penstock or pipeline; serves
- as final settling basin, maintains the required water level of
- penstock inlet and prevents foreign debris entering the penstock.

PENSTOCK

- Penstock – A close conduit or pressure pipe for supplying water under pressure to a turbine.

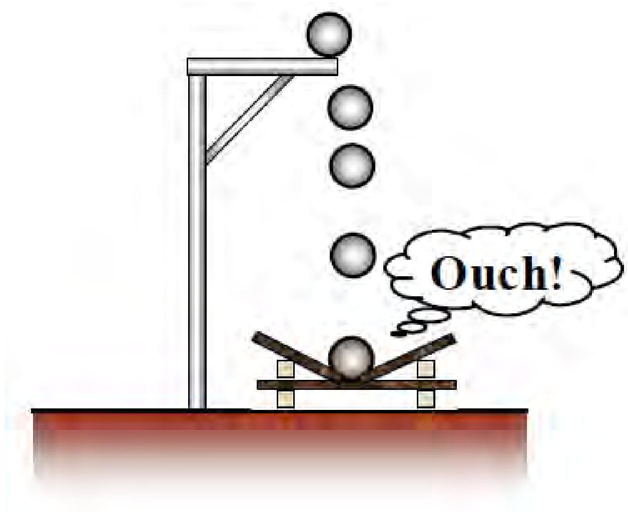
POWER HOUSE

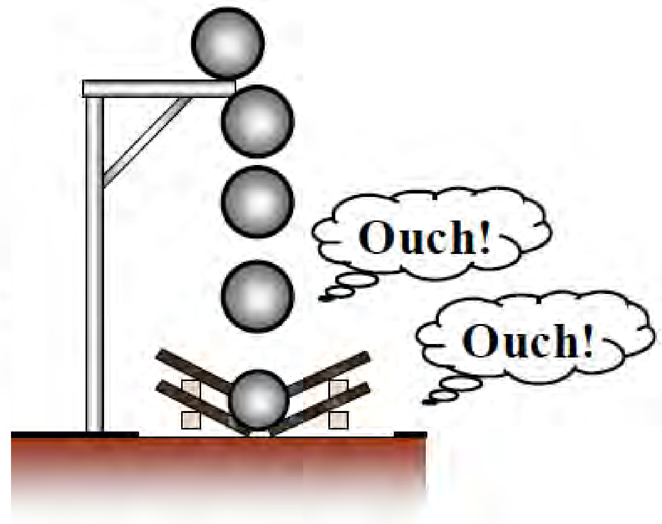
- A water turbine is a machine to directly convert the kinetic energy of the flowing water into a useful rotational energy while a generator is a device used to convert mechanical energy into electrical energy.

Topics covered

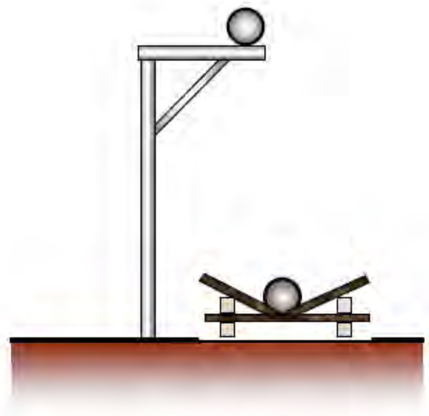
- Components of micro/mini hydropower plant
- Hydropower potential
- Types of turbines
- Types of generator
- Hydropower status in Cambodia

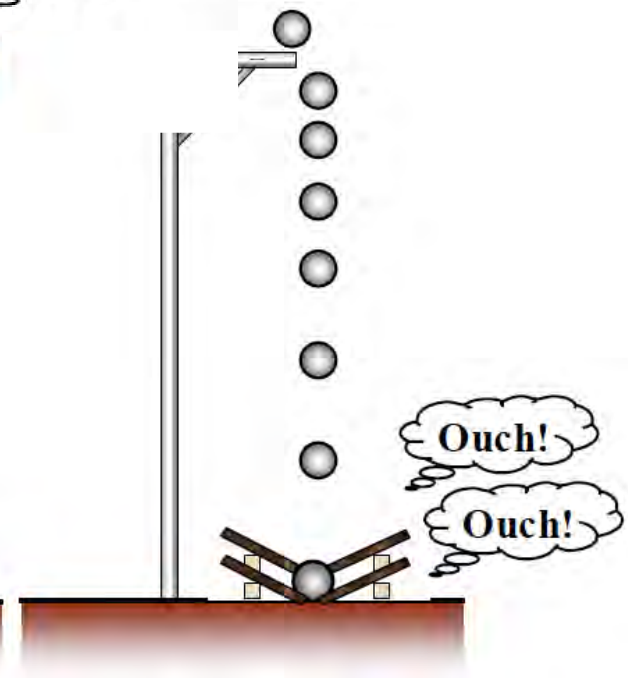
WHAT IS HYDRO POWER?



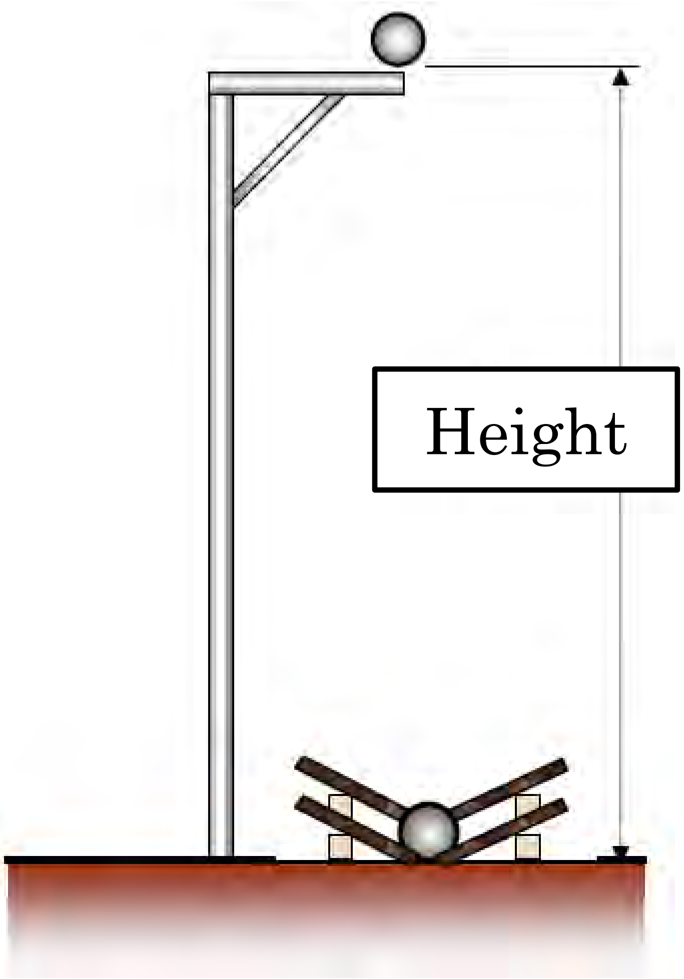


Energy of falling stone





WHAT IS HYDROPOWER?



- Energy of falling stone depends on
  - Height
  - Weight of the stone
- Energy of hydropower
  - Height → Head
  - Weight of the water → Discharge
- Power in the water

$$P = 9.8 \times Q \times H$$

- P: Power in the water [KW]
- Q: Water flow [m^3/s]
- H: Head [m]

DISCHARGE MEASUREMENT – METHOD 1

- **Using electromagnetic current meter**

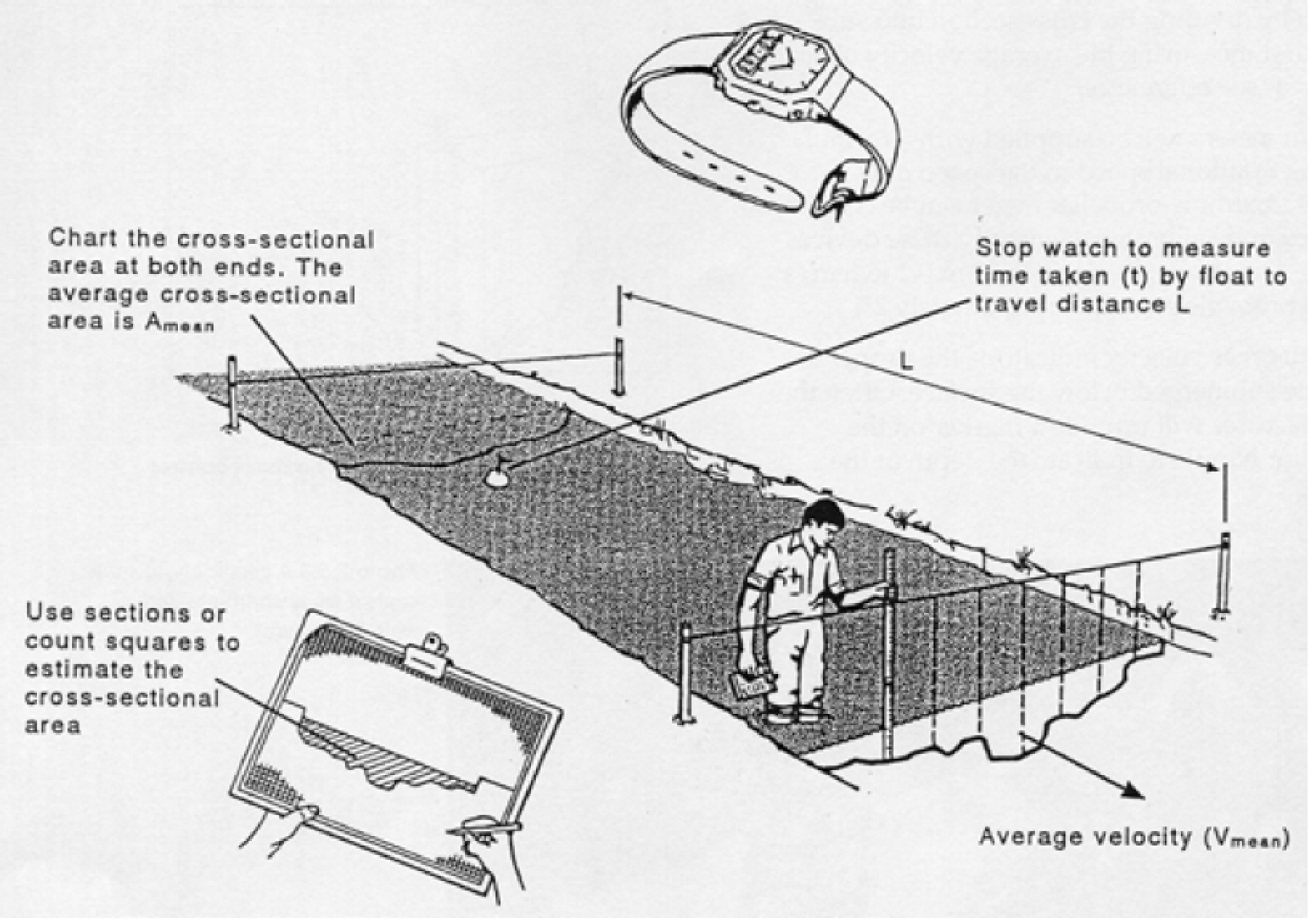
- (1) Three-points measuring method
  - $Vm = 0.25\times(V0.2 + 2V0.6 + V0.8)$
- (2) Two-points measuring method
  - $Vm = 0.50\times(V0.2 + V0.8)$
- (3) One-point measuring method
  - $Vm = V0.6$
- (4) Surface measuring method
  - $Vm = 0.8\times Vs$
- where:
  - Vm: Mean velocity
  - Vs: Surface velocity
  - V0.2: Velocity at the depth of 20% below the water surface
  - V0.6: Velocity at the depth of 60% below the water surface
  - V0.8: Velocity at the depth of 80% below the water surface

Actual Measurement

Electromagnetic Current Meter

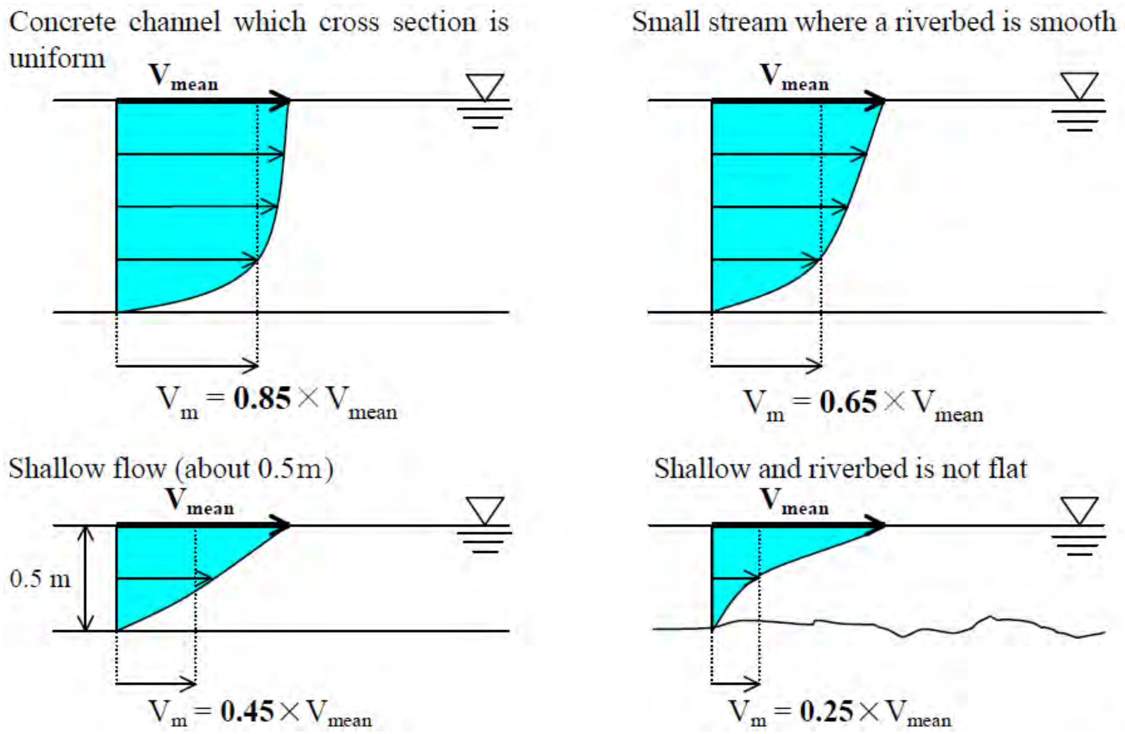
DISCHARGE MEASUREMENT – METHOD 2

- **Float measuring method**



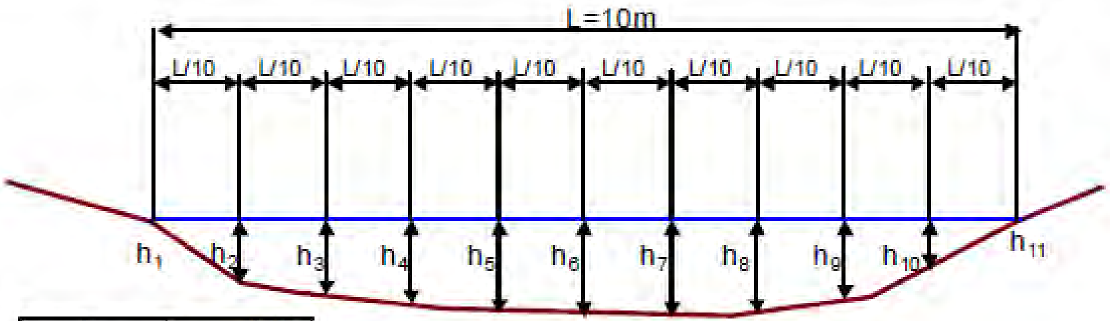
DISCHARGE MEASUREMENT – METHOD 2

- $V_m = C \times V_{mean}$
- C: (1) Concrete channel which cross section is uniform = 0.85
- (2) Small stream where a riverbed is smooth = 0.65
- (3) Shallow flow (about 0.5m) = 0.45
- (4) Shallow and riverbed is not flat = 0.25



