People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

University Ferhat Abbas Setif 1
Faculty of Sciences
Physique Department

Course

Wind Energy

This course is intended for students of Master 2
Energy Physics and renewable Energies.

Presented by

Dr. Soraya Bououden

Academic year 2025-2026

Abstract

Today, wind turbines are one of the most widely used devices for generating clean, renewable electrical energy. The rotor blades capture the wind's kinetic energy to produce rotational energy from the turbine and electrical energy from the generator. In small wind turbines, several methods are used to drive the blades to achieve the desired rotational speed and power.

Small wind turbines are an attractive alternative for off-grid electrification and water pumping, both in stand-alone applications and in combination with other energy technologies such as photovoltaics, small hydropower, or diesel engines. In this work, we will focus on wind system technology, with a particular focus on small horizontal-axis wind turbines. This study also addresses the modeling, design, and importance of these systems for achieving energy independence.

This course is organized into four chapters:

• Chapter One, introduces the concept of renewable energy, its classifications, benefits, and its role in global energy transitions. It also provides context on the environmental, economic, and policy drivers pushing the global shift away from fossil fuels.

• Chapter Two, explores the operation of wind turbines, focusing on the mechanical and electrical processes of converting wind energy into usable power. It also details the main components, such as the rotor, gearbox, generator, and control systems.

• Chapter Three is about small horizontal-axis wind turbines (HAWTs), like their structure, applications, control mechanisms, and mathematical modeling. It describes the aerodynamic concepts and mechanical characteristics that define their performance.

• Chapter Four, evaluates the current and future role, application of small wind turbines within global energy systems and discusses the main categories of MPPT techniques used to control the wind turbines and ensure the production of power at optimal levels.

Contents

I Introduction: Wind Characteristics and Resources **15**

I.1 Wind Energy 15

I.1.1 General Information on wind 16

I.1.2 Definition of wind 16

I.1.3 Types of winds 17

I.1.3.1 Global (geostrophic) winds 17

I.1.3.2 Local winds 17

I.1.3.3 Surface winds 18

I.2 Classification of winds 19

I.3 Measurement of Wind Parameters 19

I.4 Vertical structure of the atmosphere 20

I.5 Mathematical Modeling of Wind Frequency Distribution 23

I.5.1 Weibull distribution 23

I.5.2 Mean speed and standard deviation method 24

I.6 The wind rose 25

I.7 Vertical Extrapolation of wind parameters 25

I.7.1 Short term extrapolation 25

I.7.1.1 (Justus et A.S. Mikhail) The modified power law 26

I.7.1.2 (Spera et Richards model) 27

I.7.1.3 Power law known as variable coefficient 27

I.8 Long term extrapolation 27

I.8.1 Extrapolation model of Justus and Mikhail 1976 28

I.8.2 Modified Justus 1978 extrapolation model 28

I.8.3 Modified extrapolation model of Mikhail 1985 28

I.9 Wind energy in the world . . . 29
I.10 Potential of Renewable Energy in Algeria . . . 29
I.10.1 Solar potential . . . 29
I.10.2 Geothermal Potential . . . 29
I.10.3 Biomass potential . . . 31
I.10.4 Hydraulic potential . . . 31
I.10.5 Wind potential . . . 31
I.11 The national renewable energy program in Algeria PNER . . . 31
I.11.1 Wind energy in Algeria . . . 32
I.12 Conclusion . . . 33

II Wind Energy Technology : Small wind turbines 35
II.1 History of wind energy . . . 36
II.2 Methods of exploiting wind energy . . . 36
II.3 Different types of wind turbines . . . 39
II.3.1 Vertical-axis wind turbines . . . 41
II.3.1.1 Advantages of Vertical Axis Turbines . . . 43
II.3.1.2 Disadvantages of Vertical Axis Turbines . . . 43
II.3.2 Horizontal Axis Wind Turbines . . . 44
II.3.2.1 Advantage of Horizontal Axis . . . 44
II.3.2.2 Disadvantages of Horizontal Axis . . . 44
II.4 Classification of wind turbines . . . 46
II.5 Wind energy conversion chain . . . 46
II.5.1 What is a small power wind turbines . . . 47
II.5.2 Small Wind Turbines . . . 48
II.6 Main components of a small wind turbine . . . 51
II.7 Working Principle of a Wind Turbine . . . 53
II.8 Protection and control mechanisms systems . . . 54
II.8.1 Pitch Control Systems . . . 54
II.8.1.1 How Pitch Control Systems Work . . . 55
II.8.1.2 Yaw Control . . . 55
II.8.1.3 Furling systems . . . 56

II.9 Conclusion 58

III Estimation of the annual energy production of a wind turbine 59

III.1 Small Wind Turbine Modeling 59

III.1.1 Kinetic energy 60

III.1.2 Air Mass 60

III.1.3 Blade swept area 61

III.1.4 Wind Power 61

III.2 Wind power parameters 62

III.2.1 Betz Law (Betz limit) 62

III.2.2 Tip Speed Ratio 64

III.3 Wind turbine modeling 65

III.3.1 Aerodynamic model 65

III.4 The power curve of a wind turbine 68

III.4.1 Operating regions of a wind turbine 68

III.5 Estimation of wind potential energy 69

III.5.1 Average power density 70

III.5.2 Average available energy density 71

III.5.3 Average power output from a wind turbine 71

III.5.4 Extracted Wind Energy 72

III.6 Conclusion 72

IV Wind Turbine : Applications and Control 75

IV.1 Special Purpose Applications 75

IV.1.1 Mechanical water pumping 75

IV.1.2 Electrical water pumping 76

IV.1.3 Electricity generation 77

IV.1.4 Hybrid System 77

IV.1.5 Different applications of small turbine 79

IV.2 Wind Systems Control 86

IV.3 What does wind turbine control mean 86

IV.3.1 Fixed-speed wind turbine 86

IV.3.2 Variable-speed wind turbine 87
IV.4 Maximum Power Point Tracking MPPT 88
IV.4.1 Operating regions 90
IV.4.2 Maximum power point tracking (MPPT) control strategy 92
IV.5 Conclusion 94

Bibliography **99**

List of Figures

I.1 Movement of air in the atmosphere 17

I.2 Movement of air in the atmosphere (fig(I-2.a) sea breeze), fig(I-2.b) land breeze) 18

I.3 Movement of air in the atmosphere (fig(I-3.c) rising breeze), fig(I-3.d) downdraft breeze) 18

I.4 Beaufort wind scale 19

I.5 weather vane 20

I.6 The windsock (wind sock) 21

I.7 (a) Anemometer Wind Vane Set - (b) Measuring Mast with Anemometers and Wind Vanes 21

I.8 vertical structure of the atmosphere 22

I.9 Annual wind speed frequency with fitted Weibull distribution at 10 m . . 24

I.10 The Wind Rose 26

I.11 Wind energy in the world 30

I.12 Wind energy in the world 32

I.13 A domestic wind turbine for your home 33

II.1 Electricity generation from different sources including nonrenewable and renewable energy. 37

II.2 First wind turbine designed by Charle .F .Brush 38

II.3 Gedser wind turbine (Johannes Juul) 38

II.4 Old water pumping wind turbine 38

II.5 Photograph of a windmill 38

II.6 Past and Present Wind Turbine 39

II.7 Onshore and Offshore wind turbines 40

II.8 Offshore wind turbines in Danmark 40
II.9 Different types of wind turbines 41
II.10 Horizontal axis wind and Vertical axis wind turbines 42
II.11 Different types of **savonius rotor** 42
II.12 Different types of **Darrieus rotor** 43
II.13 Horizontal axis wind turbines with different blades 44
II.14 fast wind turbines 45
II.15 Upwind (a) and Downwind Turbine (b) 45
II.16 Sizes and Appliquations 47
II.17 Energy conversion process 48
II.18 Small wind (whisper 100) 49
II.19 Examples of HAWTs in urban areas 50
II.20 Wind Turbine Components 51
II.21 Wind Turbine Components 52
II.22 Pitch control 56
II.23 Pitch control 57
II.24 Furling systems 57

III.1 Air Area of wind turbine blades 60
III.2 Air Flow trough the turbine 63
III.3 Betz Coefficient of power C_p 64
III.4 Power Coefficient curve for different types of turbines 65
III.5 Wind energy scheme 67
III.6 Block diagram of wind energy converter mechanical model. 67
III.7 Operating regions of a wind turbine 69

IV.1 Mechanical wind pumping 77
IV.2 Electric wind pumping 78
IV.3 Off-grid wind electricity generation 78
IV.4 Grid-connected wind electricity generation 78
IV.5 Hybrid wind-PV systems 79
IV.6 Hybrid wind-PV systems 79

IV.7 Smal wind turbine for Telecommunications 80
IV.8 Smal wind turbine for Telecommunications 81
IV.9 Smal wind turbine for Telecommunications 81
IV.10 Smal wind turbine : Residential or residential areas 83
IV.11 Smal wind turbine : Residential or residential areas 84
IV.12 Smal wind turbine : Residential or residential areas 84
IV.13 Smal wind turbine : rural tourism and leisure 85
IV.14 Smal wind turbine : rural tourism and leisure 85
IV.15 Fixed speed wind turbine using a cage asynchronous generator 87
IV.16 Variable-speed wind turbine using a cage induction generator and a full-power converter 88
IV.17 Variable-speed wind turbine using a high-pole synchronous generator and a full-power converter 89
IV.18 Variable-speed wind turbine using a synchronous generator and a full-power converter 89
IV.19 Variable-speed wind turbine using a synchronous generator and a full-power converter 90
IV.20 Characteristics of turbine power as a function of the rotor speed for a series of wind speeds 91
IV.21 Operating regions of a variable speed wind turbine 91
IV.22 OTC 93
IV.23 PSF 93
IV.24 TRS 94
IV.25 Classification of different MPPT algorithms 95

List of Tables

IV.1 List of Application of small wind turbines 82

Chapter I

Introduction: Wind Characteristics and Resources

I.1 Wind Energy

Wind energy: an accessible, inexhaustible energy resource, exploitable on land and at sea. Low-altitude wind is the result of the movement of air masses around the Earth. It originates from solar radiation, the rotation of the Earth and the relief, which can accelerate or slow down the wind speed. As they move, air particles acquire kinetic energy and then exert pressure on the surfaces or obstacles they may encounter. They are capable of exerting a motor torque and of rotating more or less sophisticated aerodynamic machines. Electricity production is obtained when a generator is coupled to the turbine's motor shaft. In this case, we speak of wind turbines. Wind energy is an indirect form of solar energy, since it is the temperature and pressure differences induced in the atmosphere by the absorption of solar radiation that set the winds in motion.

The main step for wind applications (offshore or onshore) is to know the local nature of the winds of the place where we want to install wind machines. On the other hand, wind data makes it possible to define the potential of the site as well as the nature of the wind turbines to be used and their optimal distribution [1], [2].

I.1.1 General Information on wind

The sun heats the Earth unevenly, which creates areas of hot air and other areas of cold air that also have differences in atmospheric pressure. These differences in pressure generate air movements called wind. Wind is a source of energy that is continually renewed by natural phenomena. Wind is therefore a very fundamental atmospheric variable to measure.

I.1.2 Definition of wind

Wind is the movement of air within the atmosphere. It is born under the effect of differences in temperature and pressure. Thus, when there is a difference in pressure between two points, the air circulates from the place where the pressure is highest (where the air is cold) to the place where it is lowest (where the air is warm). In other words, the air moves from high pressure to low pressure. The main cause of this phenomenon is the sun. It heats the seas and the continents but not at the same rate (morning and evening). Once heated, the latter in turn heat the air masses. Furthermore, it should be noted that the air is under the action of four forces, which are:

1. ***Pressure forces**: These forces generate the movements of the air masses constituting the wind. They come from local pressure differences due to temperature differences depending on latitude, and continental and oceanic influences.* ;

2. ***Coriolis forces**: This force is linked to the rotation of the Earth on its axis. It is perpendicular and proportional to the wind speed. It is only significant for high-altitude atmospheric movements (geostrophic winds that we also call global winds) due to the neglect of other forces at this level.*

3. ***Friction forces**: These forces reflect the turbulent friction of the air on the ground at low altitudes. They intervene in the atmospheric boundary layer. d- Gravitational force: It is the consequence of the mutual attraction of bodies; this force intervenes because of the large mass of the Earth. It is directed towards the center of the Earth.*

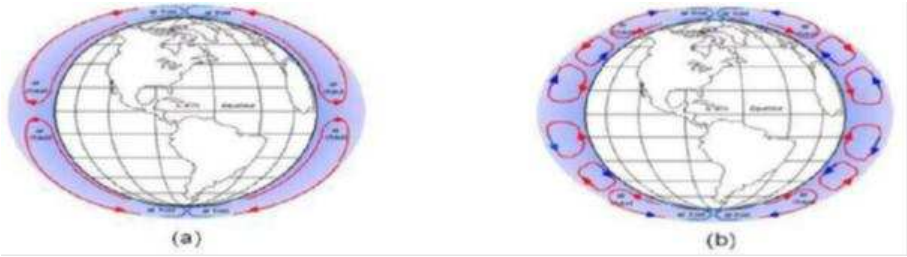


Figure I.1 : Movement of air in the atmosphere

.