Discharge measurement – method 2

- **Float measuring method**



h_1	0.00
h_2	0.45
h_3	0.50
h_4	0.57
h_5	0.60
h_6	0.62
h_7	0.65
h_8	0.60
h_9	0.50
h_{10}	0.35
h_{11}	0.00
Total	4.84
Average	4.84/11=

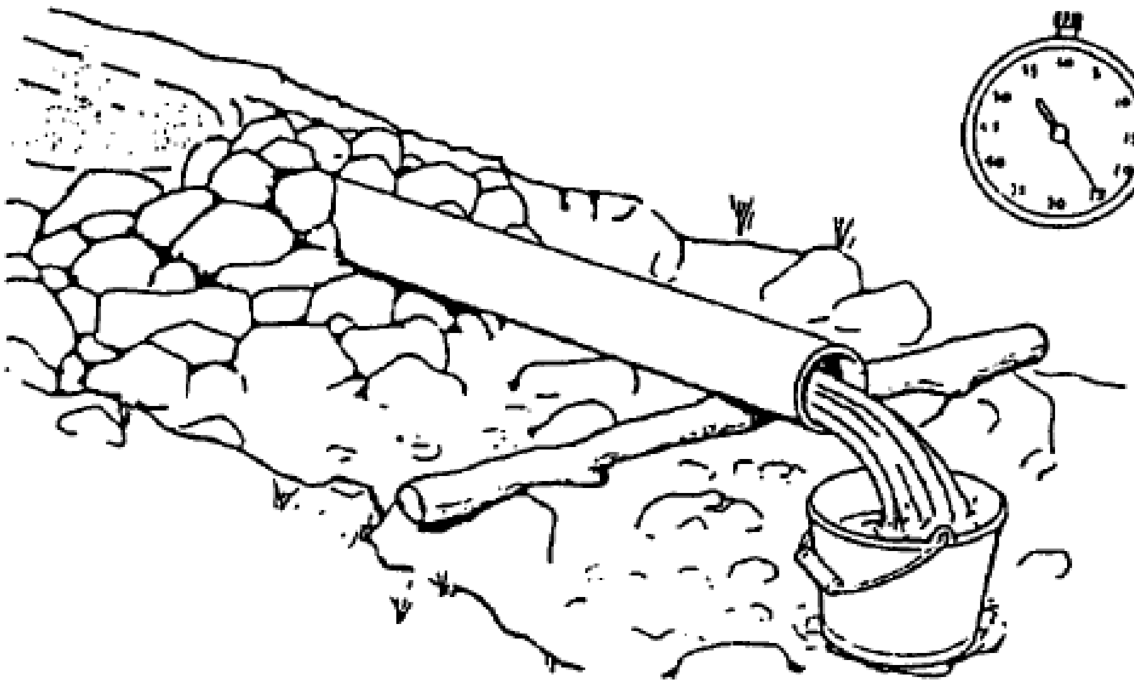
0.44 m

$$A = h_{avarage} \times L = 0.44 \times 10.00 = 4.40\ m^2$$

Measuring of Cross Sectional Area

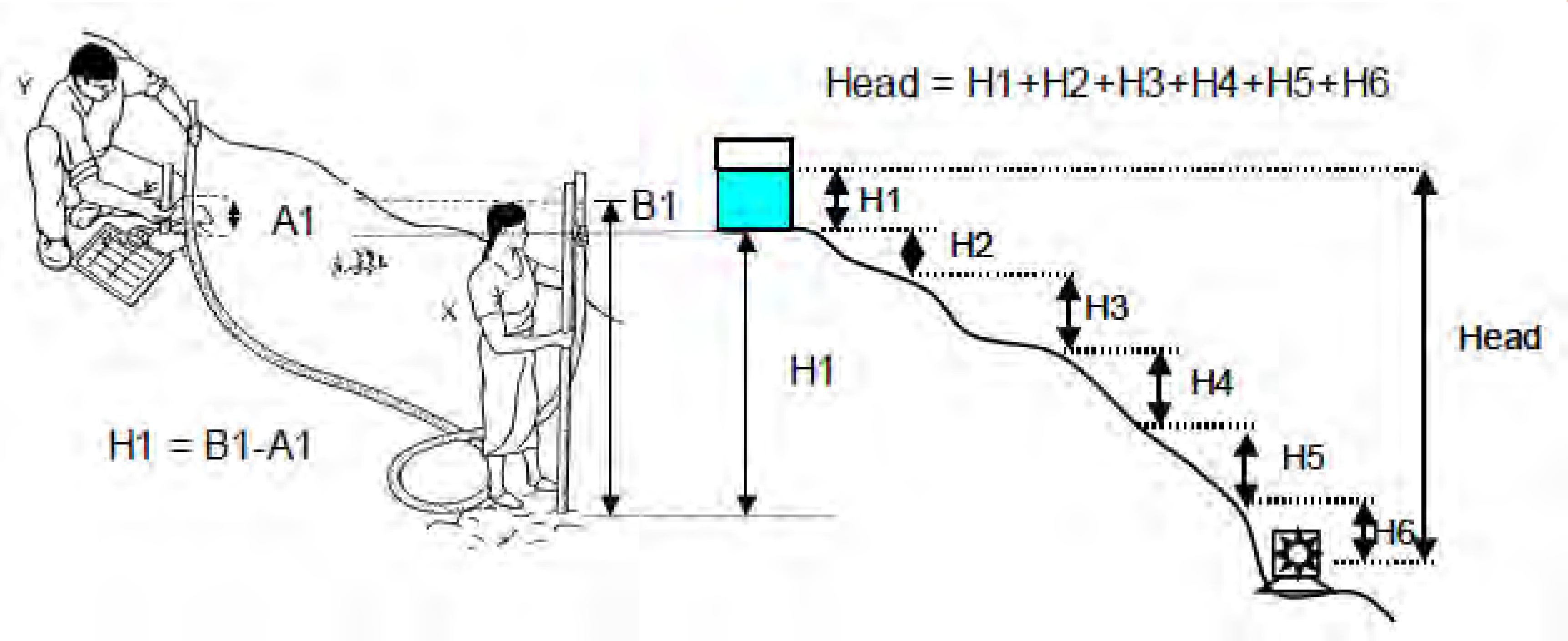
DISCHARGE MEASUREMENT – METHOD 3

- **Bucket method**



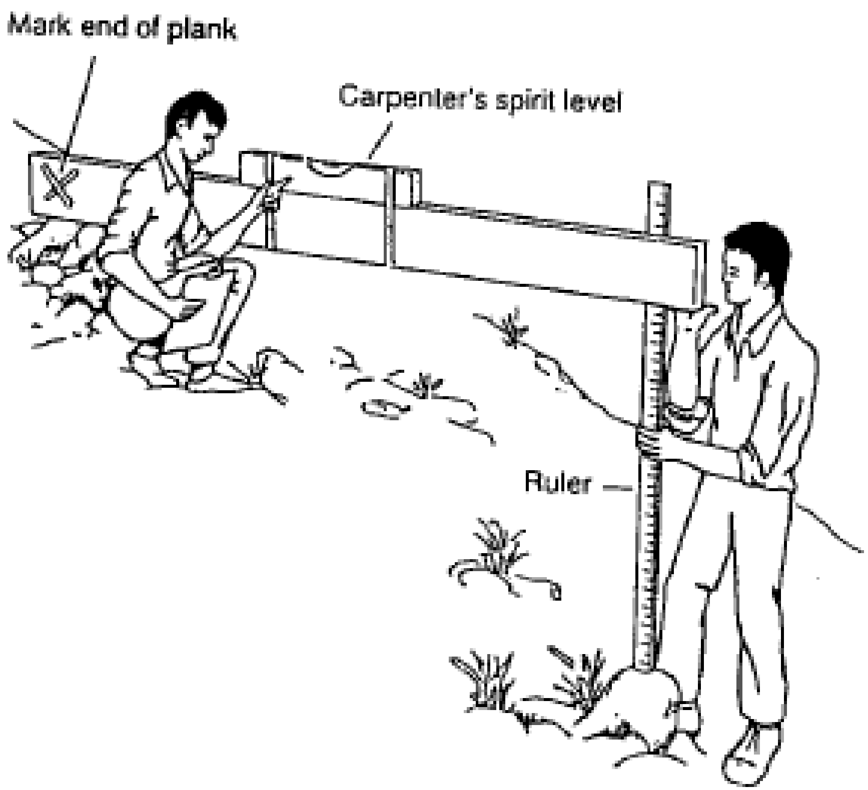
HEAD MEASUREMENT – METHOD 1

- **Clear hose method**



HEAD MEASUREMENT – METHOD 2

- **Spirit level and plank method**

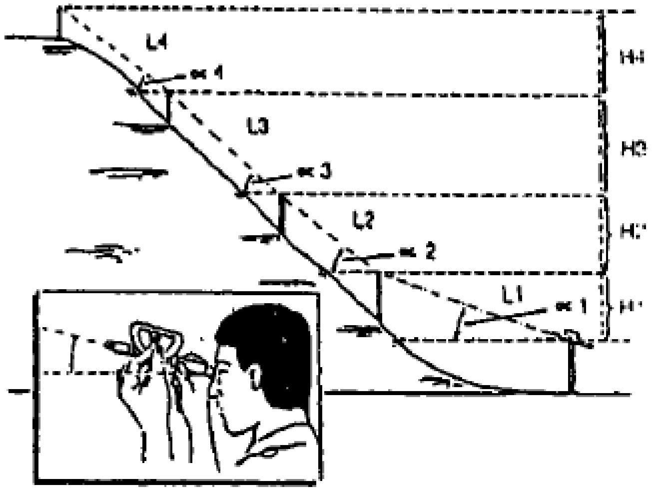


HEAD MEASUREMENT – METHOD 3

- The principle of the altimeter is that it measures atmospheric pressure.
- This method is useful in case of long survey distance or bad visibility.
- However, several measurements is required. since in one measurement, accuracy is not expectable by changes during the day in temperature, atmospheric pressure and humidity.

Head measurement – method 4

- **Sighting meters method**
- Hand-hold sighting meters measure angle of inclination of a slope
- They are often called clinometers or Abney levels).
- A head is calculated by the following formula using a vertical angle that is measured by a hand-hold sighting meter, and a hypotenuse distance measured by a tape measure.



Topics covered

- Components of micro/mini hydropower plant
- Hydropower potential
- Types of turbines
- Types of generator
- Hydropower status in Cambodia

TURBINE TYPES (1)

Impulse turbine:

The runner rotates by impulsive force of water jet with the velocity head, which has been converted from the pressure head at the time of jetting from the nozzle

- Pelton turbine
- Crossflow turbine*
- Turgo-impulse

*Crossflow turbine has characteristics of both impulse and reaction turbine

Reaction turbine:

The runner rotates by reactive force of water with the pressure head

- Francis turbine
- Propeller turbine (Kaplan, Bulb, Tubular, etc.)

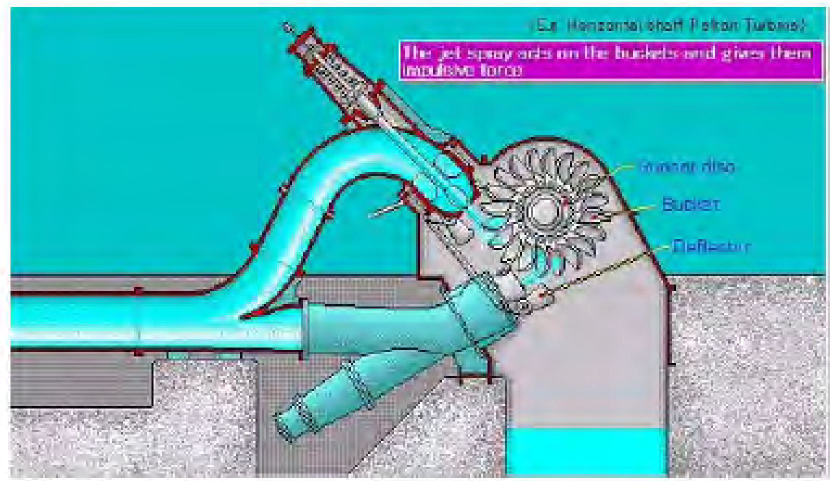
TURBINE TYPES (2)

- Pelton Turbine

■ Water jet from the nozzles acts on the buckets, and the runner is rotated by the impulsive force ■ Horizontal-shaft Pelton turbine can be applied to micro/small hydropower project ■ Suitable for run-of-river project, especially with high-head and less head change

Applicable range

- Output: 100 – 5,000 kW
- Discharge: 0.2 – 3 m^3/s
- Head: 75 – 400 m



Turbine types (3)

- Crossflow Turbine

- Arc shape runner blades are welded on the both side of iron plate discs
- Simple structure, easy O&M, and reasonable price
- Suitable for rural electrification project using micro hydropower plant

Applicable range

- Output: 50 – 1,000 kW
- Discharge: 0.1 – 10 m^3/s
- Head: 5 – 100 m

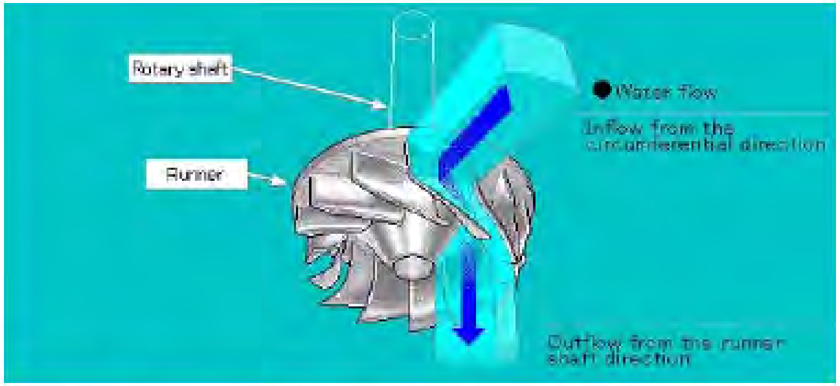
TURBINE TYPES (4)

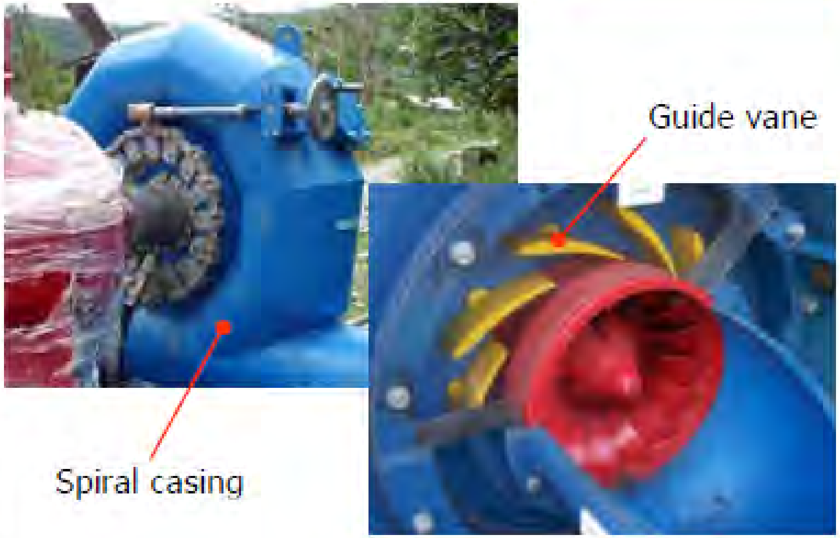
Francis Turbine

- Water flow brought from the penstock flows into the runner through casing and guide vane
- Wide applicable range of head and discharge
- Horizontal-shaft Francis turbine can be applied to micro/small hydropower project

Applicable range

- Output: 200 – 5,000 kW
- Discharge: 0.4 – 20 m^3/s
- Head: 15 – 300 m





TURBINE TYPES (5)

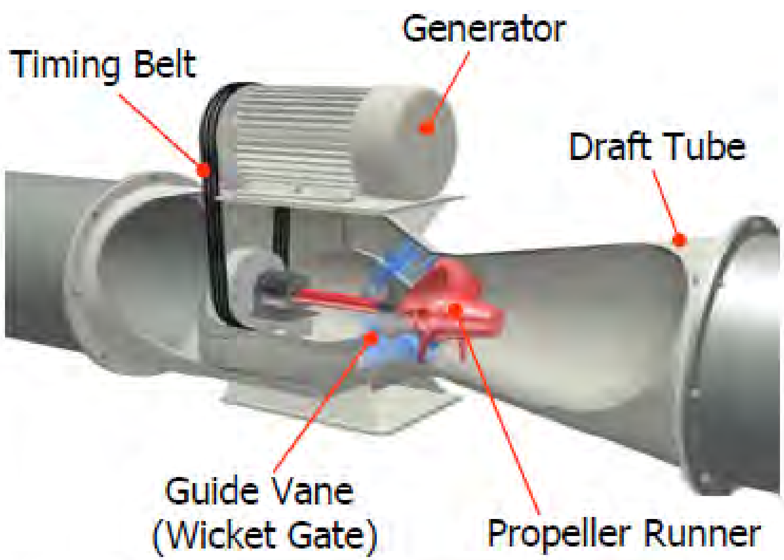
- Tubular Turbine

2.1.4 Tubular turbine

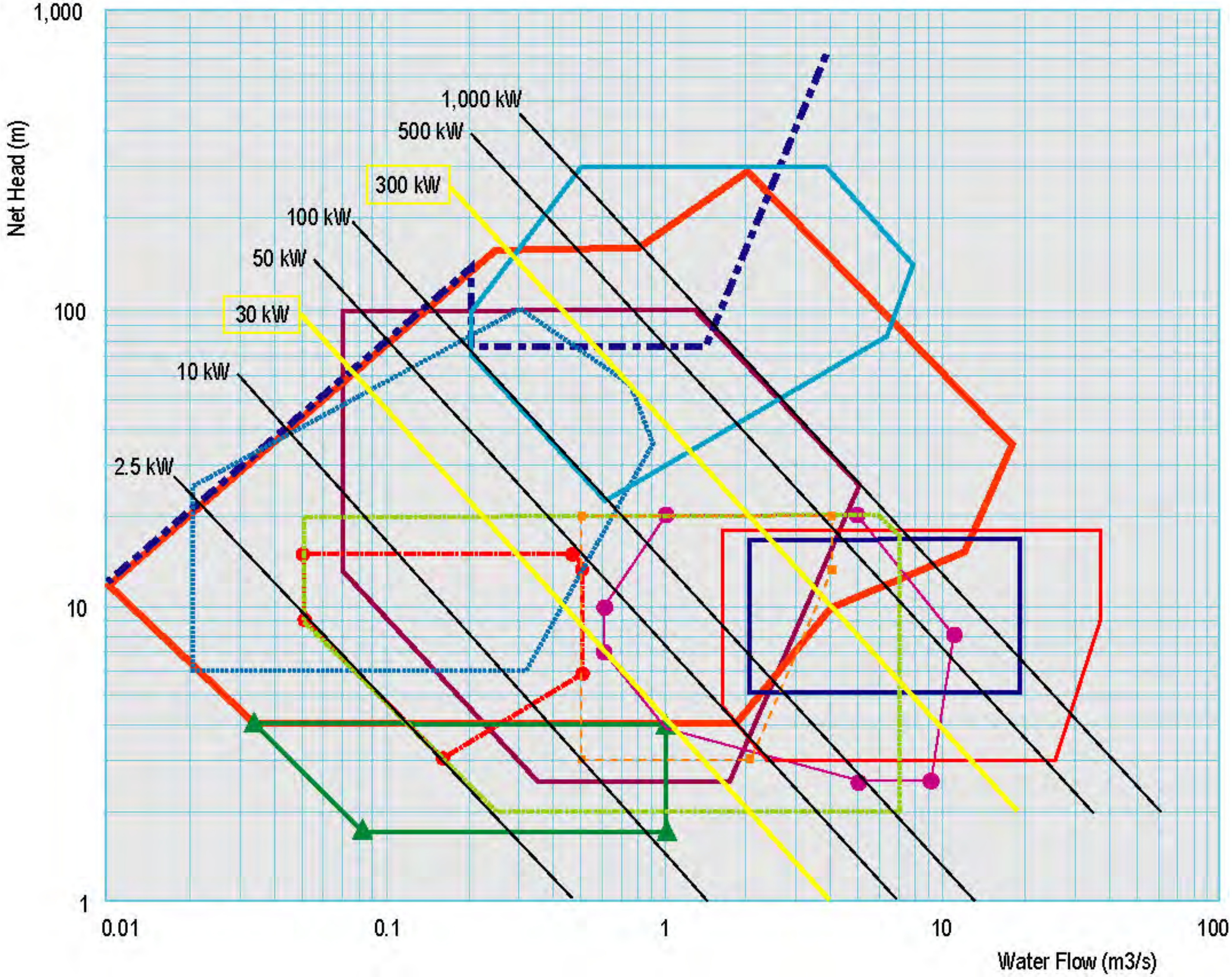
- One of propeller turbines tubular casing
- Wide applicable range of head and discharge
- Suitable for low-head sites

Applicable range

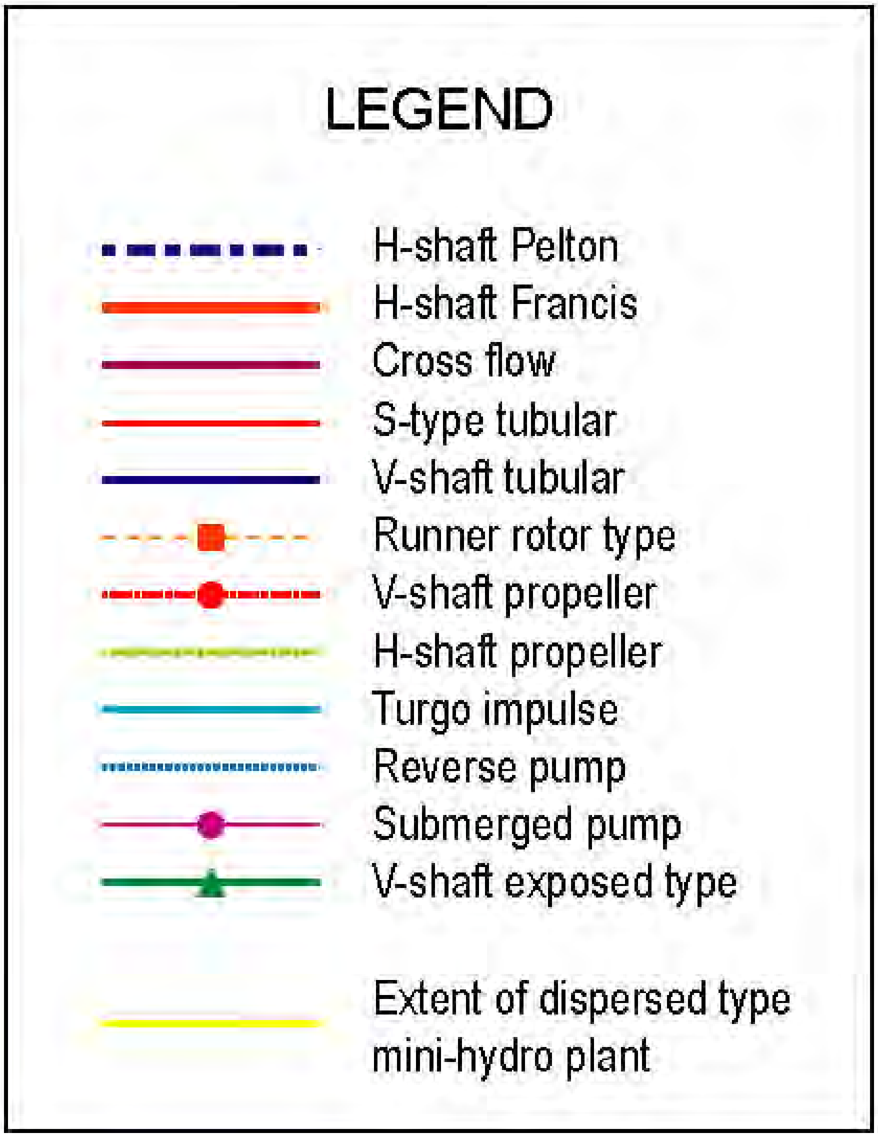
- Output: 50 – 5,000 kW
- Discharge: 1.5 – 40 m^3/s
- Head: 3 – 18 m



TURBINE TYPES (6)



TURBINE TYPES (7)



Topics covered

- Components of micro/mini hydropower plant
- Hydropower potential
- Types of turbines
- Types of generator
- Hydropower status in Cambodia

Classification (1)

- **by generator type**
  - Synchronous generator
  - Induction generator

  Features of each type are shown in the next Clause 1.2

- **by number of phase**

Single-phase	◆Simple structure and easy maintenance
Three-phase	◆High transmission efficiency due to small current with the same capacity as single-phase machine (58% of 1-pahse)

- **by shaft arrangement**

Vertical-shaft	◆Suitable for large-scale hydro
Horizontal-shaft	◆Not suitable for large-scale hydro due to limitation of shaft deflection ◆Suitable for small-scale/micro hydro ◆Easy maintenance

Classification (2)