I.1.3 Types of winds

There are several types of wind; among them, we cite three kinds, which are:

I.1.3.1 Global (geostrophic) winds

Winds caused by the temperature difference due to the inhomogeneous heating of the air in the atmosphere are known as geostrophic winds or global winds; these winds concern high altitudes composed of two forces, the Coriolis force and the pressure force. Figure (I-1.a) shows the overall movement of air in the atmosphere, in reality, the air is already cooled at 30 latitude, so it descends to the ground. From there, another 30 cycle is formed and so on (figure I.1.b).

I.1.3.2 Local winds

Local winds are always superimposed on the prevailing winds, when the global winds are weak, local winds tend to dominate the wind regime. The pressure force and the friction force can give rise to local winds. The following fig.I.2 shows the different types of local winds:

1. ***Sea and land breezes****: the temperature difference between the land and the sea causes a rise in warm air which then spreads towards the sea. The cold air coming from the sea is immediately attracted by the depression created at land level because of its warming: this is the sea breeze Figure (I-2.a). The phenomenon stabilizes because the temperatures on land and sea become more or less equal. At night, the direction of this breeze takes the opposite path (land breeze) Figure (I-2.b).*

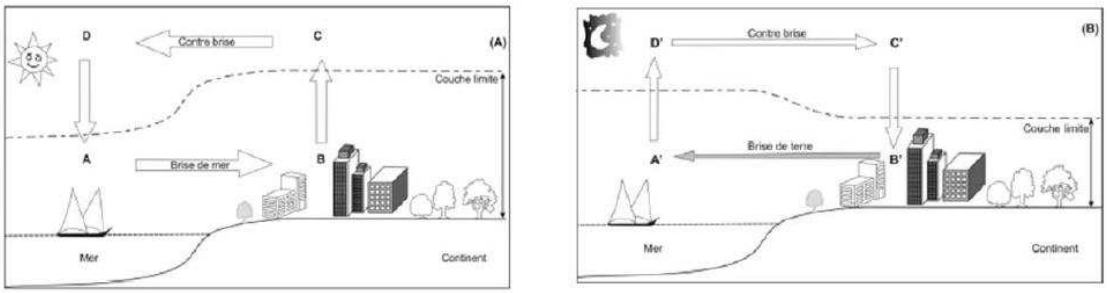


Figure I.2 : Movement of air in the atmosphere (fig(I-2.a) sea breeze), fig(I-2.b) land breeze)

.



Figure I.3 : Movement of air in the atmosphere (fig(I-3.c) rising breeze), fig(I-3.d) downdraft breeze)

.

2. ***Mountain Winds*** *The warming of the slopes and the surrounding air decreases the density of the air, so it begins to rise towards the top of the mountain, producing what is called an "upward breeze" figure (I.3.c). At night, the phenomenon reverses and a "downward breeze" occurs" figure (I.3.d).*

I.1.3.3 Surface winds

Winds are weaker on the surface than at altitude, all this is the result of the influence of the roughness of the terrain, natural or artificial obstacles. Surface winds are of the greatest interest for wind energy.

Beaufort wind scale

Beaufort wind scale	Mean Wind Speed		Limits of wind speed		Wind descriptive terms	Probable wave height in metres*	Probable maximum wave height in metres*	Seastate	Sea descriptive terms
	Knots	m/s	Knots	m/s					
0	0	0	<1	0–0.2	Calm	-	-	**0**	Calm (glassy)
1	2	0.8	1–3	0.3–1.5	Light air	0.1	0.1	**1**	Calm (rippled)
2	5	2.4	4–6	1.6–3.3	Light breeze	0.2	0.3	**2**	Smooth (wavelets)
3	9	4.3	7–10	3.4–5.4	Gentle breeze	0.6	1	**3**	Slight
4	13	6.7	11–16	5.5–7.9	Moderate breeze	1	1.5	**3–4**	Slight–Moderate
5	19	9.3	17–21	8.0–10.7	Fresh breeze	2	2.5	**4**	Moderate
6	24	12.3	22–27	10.8–13.8	Strong breeze	3	4	**5**	Rough
7	30	15.5	28–33	13.9–17.1	Near gale	4	5.5	**5–6**	Rough–Very rough
8	37	18.9	34–40	17.2–20.7	Gale	5.5	7.5	**6–7**	Very rough–High
9	44	22.6	41–47	20.8–24.4	Severe gale	7	10	**7**	High
10	52	26.4	48–55	24.5–28.4	Storm	9	12.5	**8**	Very High
11	60	30.5	56–63	28.5–32.6	Violent storm	11.5	16	**8**	Very High
12	-	-	64+	32.7+	Hurricane	14+	-	**9**	Phenomenal

Figure I.4 : Beaufort wind scale

.

I.2 Classification of winds

A graduation has been established, according to the Beaufort scale which divides the winds according to their speeds. Table (I-1) gives the classification of winds with the Beaufort scale which describes the different natures of wind according to their speeds [3].

I.3 Measurement of Wind Parameters

Direct measurement of wind is done in weather stations, where two quantities that vary with time are used to characterize it: its speed and its direction. The measured wind speed can be expressed in different units: Meter per second (m/s), Kilometer per hour (km/h).



Figure I.5 : weather vane

.

• **The weather vane**: The weather vane is an instrument that indicates the origin of the wind (the wind direction). It is a pointer (an arrow, a rooster, etc.) that is mounted on a rotating axis.

• **The windsock (wind sock)**: The windsock is an instrument that tells us where the wind is coming from and also gives us an approximation of the wind speed.

• **Anemometer**: The anemometer is an instrument that measures wind speed and pressure. Combined with a weather vane, it can also provide details regarding its direction. It is mainly used in meteorology, but the information it provides can also be used for air transport, navigation or to estimate the effects of radioactive fallout or industrial dust.

I.4 Vertical structure of the atmosphere

The atmosphere is the layer of air that surrounds the Earth. It is an envelope of microscopic gases and dust.

• The Earth's atmosphere is made up of several layers of gases and particles, about 500 km thick, that the Earth retains on its surface. Its density and temperature decrease with

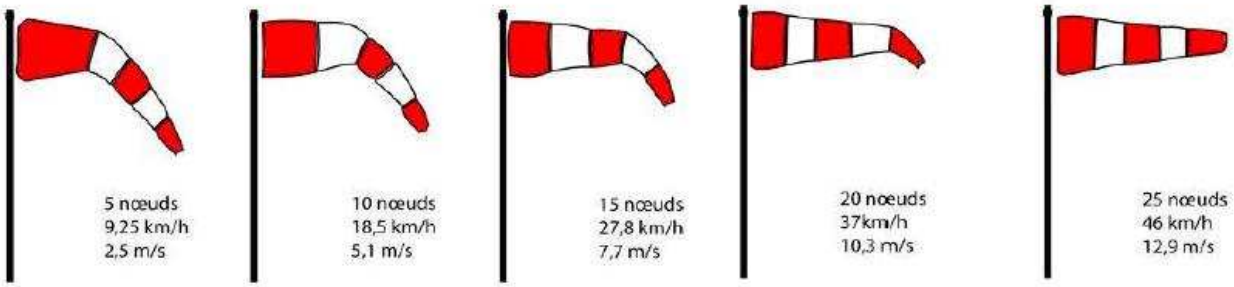


Figure I.6 : The windsock (wind sock)

.

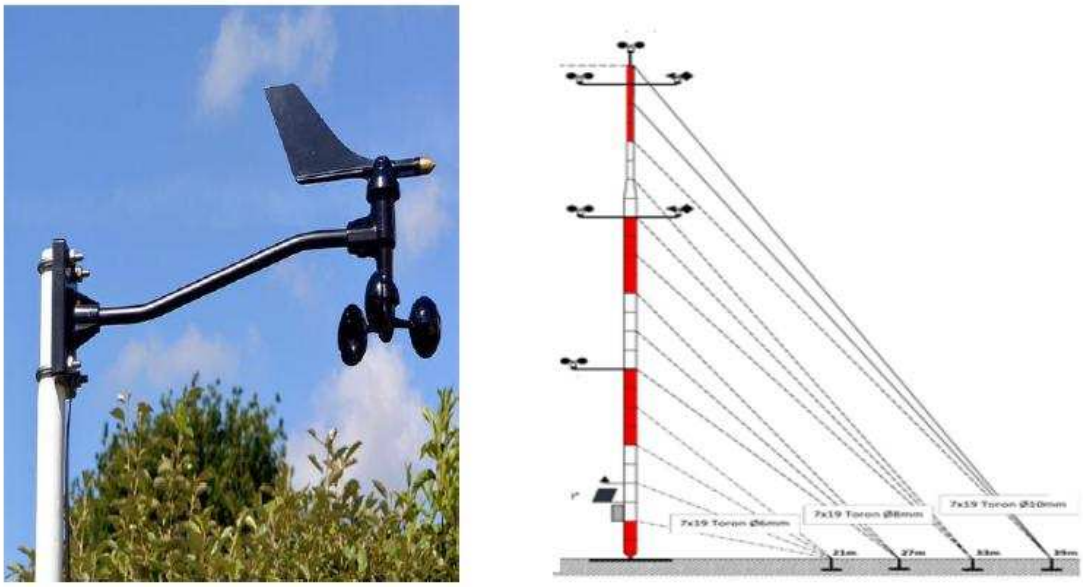


Figure I.7 : (a) Anemometer Wind Vane Set - (b) Measuring Mast with Anemometers and Wind Vanes

.

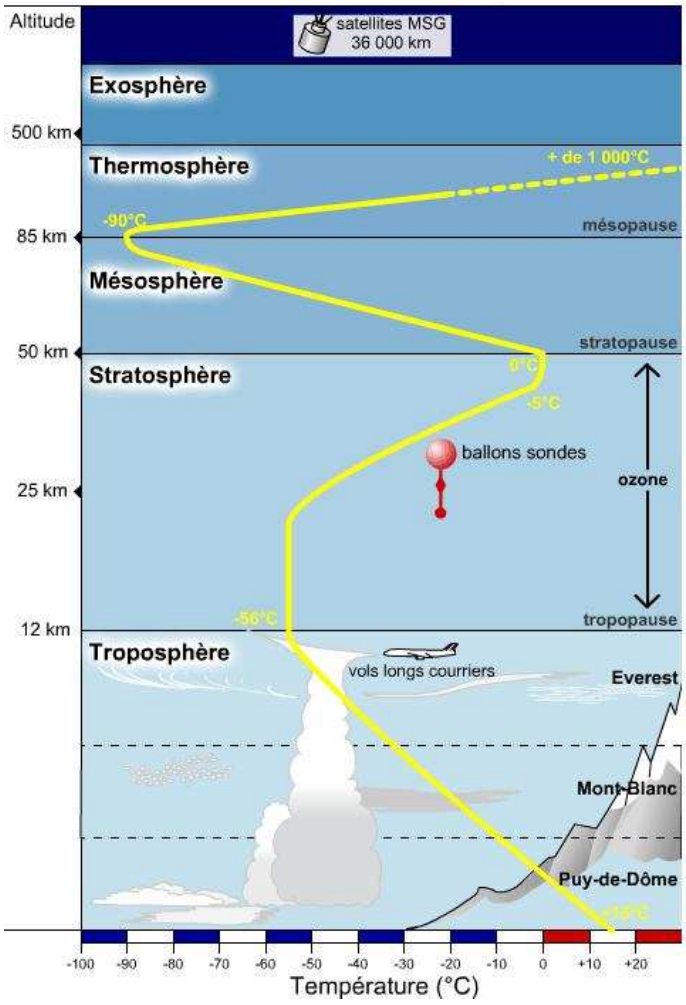


Figure I.8 : vertical structure of the atmosphere

.

altitude [4].

• Only the lowest layer of the atmosphere contains living beings.

•The atmosphere consists of 5 superimposed layers which are separated by 3 zones respectively: the tropopause, the stratopause and the mesopause, as shown in Figure I.8.

1. ***The troposphere*** *This is the layer closest to the Earth's surface and concentrates most of the air mass and meteorological phenomena. Its temperature decreases by 6.5řC per km of altitude. Its average thickness is 13 km.*

2. ***The stratosphere*** *It represents the layer that rises to an altitude of 50 km, where the temperature is close to that of the Earth's surface. The temperature increases*

gradually in the stratosphere because the ozone layer absorbs solar radiation.

3. ***The mesosphere*** *The latter is located between 50 and 80 km above sea level. The temperature drops to* $-140C$.

4. ***The thermosphere*** *The thermosphere extends between 80 and 600 km altitude. Air molecules become very rare and temperatures inside are very high (up to 1200řC).*

5. ***The exosphere*** *The exosphere extends up to 10,000 km altitude, where the atmosphere ends and space begins.*

I.5 Mathematical Modeling of Wind Frequency Distribution

I.5.1 Weibull distribution

In order to assess the wind energy potential of a site, it is important to express the frequency distribution of wind speed. The most widely used model to characterize the distribution of wind speeds is the Weibull probability distribution. The Weibull distribution function is an exponential function with two parameters, a scale parameter C (m/s) providing information on the average wind characteristic of the site, and a shape parameter K (unitless) which characterizes the asymmetry of the frequency distribution. The Weibull distribution is expressed mathematically by its probability density function f(V) for the wind blowing at a speed V is given by [4]:

$$f(v) = \frac{K}{C}(\frac{V}{C})^{K-1} exp[-(\frac{V}{C})^{K}] \tag{I.1}$$

where

- $f(V)$ represents the wind speed frequencies for a given speed
- K Form factor that characterizes the shape of the frequency distribution
- C : Scale factor that determines wind quality
- Wind speed [m/s].

k and c are commonly called the Weibull parameters. Determining these parameters allows knowledge of the wind distribution for a given site. There are several methods for

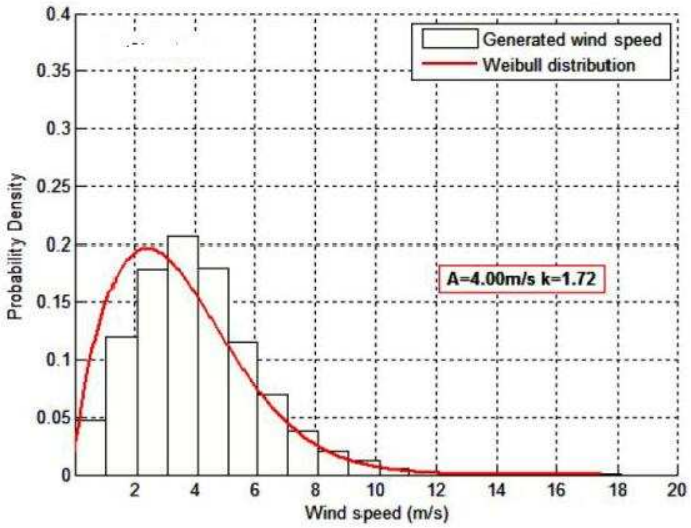


Figure I.9 : Annual wind speed frequency with fitted Weibull distribution at 10 m

.

determining the coefficients K and C of the Weibull distribution fitted to wind speed data taken over a given period. Among the most used methods, we can retain: the method of the standard deviation of the variation of speeds and their average speed that we will define in the following section.

I.5.2 Mean speed and standard deviation method

The mean velocity and standard deviation method also called the method of moments was proposed by [5]. If the mean velocity $\overline{V}$ and the standard deviation σ are known, the form factor k and the scale factor c are determined by the following equations:

$$K = (\frac{\sigma}{\overline{V}})^{-1.086} \qquad 1 \leq K \leq 10 \tag{I.2}$$

$$C = \frac{\overline{V}}{\Gamma(1 + \frac{1}{K})} \qquad C > 0 \tag{I.3}$$

with

$$\overline{V} = \frac{1}{n} \sum_{i=1}^{n} V_i \tag{I.4}$$

$$\sigma = [\frac{1}{N-1} \sum_{i=1}^{N} (V_i - \overline{V})^2]^{0.5} \tag{I.5}$$

and the function $\Gamma(x)$ is defined by

$$\Gamma(x) = \int_0^\infty exp(-t)t^{x-1}dt \tag{I.6}$$

where $t = \frac{1}{k} + 1$

I.6 The wind rose

The strongest winds usually blow from a particular direction. To get a better idea of the distribution of wind speeds and directions, a wind rose can be constructed from weather observations made in a given region. The compass rose can be divided into several angular sectors. For each sector, the following are presented:

• The wind frequency, that is to say the percentage of time during which the wind blows in this sector;

• The average wind speed multiplied by its frequency;

• The power available in the wind.

• It gives the distribution of the wind for the different directions.

The distribution of speeds and directions can be divided into 8, 12, 16 or 32 sectors which represent the different directions. See Fig.II.9.

The sections marked in red and orange are the most important because the wind energy varies with the cube of its speed, and in Figure (I-8) we see that the dominant directions are the west and west-northwest of the rose. Furthermore, this wind rose of 16 directions is constructed according to a scale, where each circle presents a percentage of 2; for example for the most predominant direction, we find a percentage of about 9.

I.7 Vertical Extrapolation of wind parameters

To know all the wind parameters, two methods of extrapolation of these parameters are presented below, namely short term and long term.

I.7.1 Short term extrapolation

Vertical extrapolation of short-term wind speed, which involves extrapolating the quasi-instantaneous wind speed measurement, averaged over a minute or hour. The first

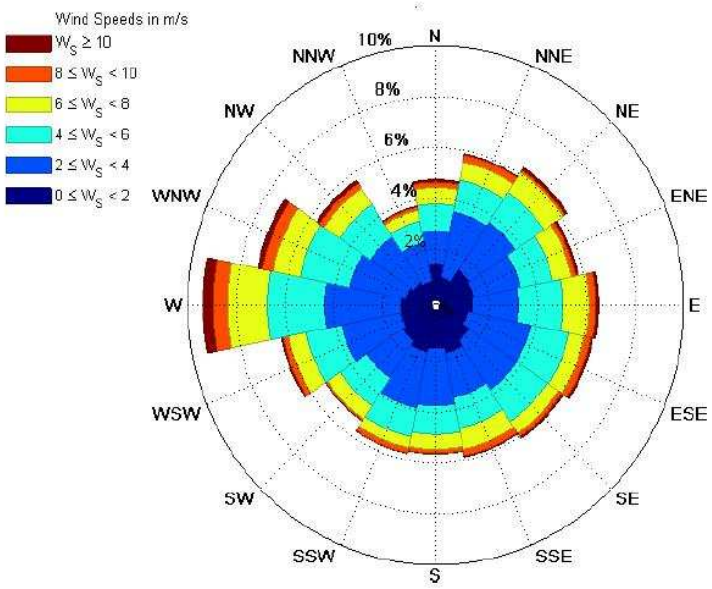


Figure I.10 : The Wind Rose

.

works on determining the formulas for extrapolating wind speed from level Z_1 to Z_2 were carried out by Justus C.G. and A.S. Mikhail who studied the variation of wind speed and Weibull parameters in 1976 [5].

I.7.1.1 (Justus et A.S. Mikhail) The modified power law

Given a speed V_1 extrapolated from an altitude Z_1 to an altitude Z_2, the power law which allows the vertical extrapolation of the wind speed from a level $Z_1 = 10m$ to a level Z_2 is in the form:

$$V_2 = V_1[\frac{Z_2}{Z_1}]^n \tag{I.7}$$

- V_1 wind speed at altitude of 10 meters
- V_2 wind speed at altitude of Z_1

The modified power model was proposed by Mikhail and Justus C.G. el all in 1981 [6]. For an altitude equal to 10m, and for neutral stability conditions, the exponent of the power law takes the form:

$$n = \frac{1}{ln(\frac{z_g}{z_0})} - [\frac{0.0881}{1 - 0.0881.ln(\frac{z_1}{10})}]ln(\frac{V_1}{V_n}) \tag{I.8}$$

Where • $V_n = 6m/S$ for neutral stability conditions.

• $z_g = \sqrt{z_1 z_2}$

• $z_{1=10}$ metres and z_0 represent round roughness.

I.7.1.2 (Spera et Richards model)

According to the study of Spera and Richards [8], the coefficient can be calculated as a function of the roughness of the terrain and the reference speed as follows:

$$n = (\frac{z_0}{z_1})^{0.2}[1 - 0.55log(V_1)] \tag{I.9}$$

This model was derived from a number of observations made across several locations in the United States. It was also used at $NASA's$ Lewis Research Center to design large-scale wind turbines.

I.7.1.3 Power law known as variable coefficient

To take into account the different values of terrain roughness, Knidiri and Laaouina [7], when establishing the wind atlas of Morocco in 1986, proposed writing the expression in the following form:

$$n = \frac{x - 0.088ln(V_1)}{1 - 0.008ln(\frac{z_1}{10})} \tag{I.10}$$

Where the coefficient x varies depending on the roughness class as follows:

1. $x = 0.25 \quad for \quad 0.005 \geq z_0 > 0m$
2. $x = 0.31 \quad for \quad 0.05 \geq Z0 > 0.005m$
3. $x = 0.37 \quad for \quad 0.5 \geq Z0 > 0.05m$
4. $x = 0.48 \quad for \quad 4 \geq Z0 > 0.5m$

I.8 Long term extrapolation

The vertical extrapolation of long-term wind data, including among others the vertical extrapolation of the two Weibull parameters, c and k which are respectively the scale factor in m/s and the shape factor (dimensionless) and which is done according to the power

law model. Thus, for values c_1 and k_1 calculated at height z_1, the values c_2 and k_2 at another height z_2.

I.8.1 Extrapolation model of Justus and Mikhail 1976

In 1976, Justus and Mikhail proposed [5], for an initial altitude reference equal to $10m$, the following extrapolation formulas:

$$\frac{k_2}{k_1} = [\frac{1 - 0.0881ln(\frac{z_1}{10})}{1 - 0.0881ln(\frac{z_2}{10})}] \tag{I.11}$$

and

$$\frac{c_2}{c_1} = (\frac{z_2}{z_1})^n \tag{I.12}$$

with

$$n = [\frac{0.37 - 0.0081ln(c_1)}{1 - 0.0081ln(\frac{Z_1}{10})}] \tag{I.13}$$

I.8.2 Modified Justus 1978 extrapolation model

Where

$$\frac{k_2}{k_1} = [\frac{1}{1 - 0.0881ln(\frac{z_2}{z_1})}] \tag{I.14}$$

and

$$\frac{c_2}{c_1} = (\frac{z_2}{z_1})^n \tag{I.15}$$

with

$$n = \frac{1}{ln\frac{Z_g}{Z_0}} - 0.0081ln(\frac{c_1}{6}) \tag{I.16}$$

the geometric mean of height $Z_g = \sqrt{Z_1 * Z_2}$ and Z_0 ground roughness [4].

I.8.3 Modified extrapolation model of Mikhail 1985

For an extrapolation from any level, Mikhail in 1985 [4], takes up the expressions of extrapolation of the parameters proposed in 1976, by modifying the exponent n such that:

$$n = \frac{1}{ln\frac{Z_g}{Z_0}} + \frac{0.0081(1 - lnc_1)}{1 - 0.0081 * ln(\frac{Z_1}{10})} \tag{I.17}$$

I.9 Wind energy in the world

According to the World Wind Energy Council, wind power represented 282 GW of installed capacity (+19percent in 2012, or an additional 45 GW) worldwide (including 35 persent in Europe and 2.5 percent in France). Wind power remains the most important renewable energy by far after hydroelectric power (750 GW installed) but far ahead of solar power, which has only just passed the 100 GW mark. For comparison, the global installed nuclear power capacity is around 370 GW.
In terms of actual electricity production, wind power now represents more than 500 TWh per year worldwide, the equivalent of France's total electricity consumption, but even if this production has tripled in 5 years, it still represents less than 3 percent of global electricity production, which is around 21,000 TWh per year.