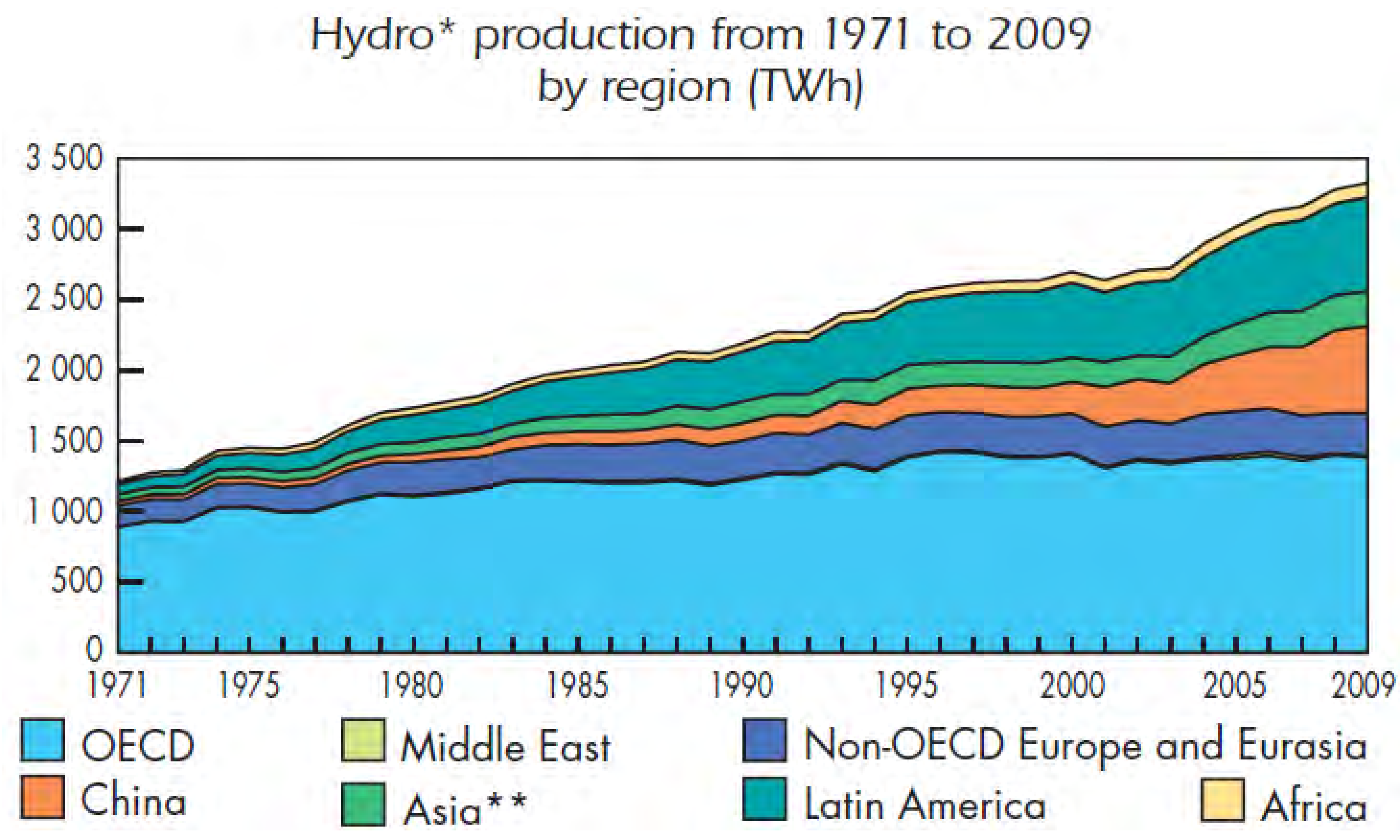
Items	Structure	Operation	Parallel-in operation
Synchronous generator	◆Excitation system is necessary ◆Complex structure (salient-pole machine) ◆Maintenance for excitation system is necessary	◆Independent operation is possible ◆Voltage, frequency, and power factor regulation is possible	◆Need synchronizer ◆Less electro-mechanical impact at parallel-in operation
Induction generator	◆Need no excitation system (Excitation current is supplied from grid) ◆Simple structure and high maintainability (squirrel-cage rotor) ◆High mechanical strength	◆Not suitable for independent operation (only on-grid operation) ◆Voltage, frequency, and power factor regulation is impossible	◆Need no synchronizer ◆Inrush current at parallel-in operation

Only synchronous generator can be selected for independent operation.

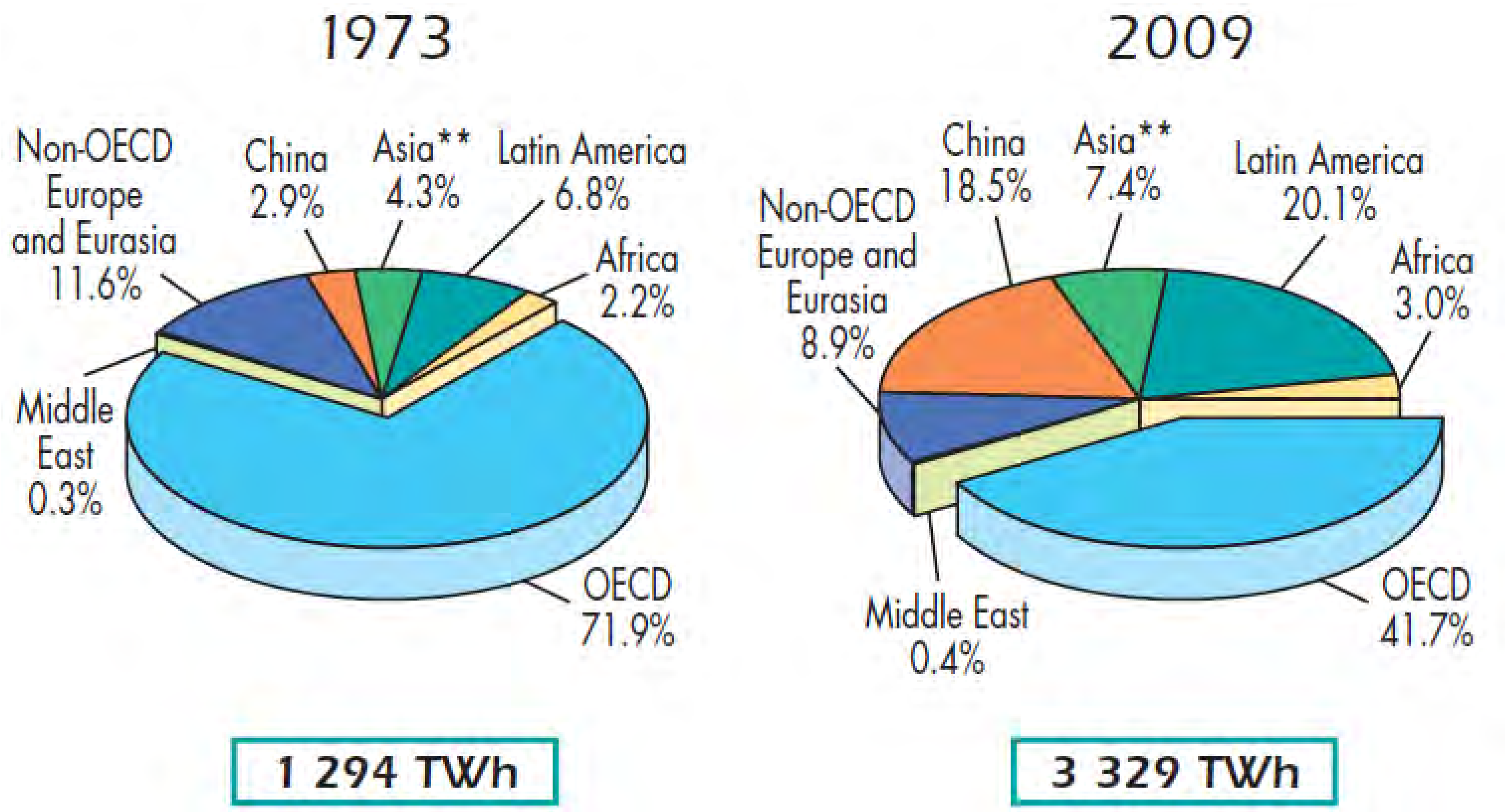
TOPICS COVERED

- Components of micro/mini hydropower plant
- Hydropower potential
- Types of turbines
- Types of generator
- Hydropower status in Cambodia

Hydro production from 1971 to 2009 by region (TWh)



1973 and 2009 regional share of hydro production (TWh)



Producers of hydro electricity

Producers	TWh	% of world total
People's Rep. of China	616	18.5
Brazil	391	11.7
Canada	364	10.9
United States	298	9.0
Russian Federation	176	5.3
Norway	127	3.8
India	107	3.2
Venezuela	90	2.7
Japan	82	2.5
Sweden	66	2.0
Rest of the world	1 012	30.4
World	3 329	100.0

2009 data

*Includes pumped storage.

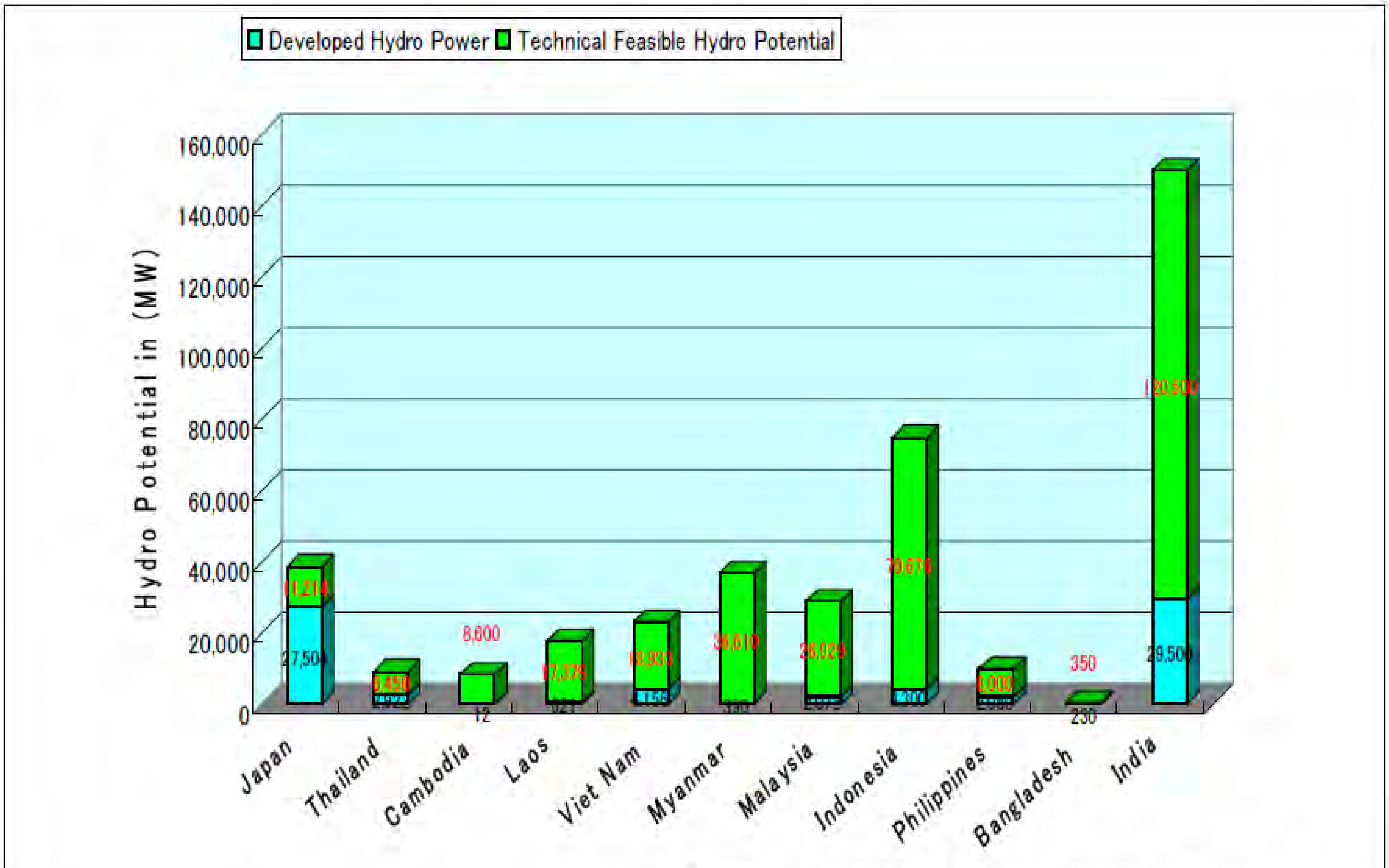
Installed capacity	GW
People's Rep. of China	168
United States	100
Brazil	78
Canada	75
Japan	47
Russian Federation	47
India	37
Norway	30
France	25
Italy	21
Rest of the world	324
World	952

2008 data
Sources: IEA, United Nations.

Country (top-ten producers)	% of hydro in total domestic electricity generation
Norway	95.7
Brazil	83.8
Venezuela	72.8
Canada	60.3
Sweden	48.3
Russian Federation	17.8
People's Rep. of China	16.7
India	11.9
Japan	7.8
United States	7.1
Rest of the world**	13.9
World	16.5

2009 data

Hydro potential in southest asia



(Source : Hydropower & Dams, 2004)

Location Map of Planned Mini Hydro Plants in Cambodia

THANK YOU

Promotion of Energy Science Education for Sustainable Development in Cambodia

Theme 5: Renewable Energy

Theme 5-5: Wind Energy

Dr. Long Bun
Vice Head of Department of Electrical and Energy Engineering
Institute of Technology of Cambodia

Content

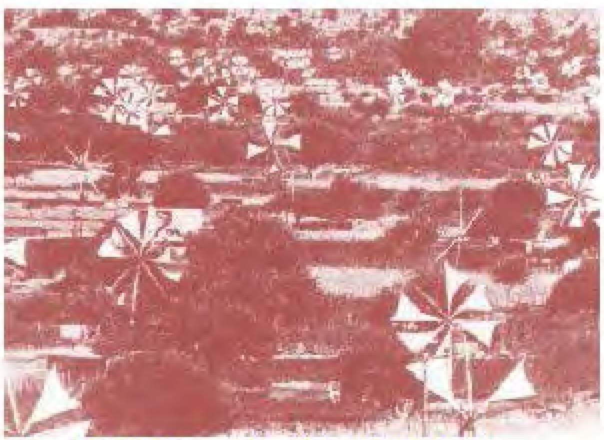
- Wind power status
- Types of wind turbine generator
- Power in the wind and power extracted
- Wind turbine generator, speed control
- Wind turbine performance