I.10 Potential of Renewable Energy in Algeria

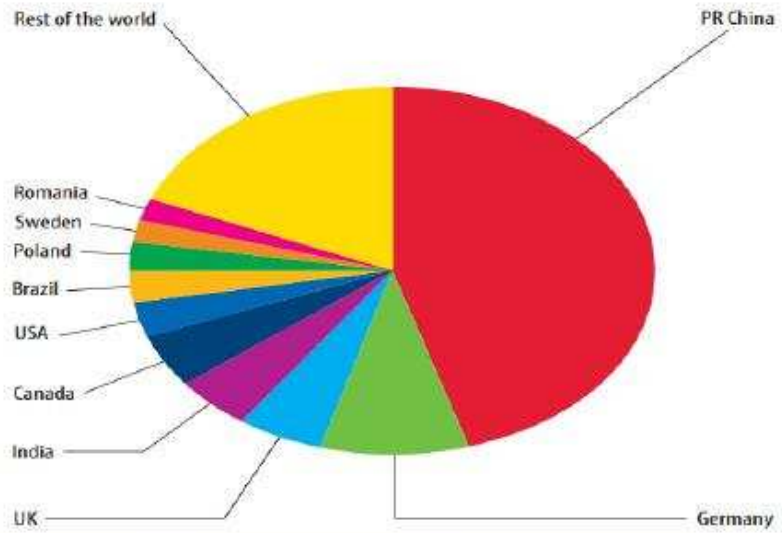
Algeria in particular and the Maghreb countries have a high renewable energy potential, while southern Algeria is characterized by its enormous wind and solar energy potential, which is the main part of the national renewable energy development program.

I.10.1 Solar potential

The solar deposit is among the highest deposits in the world, the average annual sunshine duration in the Algerian Sahara is of the order of 3500 h/year and a territory composed of 86*percent* Saharan desert, very important values are placed for renewable energy projects, as illustrated in, this potential can constitute an important factor of sustainable development in this region, if it is exploited economically.

I.10.2 Geothermal Potential

The compilation of geochemical, geological and geophysical data in northern Algeria has identified large geothermal reservoirs, more than 200 hot springs, located in the north of the country. These springs often have temperatures ranging from $40C$ to $45C$, there are also high temperature resources up to $118C$ in Biskra.



Country	MW	% SHARE
**PR China	16,100	45.4
Germany	3,238	9.1
UK	1,883	5.3
India	1,729	4.9
Canada	1,599	4.5
USA	1,084	3.1
*Brazil	948	2.7
Poland	894	2.5
Sweden	724	2.0
Romania	695	2.0
Rest of the world	6,573	18.5
Total TOP 10	**28,894**	**81**
World Total	**35,467**	**100.0**

Figure I.11 : Wind energy in the world

.

I.10.3 Biomass potential

Biomass is the overall description for all renewable long-term plant organic material, in short, biomass is stored energy. Plants use sunlight from the energy of the sun in photosynthesis to convert carbon dioxide and water into oxygen and glucose. Biomass energy or bioenergy is the process of converting biomass to usable energies in the form of heat, electricity, and liquid fuels.

I.10.4 Hydraulic potential

The total quantities falling on the territory and estimated at 65 billion m^3, but it is not widely exploited in our country for several reasons, we mention them: Strong evaporation of water from the dam, rapid evacuation to the sea, Rapid evacuation to the sea to avoid flooding, concentration on limited spaces, concentration on limited spaces, in total, 103 dam sites have been identified and more than 50 dams are currently in operation.

I.10.5 Wind potential

The topography and climate of Algeria which is very diverse to give a big step to renewable energy especially wind. The North of Algeria has a mountainous terrain, represented by the Tell Atlas and the Saharan Atlas. Among them, the plains and continental climates are penetrated. South, characterized by the desert climate. The south is characterized by stronger winds than the north, with speeds greater than 6 m / s and less than 8 m / s in the Adrar region.

I.11 The national renewable energy program in Algeria PNER

The updated renewable energy program is used to install a renewable power of around 22 GW (2 GW wind, 2.8 GW PV and 7.2 GW (thermal) power plants) with a total estimated number of 12 GW in 2011 and 22 GW after the update of this program in 2015 for the national market by 2030, while maintaining the option of export as a strategic objective.

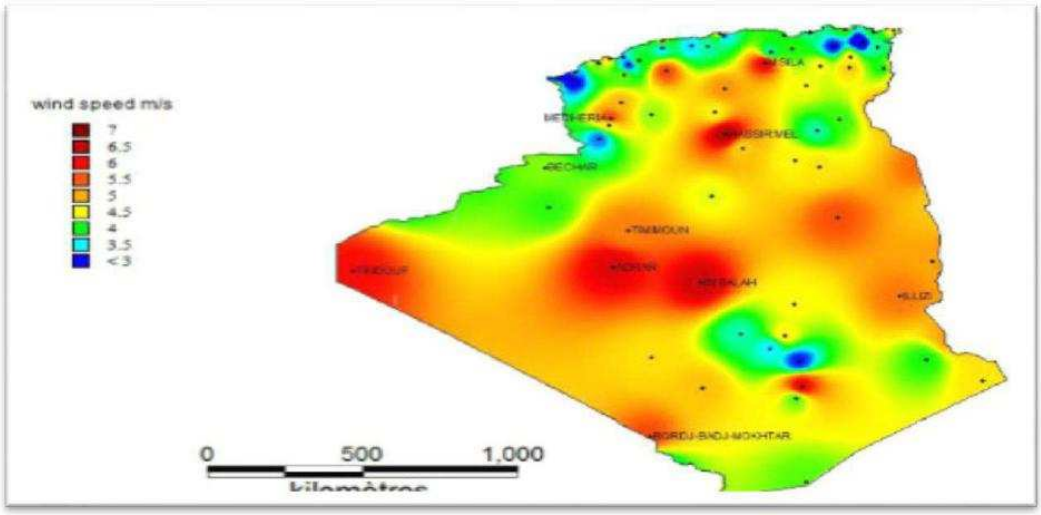


Figure I.12 : Wind energy in the world

.

Algeria intends to position itself as a major player in the production of electricity through this renewable energy program,

I.11.1 Wind energy in Algeria

Being engaged in a new phase of exploitation of renewable energies, Algeria plans to reach by 2030 nearly 40 percent of the national production of electricity from renewable sources. Although the choice of solar energy is predominant, wind energy represents the second axis of production of this program. Before studying the possibility of establishing a wind farm in a given region, it is necessary to carry out studies of the wind deposit for a precise knowledge of the meteorology of the wind.

The Wind Atlas was updated in 2011 by F. Chellali and in 2013 by S. Boudia. In 2017, a new Atlas was established by H. Daaou and S. Haddouche using databases of average three-hourly speeds from 74 ONM (National Office of Meteorology) weather stations. In the field, three 25 KW wind turbines with a diameter of 10m and a height of 18m were installed in 2006 at the big winds of Dély Brahim site in Algiers, in 2014 the first 10M W wind farm was installed and commissioned in 2014, in the Kaberten regions in the wilaya of Adrar. This electricity production plant is the first of its kind on a national scale, and consists of 12 Gamesa wind turbines with a power of 850 kW.

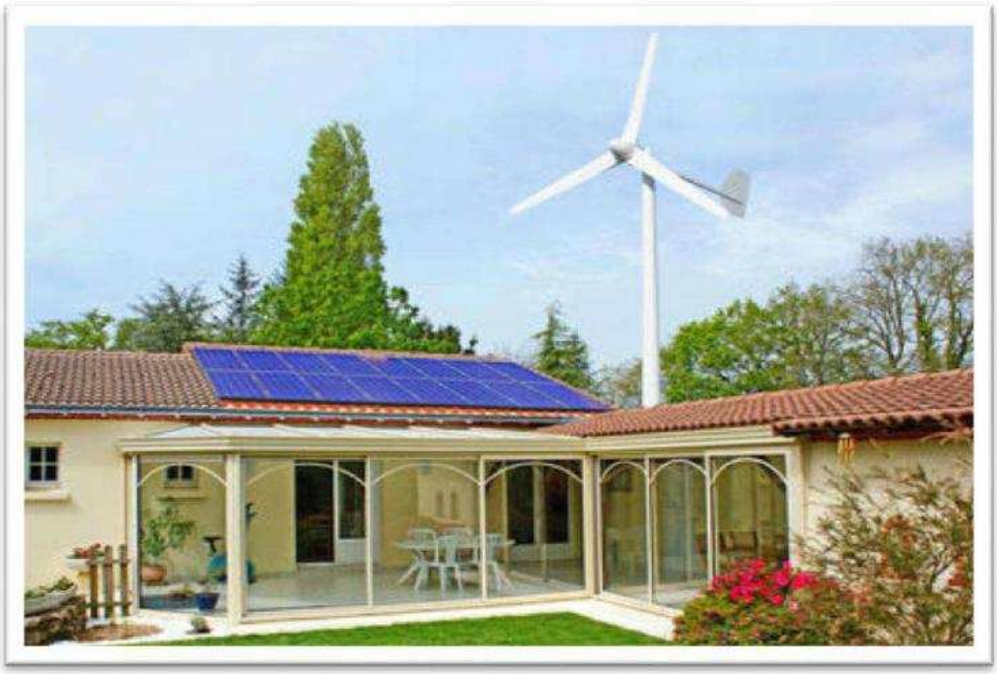


Figure I.13 : A domestic wind turbine for your home

.

I.12 Conclusion

Wind is a movement of the atmosphere. These movements of air masses are caused by two phenomena occurring simultaneously: unevenly distributed warming of the planet's surface by solar energy and the planet's rotation. On Earth, several regions have characteristic winds to which local populations have given particular names.

Chapter II

Wind Energy Technology : Small wind turbines

Much of the electrical energy utilized worldwide comes from conventional sources such as fossil fuels (coal, oil and gas), nuclear energy, as well as hydro. In such a traditional power system, the electrical energy is generated by a large power plant and transported over long distances to the user through the transmission and distribution lines. However, electricity generation from conventional sources has some consequences (Figure 1.1).

1. Reserves for fossil fuels are fast being depleted leading to limited fuel supply. It is estimated that if available reserves continue to be consumed at the current rate, the world may run out of fossil fuel in a couple of decades. Nuclear energy also has limited fuel supply.

2. Fossil fuel can cause serious problems to the environment. In the process of burning fossil fuels in power plants to generate electricity, greenhouse gases such as carbon dioxide (CO2) and nitrous oxide are released to the environment which gives rise to smog, acid rain and other environmental problems. One big consequence of this is the buildup of CO2 in the Earths atmosphere which causes global warming.

3. Nuclear and radiation accident with damaging effects on the environment and human life. One recent reminder is the Fukushima Nuclear Accident following the Japan earthquake and tsunami on 11 March 2011. Accidents from nuclear power plants can lead to the release of high amounts of radioactivity into the atmosphere.

Radioactive materials may also be released into the ground thereby contaminating agricultural land and domestic water. Deaths from direct exposure as well as future cancer deaths in the surrounding population may also occur.

II.1 History of wind energy

Wind turbine is a machine which converts the power in the wind into electricity. This is in contrast to a windmill, which is a machine which converts the wind.s power into mechanical power.

The first uses of wind as energy by man date back to windmills. Appearing in the year 600 first in the Orient and then in Egypt, windmills produced mechanical energy that was used to grind grains but also to pump water to irrigate crops (figure (II.1)).

Windmills appeared in Europe a little before the year 1000 in Great Britain and then became widespread in the 12th century (12) throughout Europe. They were built on the model of vertical axis wind turbines. The first wind turbines did not really appear until the end of the 19th century (19), in experimental form. It was Charles F. Brush who first designed this device to power his house with electricity, in 1888. The wind turbine works with vertical axis blades and several accumulators (batteries) to store the energy produced. Later, Charles F. Brush's wind turbine was taken over by the Dane Poul La Cour who designed several industrial wind turbines, one of which was sold in 72 copies at the beginning of the 20th century (20). These wind turbines aimed to produce hydrogen by using the power of the wind to convert it into chemical energy through an electrolysis process. Throughout the 20th century (20), many tests were carried out. In 1957, Johannes Juul created a turbine that he called Gedser and which still serves as a model for modern wind turbines today. In the United States, Great Britain and France, wind turbines with a power of up to 1000 kW were built [10].

II.2 Methods of exploiting wind energy

There are onshore wind turbines (an American term meaning on the ground, i.e. on the continents), and off-shore wind turbines (on the sea). The latter have advantages in

Energy conversion type		Advantages	Disadvantages
Nuclear power plant: Nuclear power provides electricity for a significant percentage of the world's population. The cooling towers release the steam produced by the nuclear power plant. A domed containment building for the reactor can be seen on the right of the photo.		Emits relatively low amounts of CO_2, therefore it has low contributions to global warming and pollution; readily available technology; relatively inexpensive; possible to generate high amounts of power in a single plant.	High risks as accidents can release radioactivity with devastating consequences for humans and the environment; possible attack on nuclear power plants or diversion of nuclear materials by terrorists; radioactive by-products are difficult to dispose; thermal pollution; limited fuel.
Fossil fuel power plant: An example is coal-fired power plant, which is the dirtiest of all fossil fuels. Despite its negative effects on the environment it generates half the electricity in United States.		Fossil fuels such as coal, are easy to find (for now); the technology is well known; they can be built anywhere; when coal is used, it is cost effective; gas-fired power plants are very efficient.	When burned they emit high amounts of CO_2, contributing to pollution and global warming; thermal pollution; land devastation from extraction of raw materials (mining); environmental hazards such as oil spills on land as well as sea; limited fuel supply.
Hydroelectric: Falling water turns turbines at the base of the dam to generate electric power. Hydro power is the most widely used renewable energy accounting for about 16% of global electricity consumption.		Hydroelectric plants do not require fuels; absence of heat engines means no air, water or thermal pollution; high efficiency; relatively inexpensive; dams can control flooding and store energy; dam water can irrigate farms.	High initial investment cost; reservoir behind dams inundate scenic land; dams block upstream migration of fish; cannot be built anywhere, few available locations for new dams; drought can affect power generation.
Wind power: A wind turbine utilizes the power from the wind to generate electric power. Several wind turbines can be sited in the same area to form a wind farm. They can be sited on land (onshore) or at sea (offshore).		Wind turbines do not employ heat engines meaning no air, water or thermal pollution; wind technology is becoming increasingly cost competitive due to advances in technology; unlimited fuel supply (wind).	Large array of wind turbines may become eyesores; turbine blades can be hazardous to migratory birds; noise from turbines sited close to homes may become a nuisance; wind not always available.
Solar power: Photovoltaic cells convert sunlight to electricity. Solar power generation employs solar panels composed of solar cells containing a photovoltaic (PV) material. Panels may be strung together to form a PV array.		No air, water or thermal pollution due to the absence of heat engines; unlimited fuel supply (sunshine).	Requires large expanse of land to generate high power (space limitations); relatively expensive; not very efficient; sunshine not available always.

Figure II.1 : Electricity generation from different sources including nonrenewable and renewable energy.

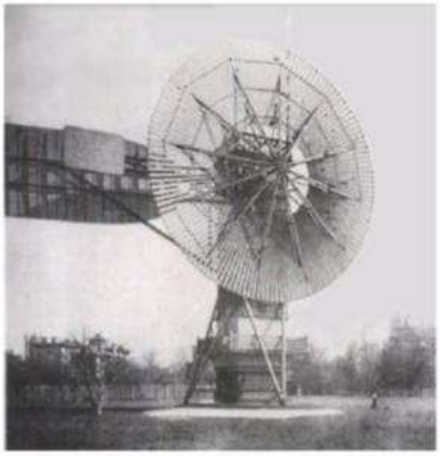


Figure II.2 : First wind turbine designed by Charle .F .Brush



Figure II.3 : Gedser wind turbine (Johannes Juul)



Figure II.4 : Old water pumping wind turbine



Figure II.5 : Photograph of a windmill

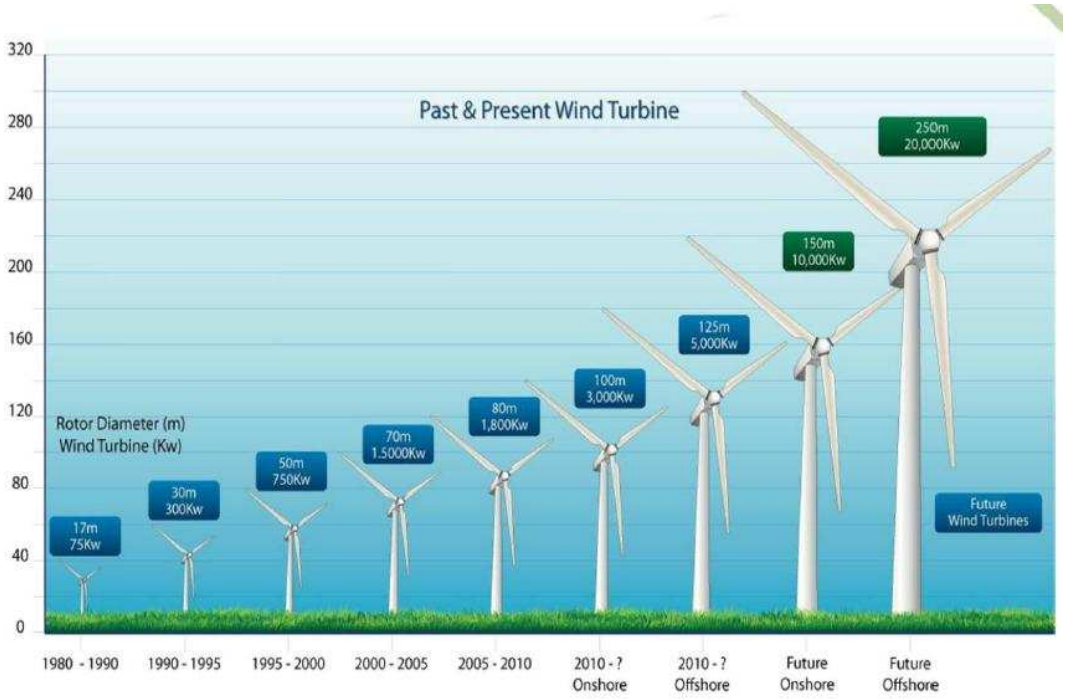


Figure II.6 : Past and Present Wind Turbine

.

terms of noise pollution since they are far from homes and in terms of winds since sea winds are more numerous and stronger than continental winds. On the other hand, they are much more difficult to install and therefore much more expensive.
We also distinguish two types of installations:

1. ***Industrial****: large wind farms (or wind farms) connected to the electricity grid* ;

2. ***domestic****: small wind turbines installed in private homes.*

II.3 Different types of wind turbines

The technical solutions for collecting wind energy are very varied. There are two main families of wind turbines:

1. ***Vertical-axis wind turbines****, in which the axis of rotation is vertical with respect to the ground (and roughly perpendicular to the wind stream),*



Figure II.7 : Onshore and Offshore wind turbines

.



Figure II.8 : Offshore wind turbines in Danmark

.

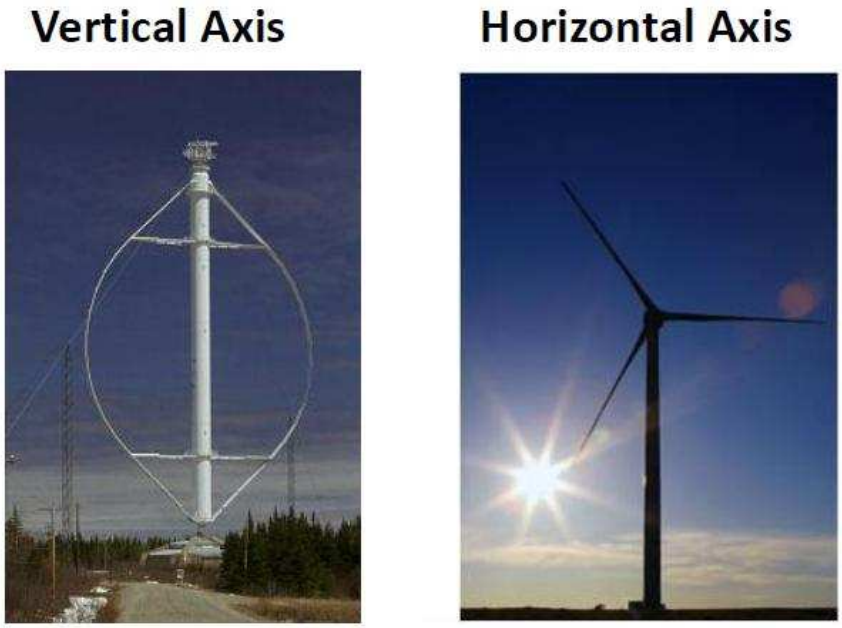


Figure II.9 : Different types of wind turbines

.

2. ***Horizontal-axis turbines****, in which the axis of rotation is horizontal with respect to the ground (and roughly parallel to the wind stream.)*

Number of blades can vary and their shape as well, they can be straight or helical.

II.3.1 Vertical-axis wind turbines

They were the first structures developed to produce electricity. Many technologies were tested, of which only two structures reached the industrialization stage; the Savonius rotor and the Darrieus rotor.

The rotor axis is perpendicular to the ground. They do not need any system to orient them in the direction of the wind, however their efficiency remains poor compared to horizontal axis wind turbines since they capture half as much energy in the wind. There are many variations of Savonius type wind turbines, the number of blades can vary and their shape as well, they can be straight or helical.

Darrieus type vertical axis wind turbines generally have a lower efficiency than "classic" blade wind turbines.



Figure II.10 : Horizontal axis wind and Vertical axis wind turbines

.

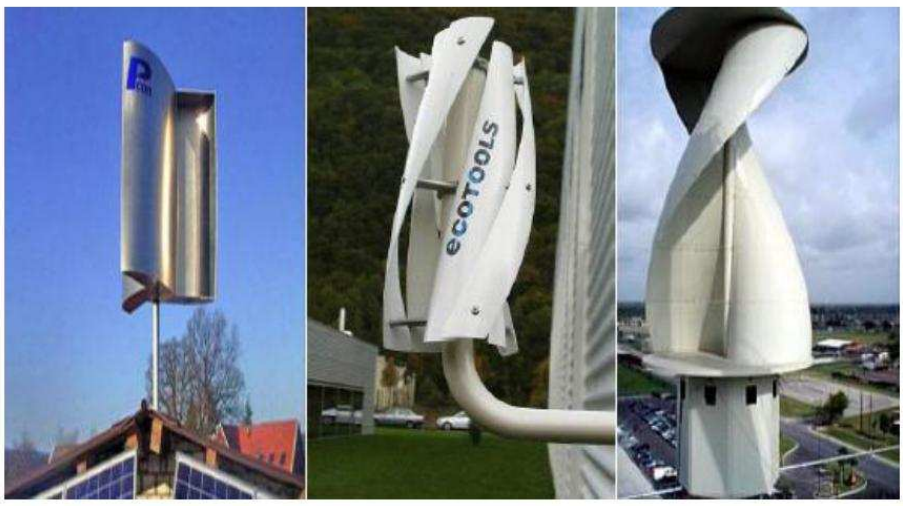


Figure II.11 : Different types of **savonius rotor**

.

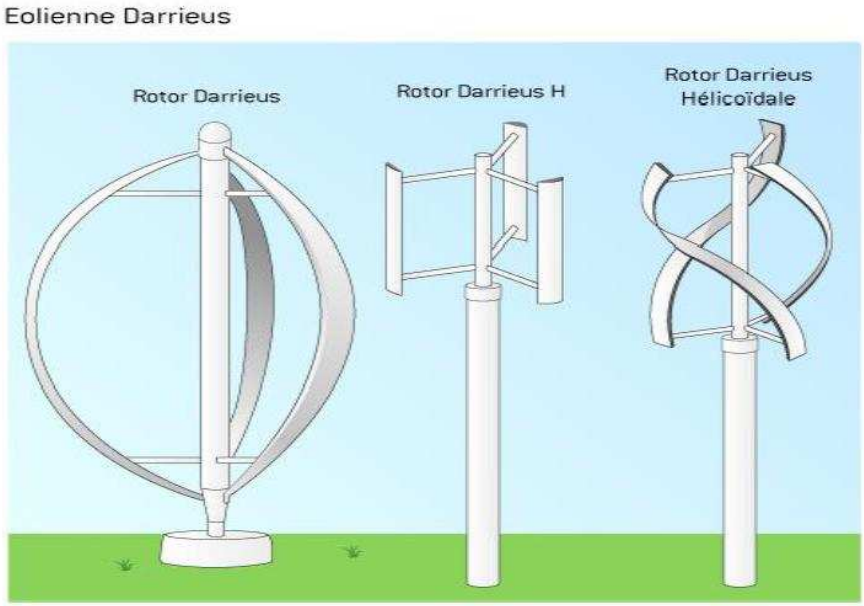


Figure II.12 : Different types of **Darrieus rotor**

.

II.3.1.1 Advantages of Vertical Axis Turbines

The vertical design offers the advantage of placing the multiplier, generator and control devices directly on the ground.

• Its vertical axis has a symmetry of revolution which allows it to operate whatever the direction of the wind without having to orient the rotor.

• Its design is simple, robust and requires little maintenance.

• They start with a lighter wind and do not need to be oriented.

• Here again, different variants exist. They have the advantage of being able to integrate more easily into the landscape.

II.3.1.2 Disadvantages of Vertical Axis Turbines

• They are less efficient than those with a horizontal axis.

• The vertical design of this type of wind turbine requires that it operates with a wind close to the ground, therefore less strong.

•Their installation on the ground requires the use of tie rods which must pass above the blades, therefore occupying a larger surface area than the tower wind turbine.