Some history

Claude Monet The Zaan River at Zaandam, Denmark, Spring 1871

SOME HISTORY

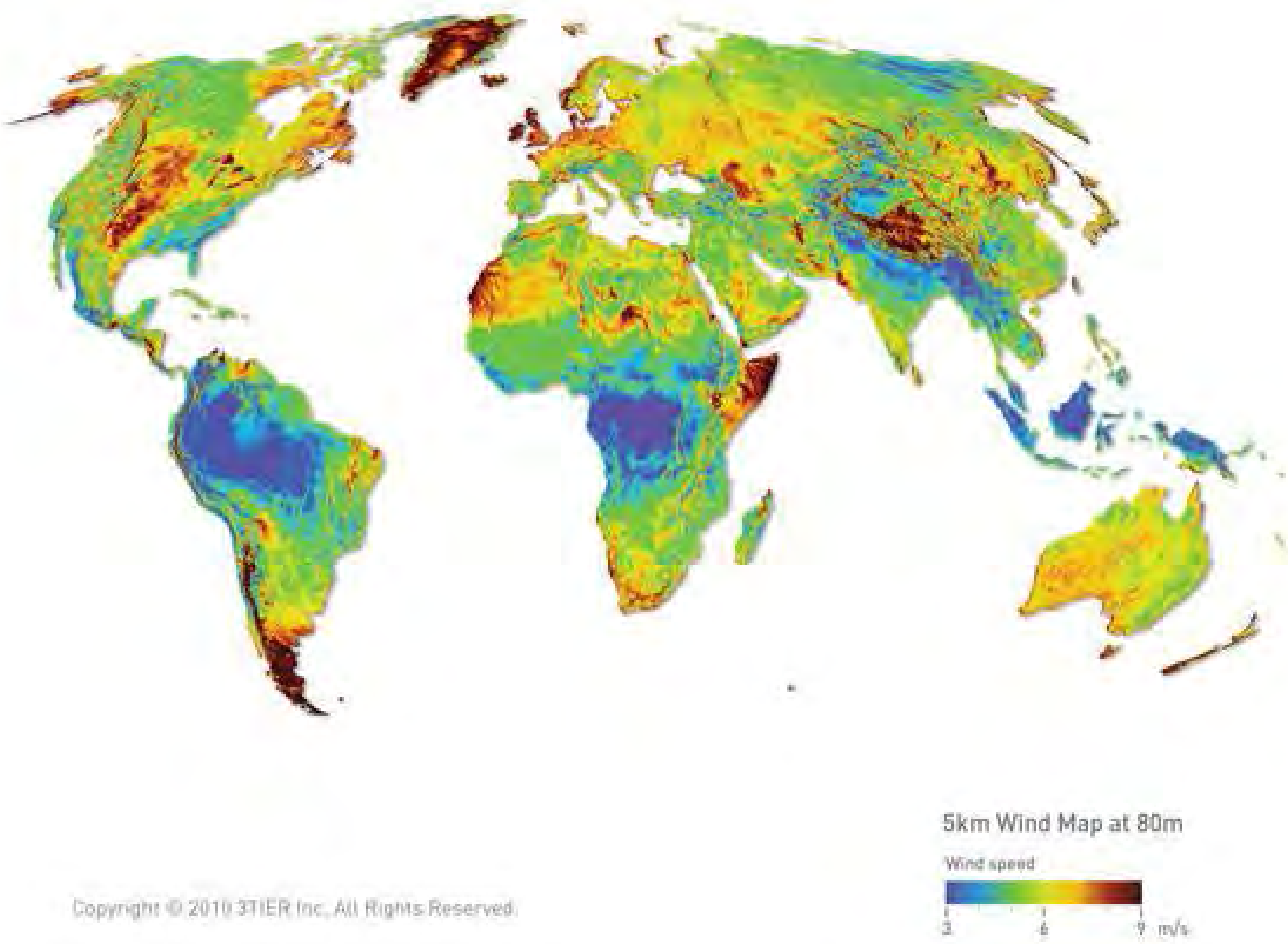
For grain grinding and water pumping



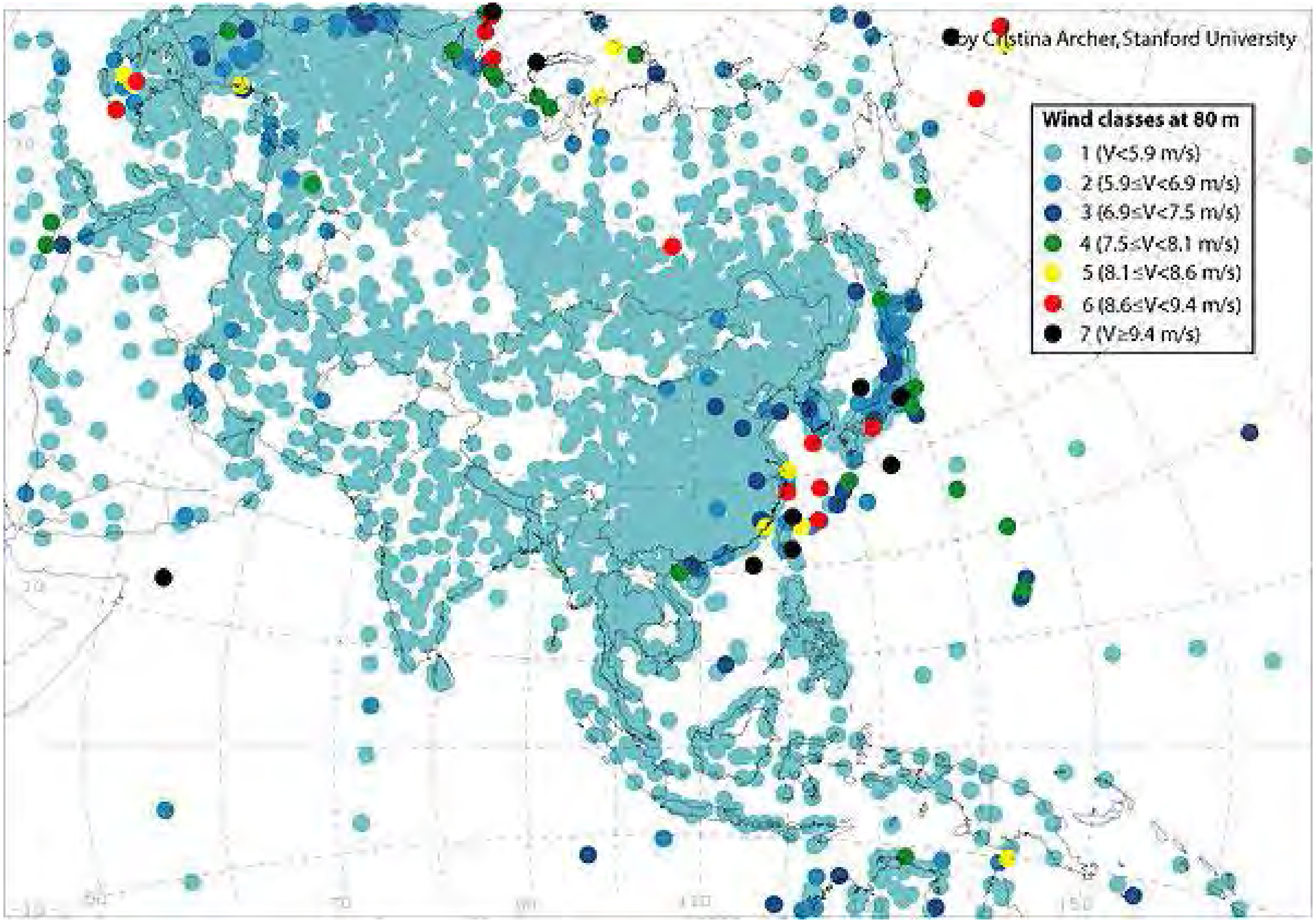
http://www.telosnet.com/wind/early.html

The first use of large windmill in Cleveland, Ohio, 1888 to generate electricity. Rotor diameter was 17meters. The windmill produced 12 kW.

Wind around the world



Wind resources in Asia



WIND RESOURCES IN SOUTHEAST ASIA

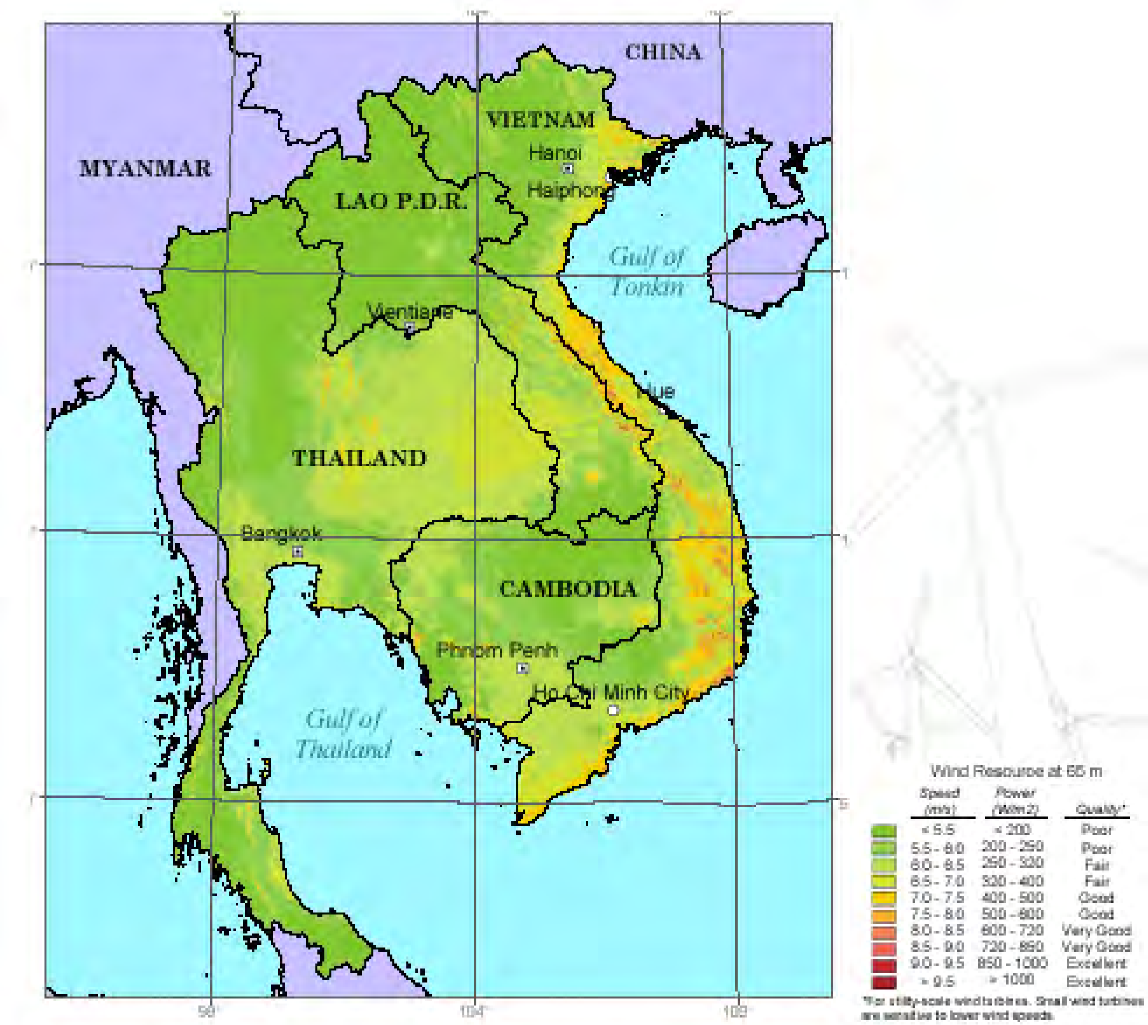
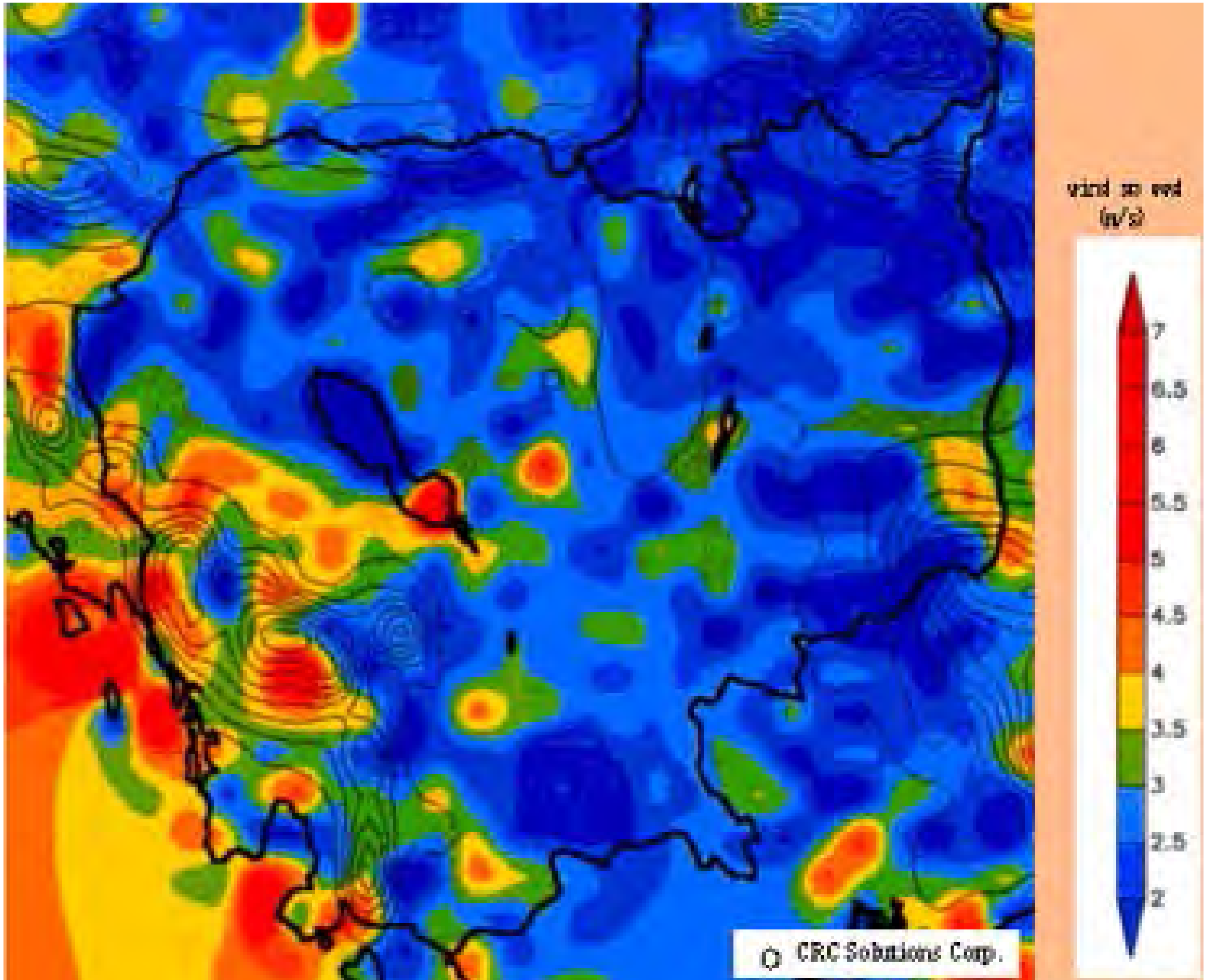