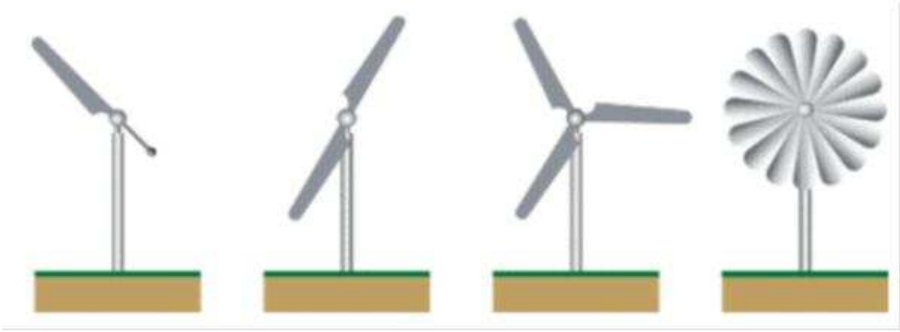


Figure II.13 : Horizontal axis wind turbines with different blades

.

II.3.2 Horizontal Axis Wind Turbines

Horizontal axis wind turbines are the most common. They are composed of blades whose number can vary greatly. For electricity production, we more frequently find models with 3 blades and for pumping, models with a few dozen blades [12].

• **Upwind type** : The wind blows across the front face of the blades toward the nacelle. The blades are rigid, and the rotor is oriented in the wind direction by a device Fig.II.15.a

• **Downwind type** : The wind blows on the rear of the blades from the nacelle. The rotor is flexible and self-orienting.Fig.II.15.b.

II.3.2.1 Advantage of Horizontal Axis

• High energy conversion efficiency

• Access to stronger wind

• Power regulation via stall and stall in case of wind exceeding nominal limits

II.3.2.2 Disadvantages of Horizontal Axis

• Installation cost, robust mast to support the weight of the nacelle.

• Longer cables from the top of the tower to the ground

• Requires orientation systems.



Figure II.14 : fast wind turbines

.

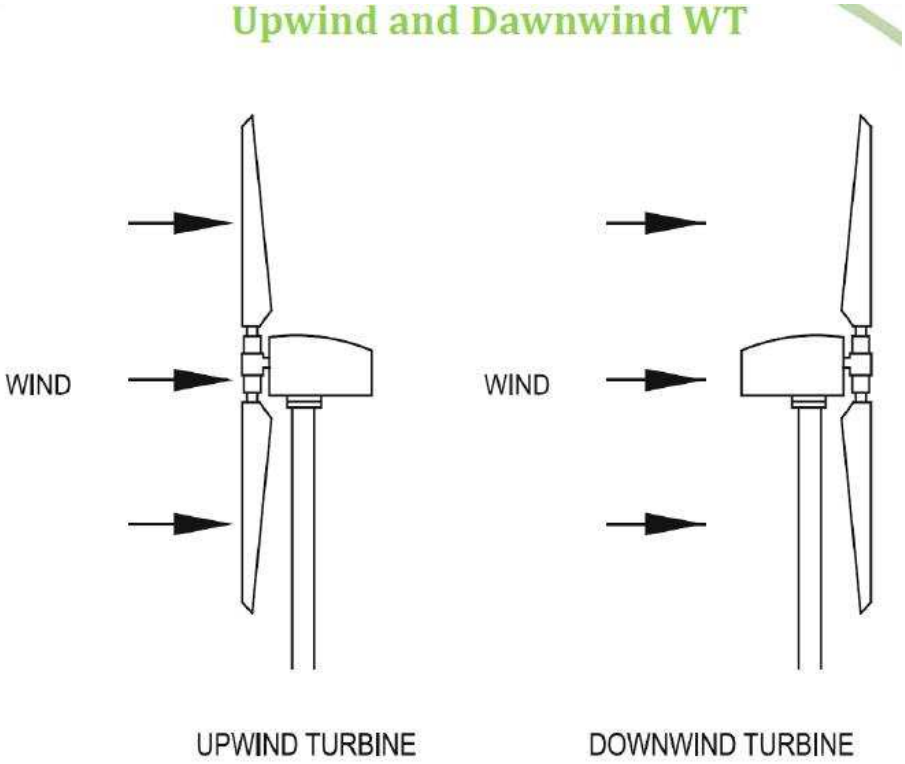


Figure II.15 : Upwind (a) and Downwind Turbine (b)

.

II.4 Classification of wind turbines

Wind turbines are divided into six categories according to their nominal power.

1. ***Micro wind turbines*** *(0.25kw): generally to cover very limited needs and isolated sites (for example, fishing sites, boats, caravans).*

2. ***Mini wind turbines*** *(1.5kx): mainly for recharging batteries on sites isolated from the grid, the most powerful can be used for domestic power supply off the grid (isolated houses).*

3. ***Domestic wind turbines*** *(15kw): they cover a fairly wide spectrum ranging from rotors of 3 to 10 m in diameter. This is typically the type of wind turbines offered for individuals.*

4. ***Small commercial wind turbines*** *(100kw): these are typically designed for small businesses, farms, ... but there are very few models produced in this range.*

5. ***Medium commercial wind turbines*** *(1000kw): These are typically used for commercial applications on farms, factories, businesses or even small wind farms.*

6. ***Large commercial wind turbines (3000kw)****: these are the wind turbines found in modern wind farms, they are also the most efficient.*

II.5 Wind energy conversion chain

To obtain electricity from wind, we find the same basic elements in the different configurations, namely:

1. *A turbine that transforms wind energy into mechanical energy*

2. *A mechanical transmission.*

3. *A generator.*

4. *An electrical connection system.*



Figure II.16 : Sizes and Appliquations

.

Depending on the use of the wind turbine, some of these parts are more or less developed, we distinguish two main families of wind turbines:

1. *Wind turbines connected to the network.*

2. *Autonomous wind turbines.*

II.5.1 What is a small power wind turbines

Small wind turbines or individual wind turbines are defined as wind turbines that are specifically designed to be installed near where the electricity produced is used, such as remote areas (rural homes, farms, small businesses, etc.).
Not only an effective solution to isolated areas, but they can also be connected directly to the power grid to resell the electrical energy produced. These wind turbines are usually installed at heights of 10 to 35 m, and its power does not exceed 36KW. In another report, small wind turbines are defined as turbines with a maximum swept rotor area of 200 m^2. The main difference between small and large wind turbines is the power demand to be satisfied, but remember that it will be easier and cheaper to install a small wind turbine in front of a house, factory, hotel, etc., instead of a large wind turbine installed in the

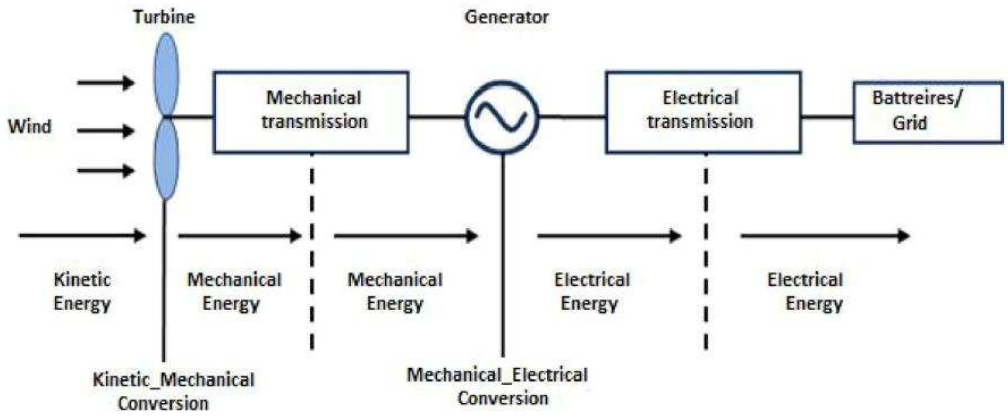


Figure II.17 : Energy conversion process

.

mountains which requires an additional cost for the transport of the electricity produced [13].

II.5.2 Small Wind Turbines

Can I use wind energy to power my home? This question is being asked as more people look for affordable and reliable sources of electricity.
A small wind electric system will work for you if:

1. There is enough wind where you live
2. Tall towers are allowed in your neighborhood or rural area (or you live in flat terrain with no tall obstacles nearby)
3. You have enough space
4. You can determine how much electricity you need or want to produce
5. You can interconnect with your utility service provider (assuming you have a grid-connection application)
6. It works for you economically.

Wind energy systems can be one of the most cost-effective home-based renewable energy systems. Depending on your wind resource, a small wind energy system can lower your



Figure II.18 : Small wind (whisper 100)

.

electricity bill slightly or up to 100 percent, help you avoid the high costs of extending utility power lines to remote locations, and sometimes can provide DC or off-grid power. In addition, wind energy is local energy.

The figures (II.18) below show some examples of small horizontal axis wind turbines (HAWTs) used in different environments. Models such as Skystream, WES Tulipo, Sirocco, and Proven are typical designs used by the small wind energy sector.

Those horizontal axis wind turbines (HAWTs) types are wind turbines which are in popular use today. These turbines are almost all installed on large wind farms and have two or three blades which are rotating around a horizontally mounted shaft. Today the most widespread turbine type is the three bladed HAWT. Large turbines are grid connected to feed electricity in to a regional or national as any generation sources. Small-scale turbines (particularly those that are privately owned) can be also be grid-connected, but they are usually used as a complement to the gridsupplied electricity While excess power is stored in batteries or returned to the grid with a use of transformer arrangements

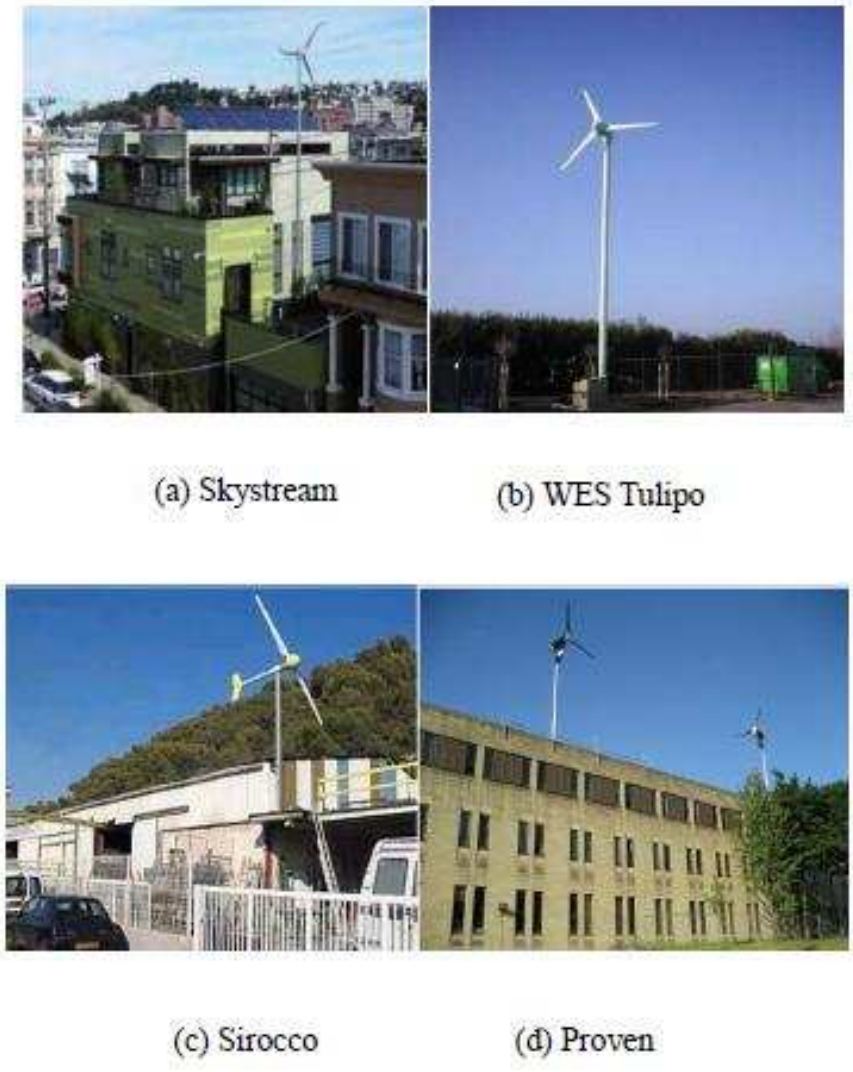


Figure II.19 : Examples of HAWTs in urban areas

.