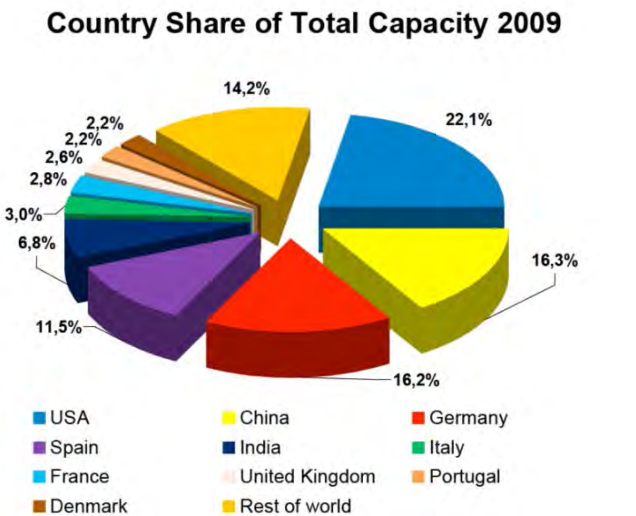
Figure 2.1b. Wind Resources in Southeast Asia at 30 m

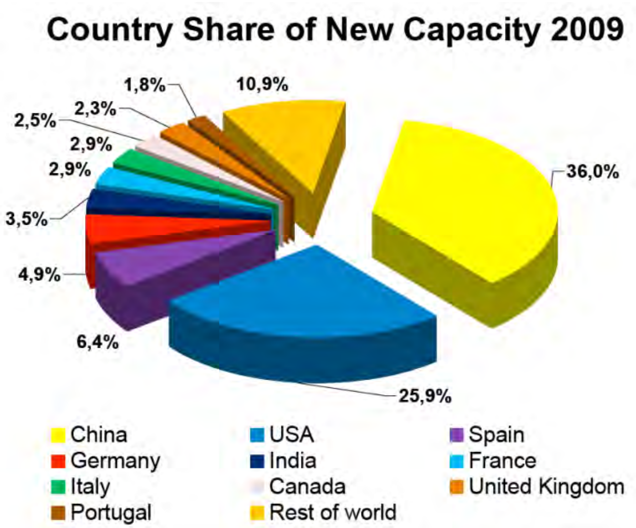
WIND RESOURCES IN CAMBODIA

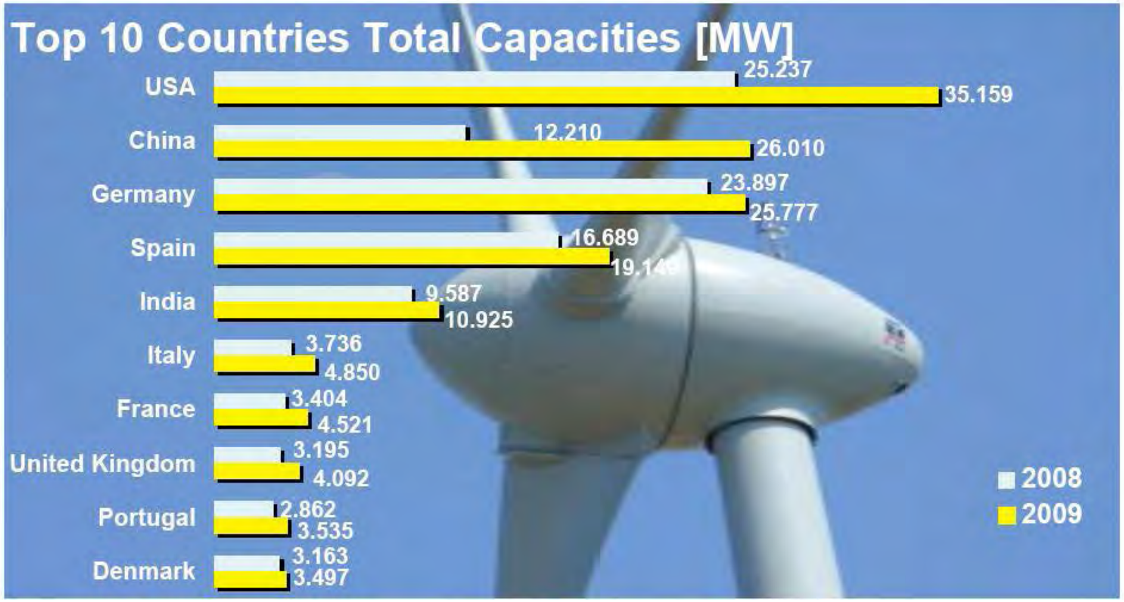


World total installed capacity

World total installed capacity



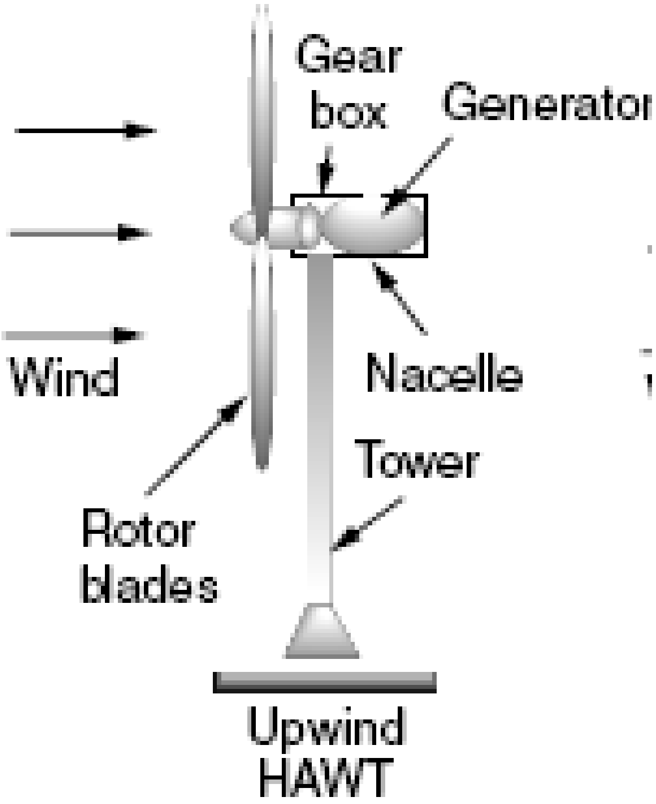


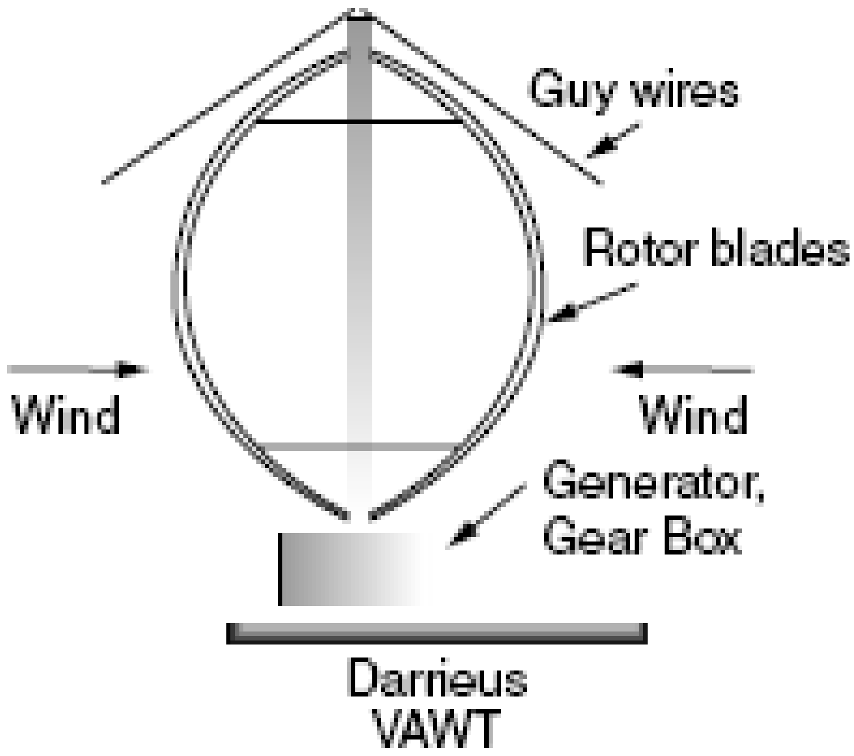


Content

- Wind power status
- Types of wind turbine generator
- Power in the wind and power extracted
- Wind turbine generator, speed control
- Wind turbine performance

TYPES OF WIND TURBINE





Horizontal Axis Wind Turbine **Vertical Axis Wind Turbine**

Horizontal Axis

- **Upwind turbine**
  - Complex yaw control system.
  - Keep blade facing wind.
  - Operate more smoothly.
  - Deliver more power.
- **Downwind turbine**
  - Let the wind control left-right motion (the yaw).
  - Orient itself correctly to wind direction.
  - Wind shadowing effect by the tower, cause the blade to flex.
  - Increase noise and reduce power output.

Number of Blades

- Multi-blade windmill need high starting torque and low wind speed for continuous water pumping function.
- As rpm increases, turbulence caused by one blade affects efficiency of the blade that follows
- Fewer blades allow the turbine to spin faster => smaller generator.
- Two and three blades are the most common in modern wind turbine.

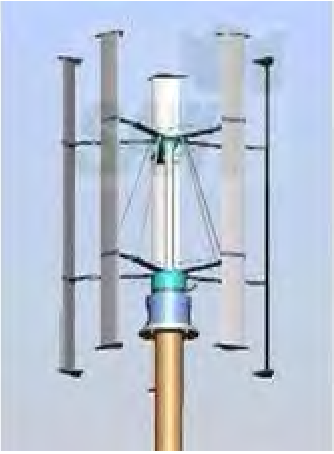
Some pictures of horizontal axis wind turbine

VERTICAL AXIS

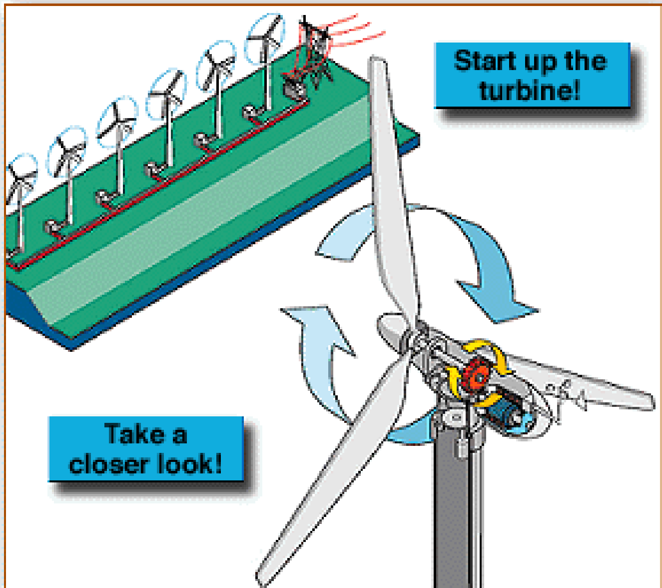
- Advantages :
  - Always turn into the wind direction → no control
  - the generator and gearbox can be placed near the ground → easy maintenance

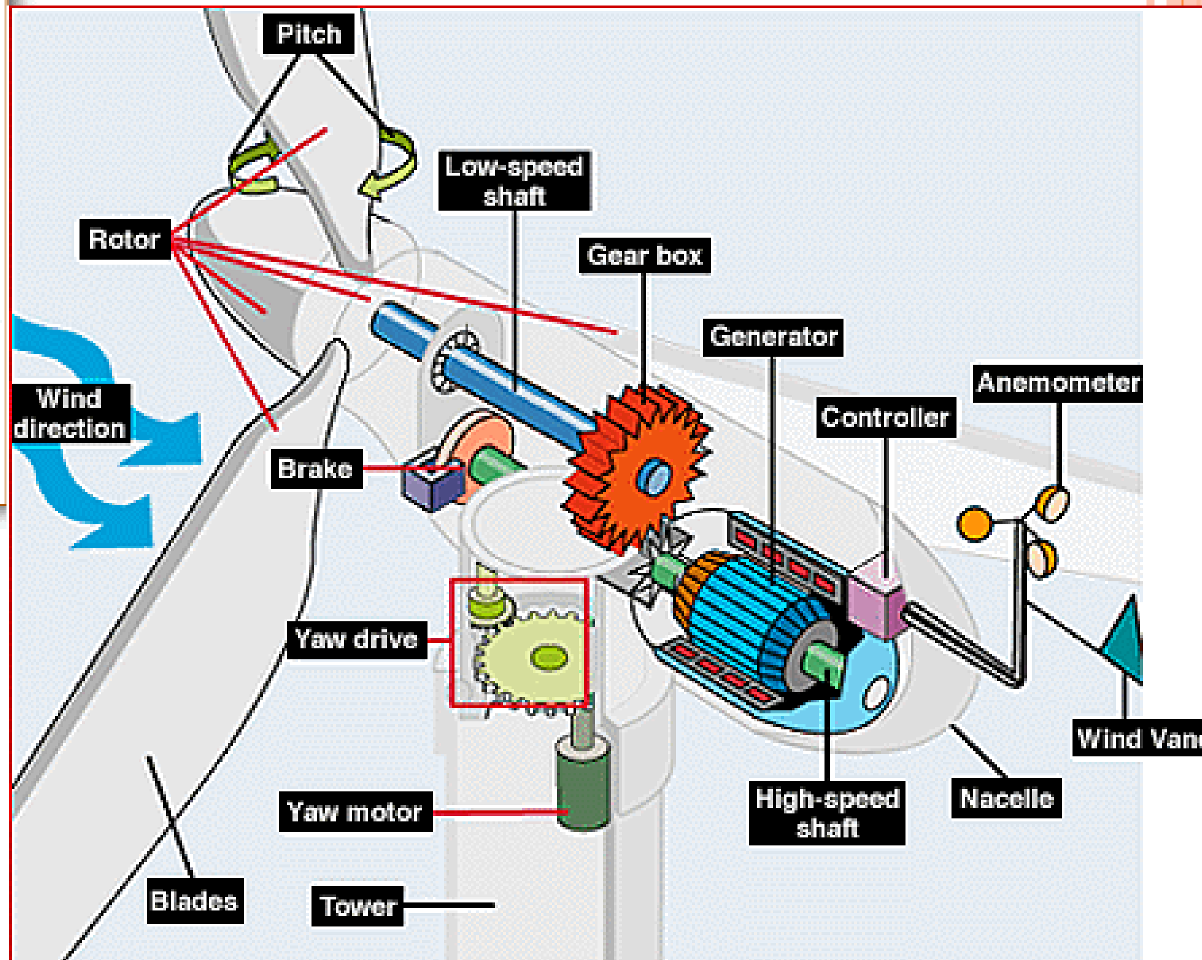
- Disadvantages:
  - Self starting is impossible
  - The pulsating torque generated by the rotor → Mechanical problem