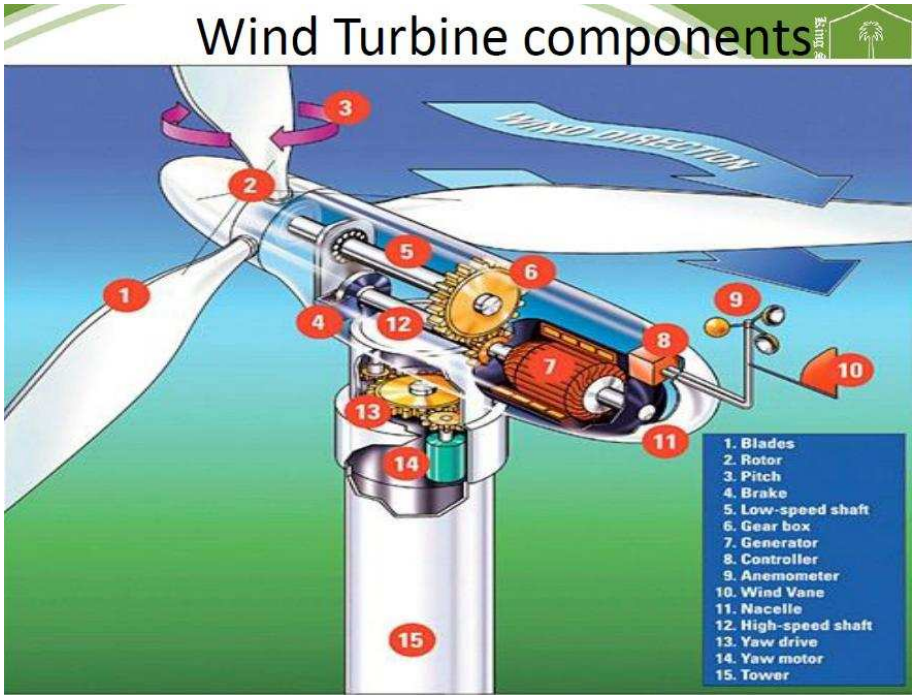


Figure II.20 : Wind Turbine Components

.

II.6 Main components of a small wind turbine

We will not discuss vertical axis wind turbines here, since the majority of wind turbines installed worldwide are horizontal axis. Figure II.20 and Figure.II.21 shows the key components of a wind turbine

1. ***The tower*** *: It must be as high as possible to avoid disturbances near the ground. Given that wind speed increases as one moves away from the ground, a tower can measure between 50 and 80m high. The tower (a truncated cone) or, inside, are arranged the cables for transporting electrical energy, the control elements, the connection equipment to the distribution network as well as the access ladder to the nacelle.*

2. ***The nacelle****: Mounted at the top of the tower: composed of a frame which envelops, protects and connects together all the mechanical elements enabling the wind rotor to be coupled to the electric generator: slow and fast shafts, bearings, multiplier.*

3. ***Blades****: For wind turbines intended for electricity production, the number of blades*

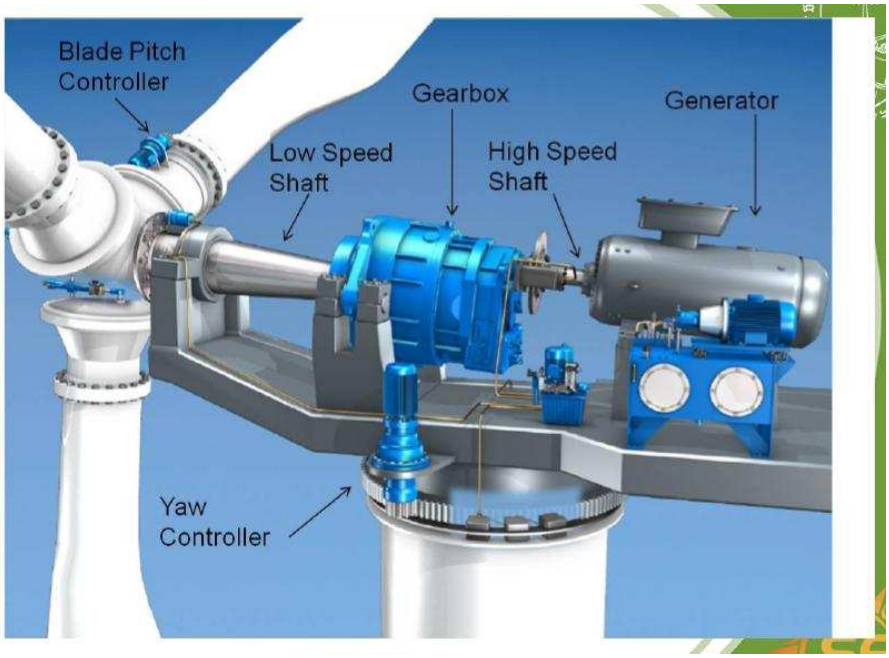


Figure II.21 : Wind Turbine Components

.

typically varies from 1 to 3. They capture the wind and transfer its power to the rotor hub. Each blade of a wind turbine is about 27m long and its design is very similar to that of the wings of an airplane.

4. ***The primary shaft****: (or slow shaft) connects the blades with multiplier.*

5. ***The multiplier****: The multiplier: It is located to the right of the slow shaft. It makes the fast shaft rotate at a speed 75 times higher than that of the slow shaft.*

6. ***The secondary shaft*** *(the fast shaft): It rotates at about 1500 rot/min and drives the electric generator. It is equipped with a mechanical disc brake activated in an emergency when the aerodynamic brake falls during maintenance of the wind turbine.*

7. ***The rotor (electric generator)****It allows part of the wind power to be transferred to the wind turbine shaft. Its diameter determines the power that can be recovered. It ensures electrical production. Its power can reach up to 5 MW. It can be a dynamo (produces direct current) or an alternator (produces alternating current). The alternator is the most used for reasons of cost of performance.*

8. ***The nacelle orientation system*** *It uses electric motors to pivot the nacelle and the rotor so that it is always oriented towards the wind. The orientation device is controlled by the control-command system which records the wind direction thanks to the signals emitted by the wind vane.*

9. ***The cooling system****: The cooling system: It is air or oil and is intended for the multiplier and the generator. It contains an electric fan used to cool the generator. In addition, the system has an oil cooler intended to cool the generator oil.*

10. ***Wind measuring tools*** *(wind vane and anemometer) They are used to measure the wind speed and direction respectively. The electronic signals emitted by the anemometer are used by the wind turbine control system to start it when the wind speed reaches approximately 5m/s, the control system automatically stops the wind turbine if the wind speed is greater than 25m/s, the control system uses the signals from the wind vane to orient the wind turbine in the wind direction using the orientation device.*

11. ***Wind measuring tools*** *(The electronic control system) It includes a computer that constantly monitors the status of the wind turbine while controlling the orientation device. In the event of a failure (e.g. overheating of the gearbox or generator) the system automatically stops the wind turbine and reports it to the operator's computer via a telephone modem.*

12. ***A transformer*** *it is located at the foot of the tower*

II.7 Working Principle of a Wind Turbine

A wind turbine is the opposite of a fan. Instead of electricity powering a fan to make wind, wind turbines use wind to power electricity. When wind flows over the blade, the air pressure on one side of the blade decreases. The difference in air pressure between the two surfaces of the blade creates both lift and drag [2]. The basic steps of how wind generates electricity are:

1. **Wind Pushes Blades:** The wind turbine stands in a place where there is constant

and regular winds. The blades are lifted by the wind and spin the rotor by about fifteen revolutions per minute (rpm).

2. **Kinetic Energy is Transformed** Kinetic energy is transformed into mechanical energy when the wind hits the blades and pushes them.the rotor is connected with the main shaft that translates the turning into the gearbox.

3. **Electricity is Generated** The gearbox speeds up the rotation by a factor of 100 which in turn powers a generator. Once the gears are rotating sufficiently quickly, they can power a generator that produces electricity.

4. **Transformer Converts Electricity** A transformer may be needed to change that to another form of electricity (Direct current DC), depending on local conditions.

5. **Electricity Is Used or Stored** Electricity produced by a wind turbine might be used on site, it might be sent to transmission lines for use at once, or it might be stored in a battery.

II.8 Protection and control mechanisms systems

Wind turbine control systems continue to play important roles for ensuring wind turbine reliable and safe operation and to optimize wind energy capture. The main control systems in a modern wind turbine include pitch control, stall control (passive and active), yaw control, and others.
Under high wind speed conditions, the power output from a wind turbine may exceed its rated value. Thus, power control is required to control the power output within allowable fluctuations for avoiding turbine damage and stabilizing the power output. There are two primary control strategies in the power control: pitch control and stall control. The wind turbine power control system is used to control the power output within allowable fluctuations.

II.8.1 Pitch Control Systems

The pitch control system is a vital part of the modern wind turbine. This is because the pitch control system not only continually regulates the wind turbine's blade pitch

angle to enhance the efficiency of wind energy conversion and power generation stability, but also serves as the security system in case of high wind speeds or emergency situations. It requires that even in the event of grid power failure, the rotor blades can be still driven into their feathered positions by using either the power of backup batteries or capacitors or mechanical energy storage devices.

II.8.1.1 How Pitch Control Systems Work

The goal of pitch control in a wind turbine is to adjust the angle of turbine blades based on the wind speed and direction. Even though the foundational principle is simple, executing it involves complex components that must be understood.
A pitch control system involves the following components:

1. **Sensors and controllers:** These components continuously monitor wind speed and adjust turbine speed to achieve the target power output. Data from sensors is sent to controllers, which then determine the optimal angle of the blades.

2. **Actuators:** Controllers and actuators work together to adjust the turbine blades. The controller sends signals to the turbineŠs actuators, which perform the physical adjustments to create the optimal pitch. Bearings are also involved to enable smooth movements.

3. **Feedback loop:** Wind conditions can change dramatically quickly, so the feedback loop of the above components continuously monitors and adjusts pitch as necessary.

   Any issues with the sensors, controllers, or actuators can result in miscalculations that affect performance or unplanned downtime. Ongoing inspections and maintenance are critical to benefiting from pitch control systems rather than having them cause issues.

II.8.1.2 Yaw Control

In order to maximize the wind power output and minimize the asymmetric loads acting on the rotor blades and the tower, a horizontal-axis wind turbine must be oriented with rotor against the wind by using an active yaw control system. Like wind pitch systems,

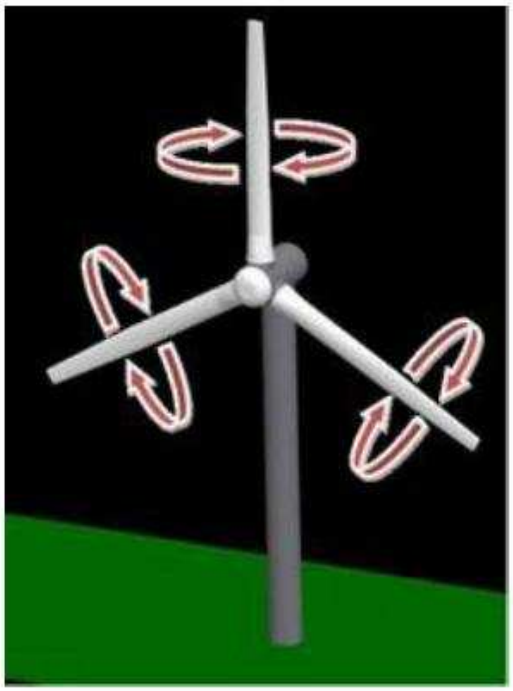


Figure II.22 : Pitch control

.

yaw systems can be driven either electrically or hydraulically. Generally, hydraulic yaw systems were used in the earlier time of the wind turbine development. In modern wind turbines, yaw control is done by electric motors. The yaw control system usually consists of an electrical motor with a speed reducing gearbox, a bull gear which is fixed to the tower, a wind vane to gain the information about wind direction, a yaw deck, and a brake to lock the turbine securely in yaw when the required position is reached.

II.8.1.3 Furling systems

Furling is a passive control mechanism for limiting the rotational speed and the output power of small-scale wind turbine in high winds. Though other mechanisms can be encountered sometimes, furling is the most encountered mechanism. The idea in general is to turn the rotor out of the wind once a critical value of wind speed has been reached. This idea is illustrated in Fig. II.24 where images of an operating commercial wind turbine under normal (left) and furled (right) conditions are shown.