Some pictures of vertical wind turbine



WIND GENERATOR





Content

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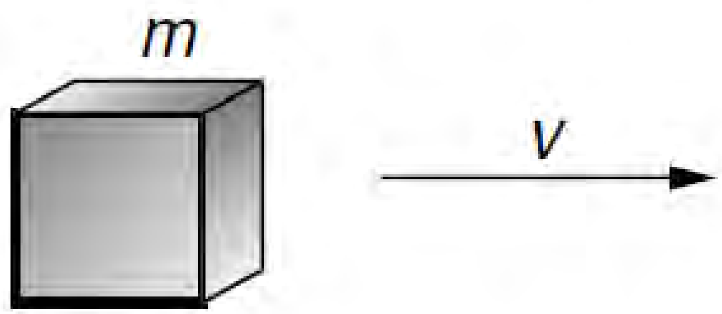
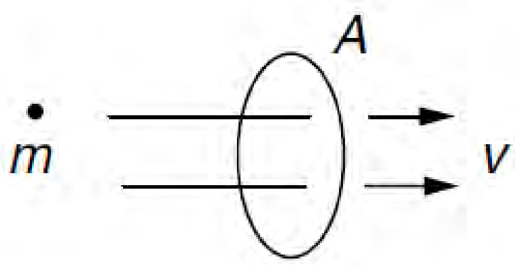
Power in the Wind



$$\text{K.E.} = \frac{1}{2} m v^2$$



$$\text{Power through area } A = \frac{\text{Energy}}{\text{Time}} = \frac{1}{2}\left(\frac{\text{Mass}}{\text{Time}}\right) v^2$$

POWER IN THE WIND (CONT)

Mass flow rate:

$$\left(\frac{\text{Mass passing through A}}{\text{Time}}\right) = \dot{m} = \rho A v$$

ρ = Air density (kg/m^3) = 1.225 kg/m^3 at 15°C and 1 atm

$$\text{Power through area } A = \frac{\text{Energy}}{\text{Time}} = \frac{1}{2}\left(\frac{\text{Mass}}{\text{Time}}\right)v^2 = \frac{1}{2}\rho A v^3$$

$$P_w = \frac{1}{2}\rho A v^3$$

P_w is power in the wind (watts)

Power density (specific power) = power per square meter ($Watts/m^2$)

Power in the wind (cont)

- Power in the wind depends on,
  - Air density,
  - Area that wind flow through (i.e. swept area of the turbine rotor), and
  - Wind speed.

POWER VS WIND SPEED

Windspeed (m/s)	Windspeed (mph)	Power (W/m^2)
0	0	0
1	2.24	1
2	4.47	5
3	6.71	17
4	8.95	39
5	11.19	77
6	13.42	132
7	15.66	210
8	17.90	314
9	20.13	447
10	22.37	613
11	24.61	815
12	26.84	1058
13	29.08	1346
14	31.32	1681
15	33.56	2067

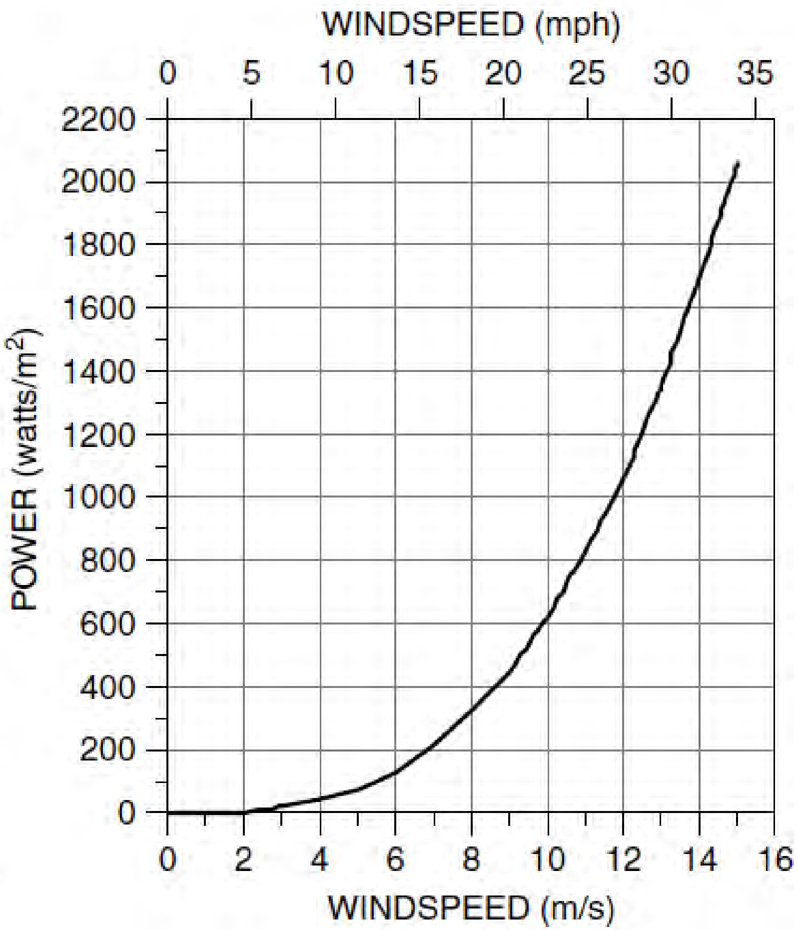


Figure 6.5 Power in the wind, per square meter of cross section, at 15°C and 1 atm.

Power VS Swept Area

- Power increases as proportional to swept area of the rotor.

$$A = (\pi/4)D^2$$

- This implies that power is proportional to square of the diameter; the bigger, the better.

- This explains economies of scale of wind turbines.

POWER VS AIR DENSITY

- At 15°C and 1 atmosphere, ρ= 1.225 kg/m³.

$$\rho\,(\text{kg/m}^3) = \frac{\text{n(mol)} \cdot \text{M.W.(g/mol)} \cdot 10^{-3}\,(\text{kg/g})}{V\,(\text{m}^3)}$$

$$\rho = 1.225 K_T K_A$$

TABLE 6.1 Density of Dry Air at a Pressure of 1 Atmosphere[a]

Temperature (°C)	Temperature (°F)	Density (kg/m³)	Density Ratio (K_T)
−15	5.0	1.368	1.12
−10	14.0	1.342	1.10
−5	23.0	1.317	1.07
0	32.0	1.293	1.05
5	41.0	1.269	1.04
10	50.0	1.247	1.02
15	**59.0**	**1.225**	1.00
20	68.0	1.204	0.98
25	77.0	1.184	0.97
30	86.0	1.165	0.95
35	95.0	1.146	0.94
40	104.0	1.127	0.92

[a] The density ratio K_T is the ratio of density at T to the density at the standard (boldfaced) 15°C.

TABLE 6.2 Air Pressure at 15°C as a Function of Altitude

Altitude (meters)	Altitude (feet)	Pressure (atm)	Pressure Ratio (K_A)
0	0	1	1
200	656	0.977	0.977
400	1312	0.954	0.954
600	1968	0.931	0.931
800	2625	0.910	0.910
1000	3281	0.888	0.888
1200	3937	0.868	0.868
1400	4593	0.847	0.847
1600	5249	0.827	0.827
1800	5905	0.808	0.808
2000	6562	0.789	0.789
2200	7218	0.771	0.771

Impact of Tower Height

- Wind speed near the ground is greatly affected by the friction that air experiences.
- Smooth surface, such as sea --> less friction.
- Rough surface, such as city with tall buildings --> more friction.
- Wind speed as a function of,
  - Height,
  - Earth's surface.

IMPACT OF TOWER HEIGHT (CONT)

- Power law, often used in US.
  - H_0 = reference height of 10m.
  - v_0 = reference wind speed at H_0.
  - α= friction coefficient

$$\left(\frac{v}{v_0}\right) = \left(\frac{H}{H_0}\right)^{\alpha}$$

IMPACT OF TOWER HEIGHT (CONT)

$$\left(\frac{v}{v_0}\right) = \left(\frac{H}{H_0}\right)^{\alpha}$$

Terrain Characteristics	Friction Coefficient α
Smooth hard ground, calm water	0.10
Tall grass on level ground	0.15
High crops, hedges and shrubs	0.20
Wooded countryside, many trees	0.25
Small town with trees and shrubs	0.30
Large city with tall buildings	0.40

Overall effiency

Assume that rotor blades has 45% efficiency and gearbox and generator has 2/3 efficiency

Average power in the wind (W/m²) → Power extracted from the wind (W/m²), depending turbine blade (rotor) efficiency → Electrical power output (W/m²), depending on the gearbox and generator efficiency

$$P_w = \frac{1}{2}\rho A v^3$$

100%

$$P_b = \frac{1}{2}\rho A v^3 \cdot C_p$$

45%

Overall efficiency = 30%!!

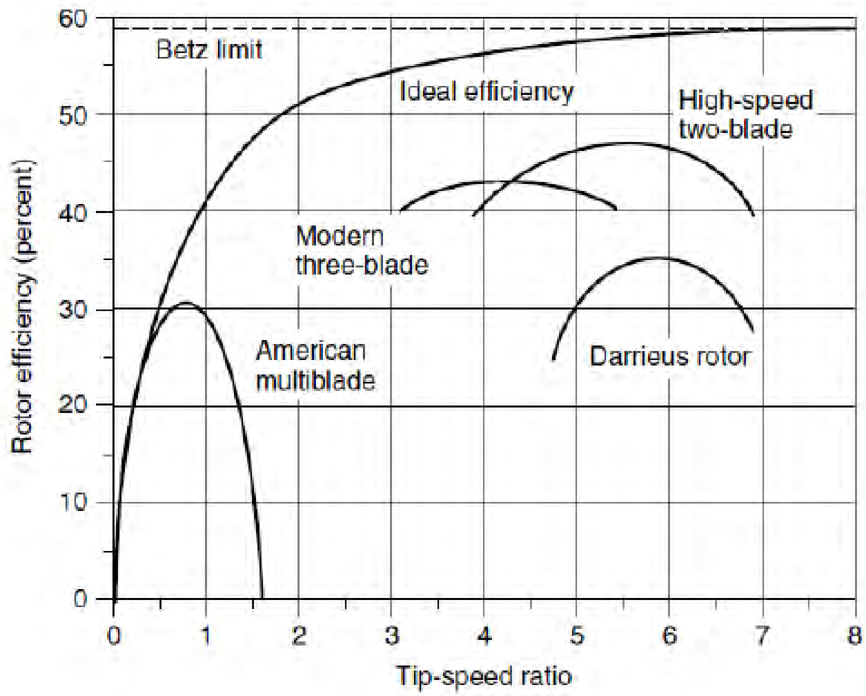
Betz's Law

- Maximum theoretical efficiency of a rotor is 59.3%.
- Sometimes called 'Betz efficiency'
- How close are modern wind turbine to this Betz limit?
  - Around 80% of the limit, 45-50%

Tip-Speed Ratio

- For a given wind speed, rotor efficiency is a function of the rate at which a rotor turn.
  - Rotor turns too slow letting too much wind pass -> efficiency drop.
  - Rotor turns too fast causing turbulence -> efficiency drop.
- TSR is the speed at rotor tip divided by the wind speed.

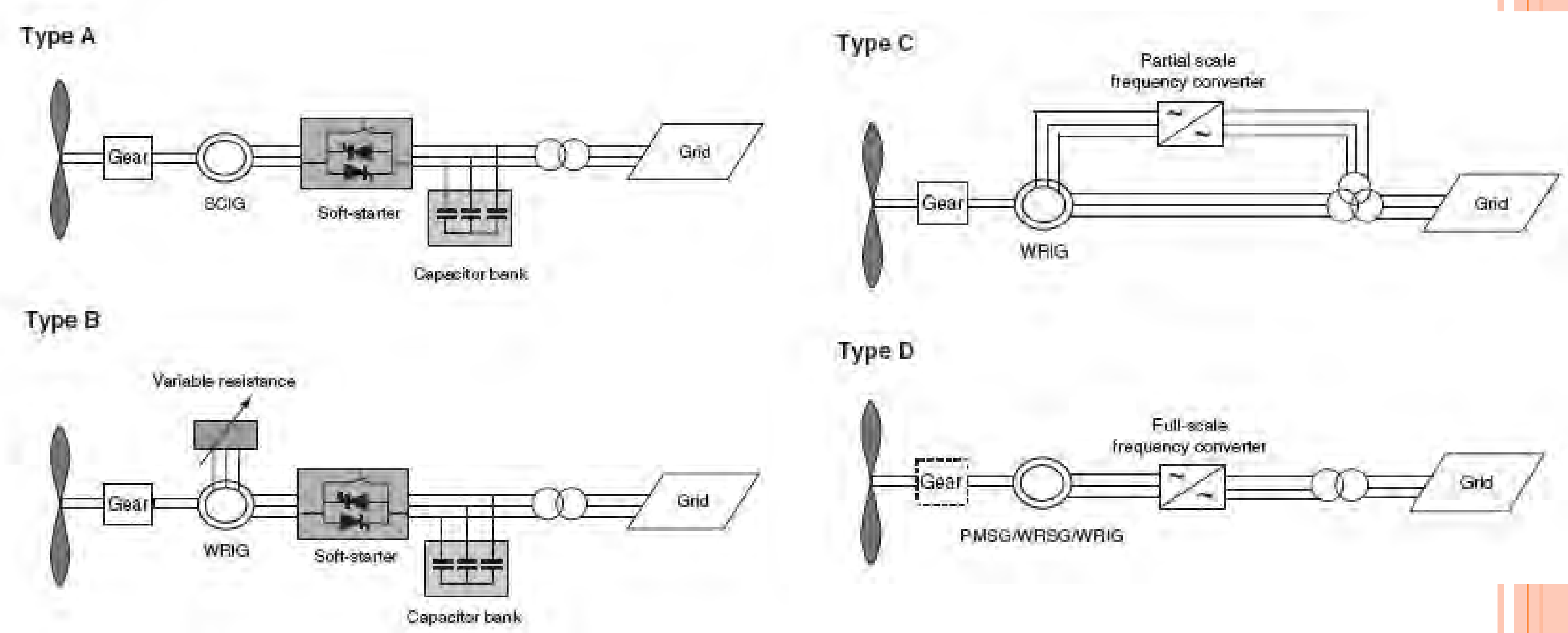
$$\frac{\text{Rotor tip speed}}{\text{Wind speed}} = \frac{\text{rpm} \times \pi D}{60\, v}$$



Content

- Wind power status
- Types of wind turbine generator
- Power in the wind and power extracted
- Wind turbine generator, speed control
- Wind turbine performance

TYPES OF GENERATORS



Asynchronous generator (A, B, C)

- Squirel cage induction generator (SCIG)
- Wound rotor induction generator (WRIG)

Synchronous generator (D)

- Wound rotor synchronous generator (WRSG)
- Permanent magnet synchronous generator (PMSG)

Comparison

Synchronous generator

- Operate at constant rotational speed to create constant voltage frequency.
- Need magnetic fields,
  - Permanent magnet rotor for small machine.
  - Almost all wind turbine with synchronous generator creates magnetic field by DC current.
- Require slip rings and brushes, adds to maintenance routine required by the machine.
- Expensive

Asynchronous generator

- Do not operate at fix speed
- Magnetic field is induced from AC voltage.
- Do not require separate circuit (exciter) for magnetic field.
- Do not require slip rings and brushes. So, less maintenance cost.
- Very common for wind turbine, less expensive

Content

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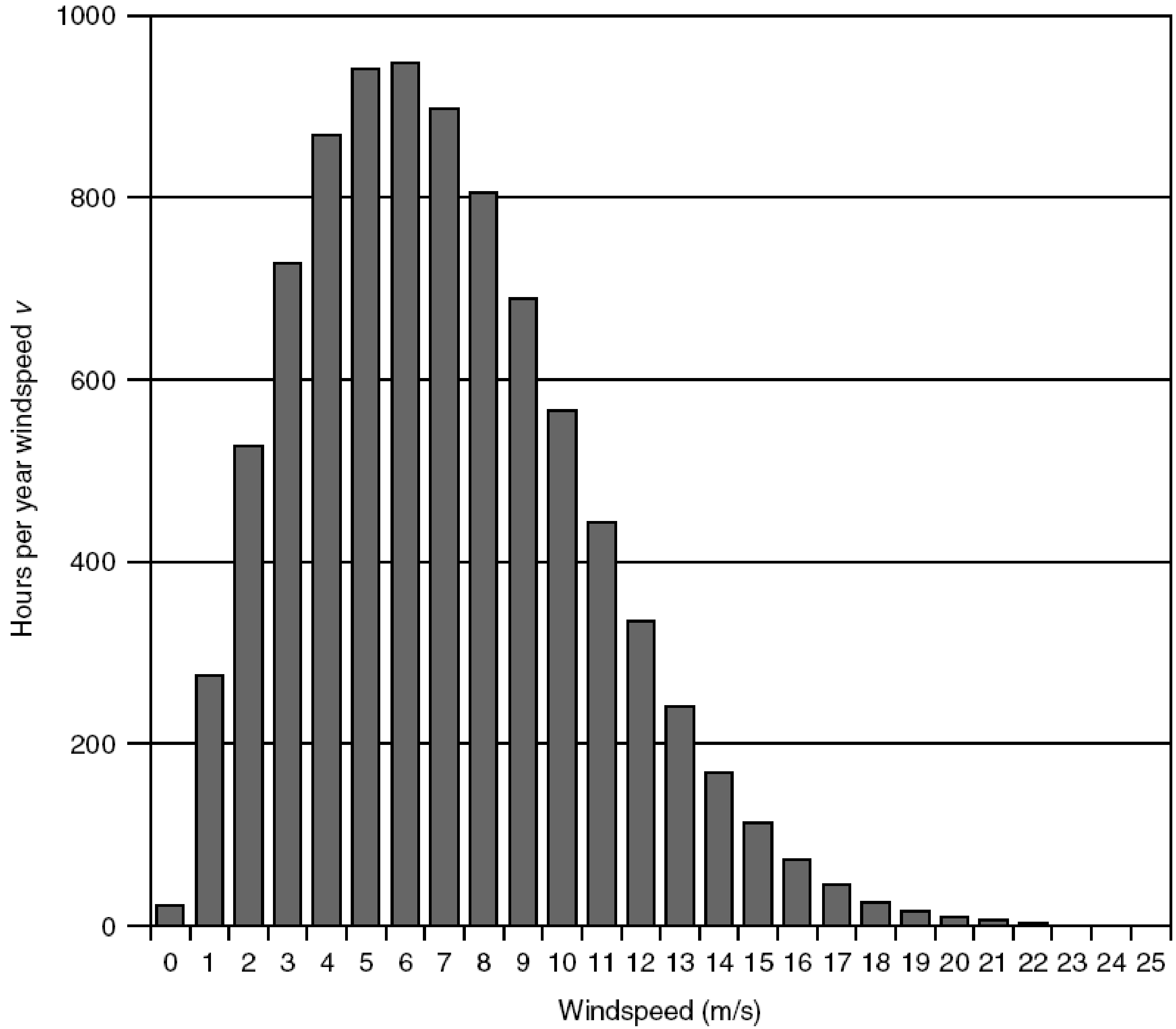
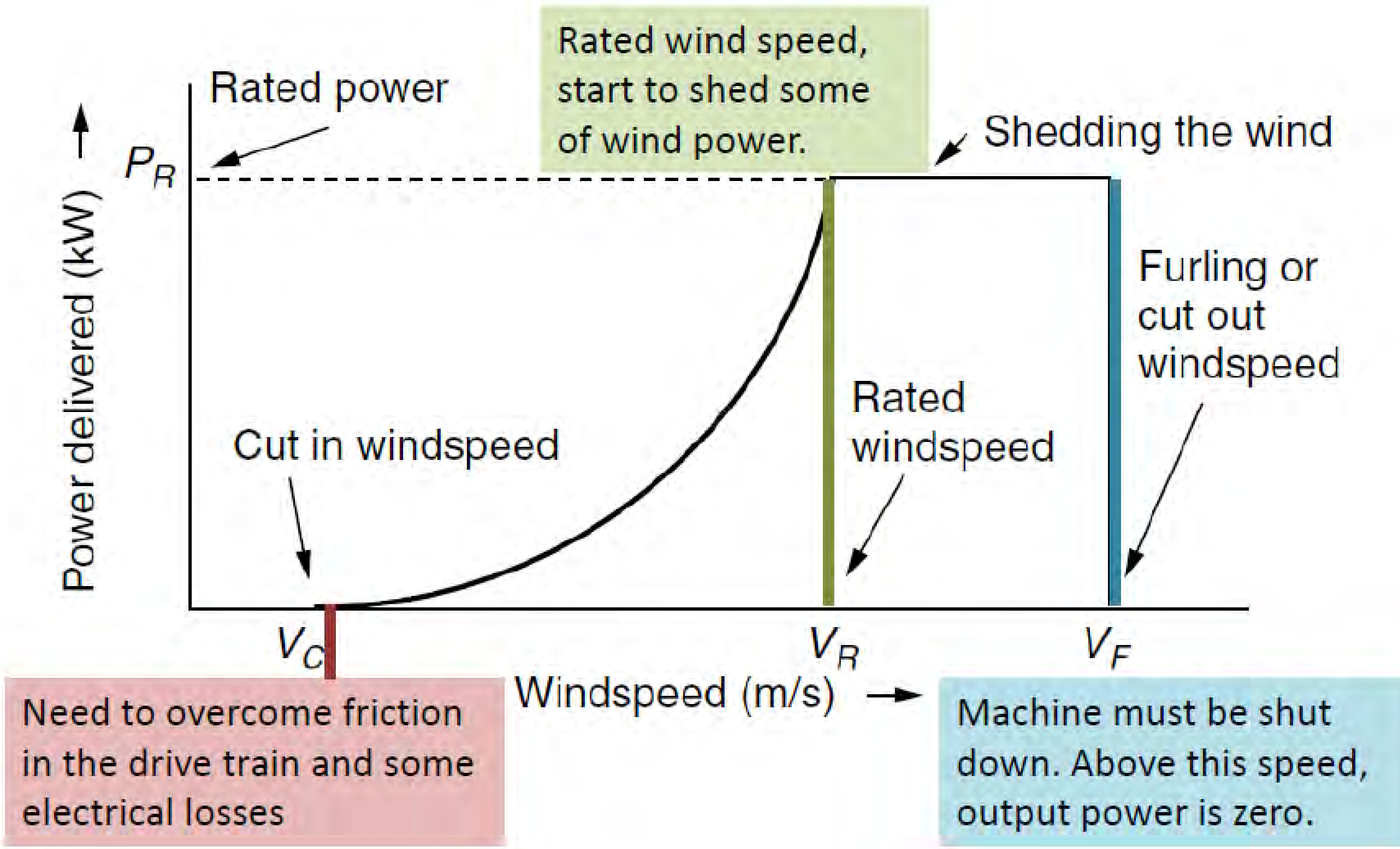
Typical Wind Speed Histogram

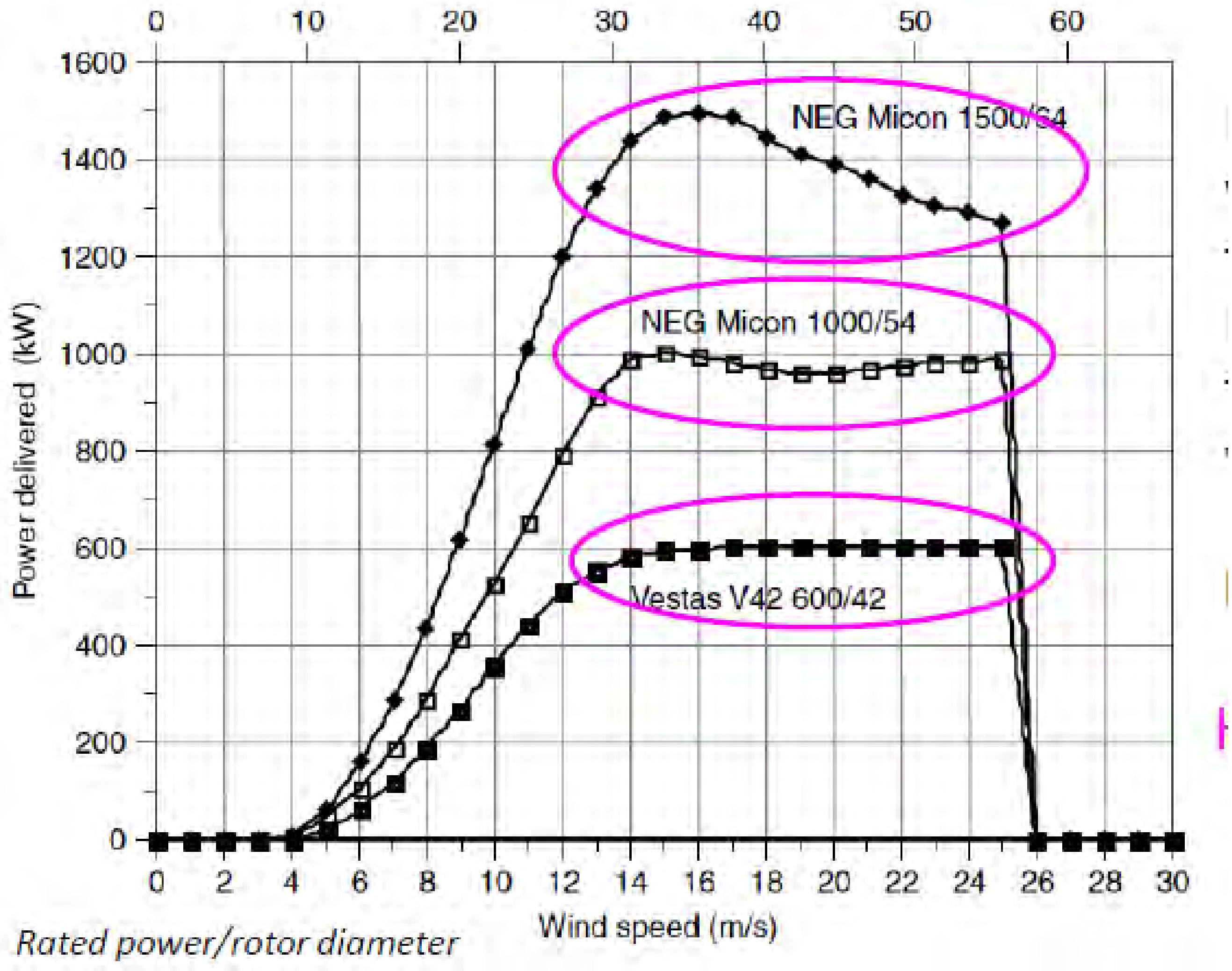
v (m/s)	Hrs/yr
0	24
1	276
2	527
3	729
4	869
5	941
6	946
7	896
8	805
9	690
10	565
11	444
12	335
13	243
14	170
15	114
16	74
17	46
18	28
19	16
20	9
21	5
22	3
23	1
24	1
25	0
Total hrs	8,760



IDEAL POWER CURVE



Real power curve



THANK YOU