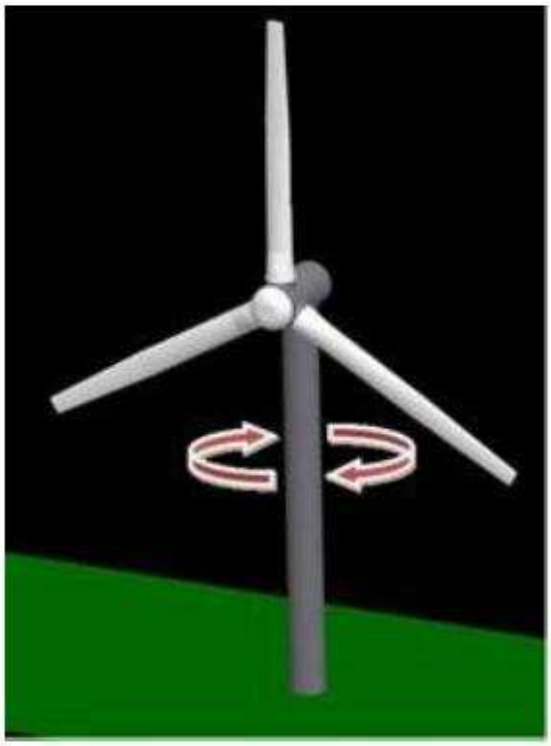


Figure II.23 : Pitch control

.



Figure II.24 : Furling systems

.

II.9 Conclusion

Small wind turbines are an attractive alternative for off-grid electrification and water pumping, both as stand-alone applications and in combination with other energy technologies such as photovoltaic, small hydro or Diesel engines.

Small horizontal axis wind turbines (HAWTs) are an economical and flexible option for decentralized renewable power generation. Their small size, moderate speed operation capability, and applicability to residential, agricultural, and off-grid applications make them a viable option in rural and semi-urban areas. This chapter has described the main characteristics and their function in wind energy conversion, and why they must be modeled to optimize performance and system design.

Chapter III

Estimation of the annual energy production of a wind turbine

A typical large scale wind turbine is one with a diameter 50 m to 100 m rotor. It produces power between 1 MW and 3 MW. Compared to large scale wind turbines, small scale wind turbines are those whose rotor 3 m to 10 m diameter and with a power capacity of $1.4 - 20kW$. Small scale wind turbines with a nominal power rating of 50 W produce more costly electricity than the medium and large scale wind turbines especially in poor wind sites. They are also suitable in some autonomous applications which require a very high level of reliability. These wind turbines can be used as a reliable source of power when they are correctly sized and operated at their optimum levels.
There are two different types of small wind turbines: horizontal axis and vertical axis, in this chapter will concentrate exclusively on small horizontal axis wind turbines, which is the most widely utilized configuration because they have high efficiency and uncomplicated mechanical structure.

III.1 Small Wind Turbine Modeling

Modeling is a process of creating a simplified representation of an existing system, phenomenon or situation. This representation, known as a model, can be in many forms and achieved through many different techniques. Wind first gives kinetic energy to the turbine, which is transferred as mechanical energy. The mechanical energy is transferred

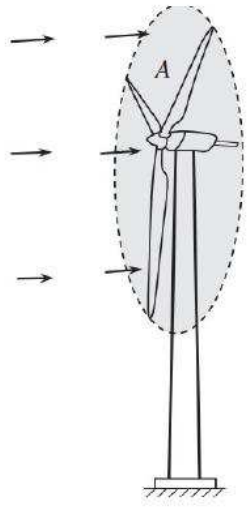


Figure III.1 : Air Area of wind turbine blades

.

to a generator that transforms it into electrical energy. The electricity is then supplied and transmitted either to the grid or to storage systems such as batteries [14]

III.1.1 Kinetic energy

Kinetic energy is present whenever an object of a particular mass is moving with a translational or rotational speed. When air is flowing, then kinetic energy in flowing air can be determined as:

$$E_k = \frac{1}{2}mv^2 \tag{III.1}$$

where:

- E_k : Kinetic energy (in joules)
- m: Mass of the object (in kilograms)
- v: Velocity of the object (in meters per second)

III.1.2 Air Mass

An air mass is a large body of air in the atmosphere that is more or less uniform in temperature and moisture. Air masses can extend for thousands of kilometers in any

direction, it can be expressed as the product of air density (ρ) and volume (V), where:

$$m = \rho \times V \tag{III.2}$$

where:

• m : mass of air

• ρ: air density (kg/m^3)

• V: Volume of Air (m^3)

Substituting (2) into (1), the Kinetic energy can be expressed as:

$$E_k = \frac{1}{2}.\rho.V.v^2 \tag{III.3}$$

III.1.3 Blade swept area

The swept area refers to the area of the circle created by the blades as they sweep through the air.

$$A = \pi.r^2 \tag{III.4}$$

The volume of air passing through the turbine depends on the swept area of the blades and the distance the wind travels:

$$V = A.d \tag{III.5}$$

We replace (Eq.III.5) with (Eq.III.3):

$$E_k = \frac{1}{2}.\rho.A.d.v^2 \tag{III.6}$$

III.1.4 Wind Power

Power is energy per second. So, if we divide the energy by the time $d = v.t$, and because , we substitute:

$$\begin{aligned} P &= \frac{E_k}{t} \\ P &= \frac{1}{t} \cdot (\frac{1}{2}.\rho.A.d.v^2) \\ P &= \frac{1}{t} \cdot (\frac{1}{2}.\rho.A.v.t.v^2) \end{aligned} \tag{III.7}$$

The wind power can be calculated as:

$$P_{wind} = \frac{1}{2}.\rho.A.v^3 \tag{III.8}$$

Where:

- P : Power in watts (W)
- ρ : Air density (kg/m^3)
- A : Rotor swept area (m^2)
- v : Wind speed (m/s)

III.2 Wind power parameters

III.2.1 Betz Law (Betz limit)

The Betz limit is the theoretical maximum efficiency for a wind turbine, conjectured by German physicist Albert Betz in 1919. Betz concluded that this value is 59.3 percent, meaning that at most only 59.3 percent of the kinetic energy from wind can be used to spin the turbine and generate electricity. In reality, turbines cannot reach the Betz limit, and common efficiencies are in the $35 - 45$ percent range [15].

Air surrounds the turbine as seen in (Fig.III.2). The amount of air incoming in one second at a speed of V_1 (from the right) must be the same as the amount of air exiting on the left at a speed of V_2 because the stream continuity state ought to be maintained for the gas in flow:

$$A_1.V_1 = A_2.V_2 \tag{III.9}$$

Where:

- A_1: surface determined by the rotor in m^2
- A_2: air stream surface downstream of the rotor in m^2
- V_1 : wind speed upstream of the turbine rotor in m/s
- V_2 : wind speed downstream of the turbine rotor in m/s

Therefore, the region A_2 must be increased to the extent equal to reduction in speed. Air mass flowing through the rotor in one second. Where

$$m = \rho.\ A.\ \frac{V_1 + V_2}{2} \tag{III.10}$$

The power Extracted by the Rotor is:

$$P = \frac{1}{2}.\ m.(V_1^2 - V_2^2) \tag{III.11}$$

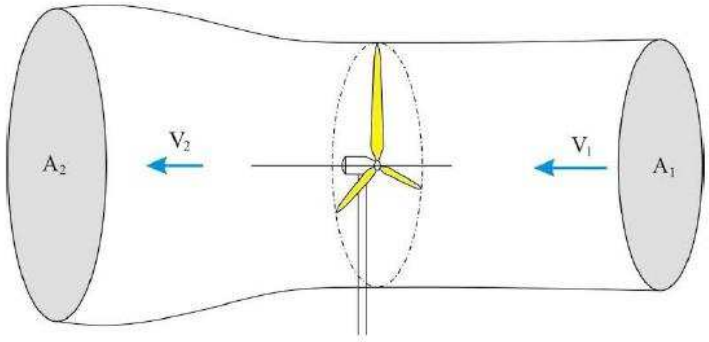


Figure III.2 : Air Flow trough the turbine

.

Substituting (Eq.III.10) into (Eq.III.11), The power extracted from the wind is:

$$P = \frac{\rho.\ A}{4}.\ (V_1 + V_2).\ (V_1^2 - V_2^2) \tag{III.12}$$

The wind power is equal to:

$$P_w = \frac{1}{2}.\ \rho.\ A.\ V_1^3 \tag{III.13}$$

The ratio of the wind power and the power to be received is:

$$\frac{P}{P_w} = \frac{1}{2}.\ (1 - (\frac{V_2}{V_1})^2).(1 + \frac{V_2}{V_1}) = C_p \tag{III.14}$$

When the Betz function is tested, the optimum variation of the air flow velocity in the wind turbine rotor can be calculated in order to utilize the maximum amount of the wind power. By finding the derivative of the equation Eq.(14) with regard to the variables $\frac{v_2}{v_1}$ and by setting it equal to zero, the following maximum value can be found:

$$(\frac{V_2}{V_1})_{opt} = \frac{1}{3} \tag{III.15}$$

We can get the expression for the maximum power that could be extracted from a wind stream as:

$$P_{max} = \frac{1}{4}.\ \rho.\ A.(V_1^2 - V_2^2)(V_1 + V_2) \tag{III.16}$$

$$= \frac{1}{4}\ \rho.\ A.(V_1^2 - \frac{V_1^2}{9})(V_1 + V_1/3)$$

$$= \frac{1}{4}\ \rho.\ A.\ V_1^3(1 - \frac{1}{9}).(1 + \frac{1}{3})$$

$$P_{max} = \frac{16}{27}.(\frac{1}{2}\ \rho.\ A.\ V_1^3) \tag{III.17}$$

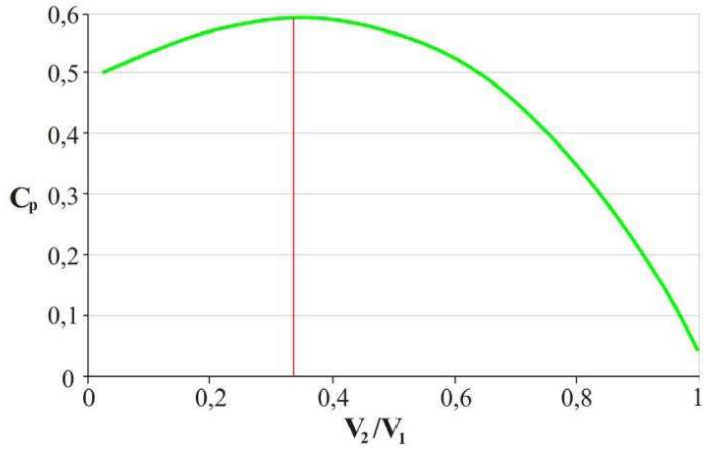


Figure III.3 : Betz Coefficient of power C_p

.

The maximum power is achieved when the ratio $\frac{V_2}{V_1}$ is $\frac{1}{3}$. The maximum extractable wind power is 16/27 of the wind power. More than 59.2 percent of power cannot be harvested from the power in the air flow stream, as it is theoretically impossible. Figure III.3 shows the waveform of the Betz coefficient function versus the speed ratio $\frac{V_2}{V_1}$. As one can see, the function achieves the extremum when the ratio given is 1/3, and for larger and smaller values it takes smaller values.

III.2.2 Tip Speed Ratio

Tip Speed Ratio (TSR) is an extremely important design parameter for wind turbines. It is the proportion of the tip speed of the blades to the speed of the wind [16].

$$\lambda = \frac{V_{tip}}{V_{wind}}$$

$$\lambda = \frac{R.\Omega}{V_{wind}} \tag{III.18}$$

Where

- Ω angular speed of the turbine rotor
- R the rotor radius.
- V_{wind} wind speed (m/s).

The Power Coefficient curve for different types of wind turbines is shown in Fig.III.4.

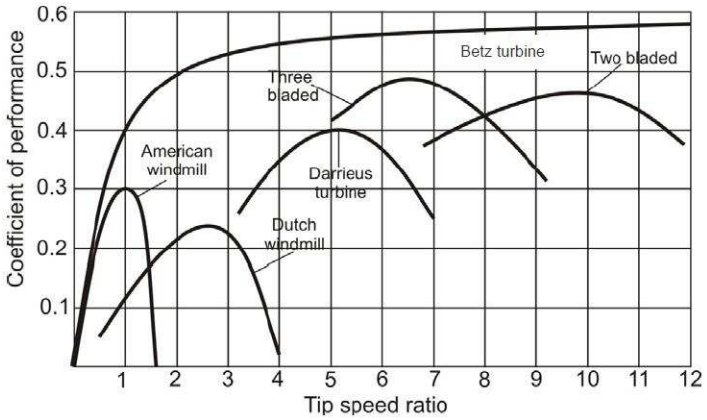


Figure III.4 : Power Coefficient curve for different types of turbines

.

III.3 Wind turbine modeling

The mechanical energy produced by the wind turbine, which is characterized by a speed of rotation and a mechanical torque, is created from the kinetic energy of the wind. Therefore, according to Betz theory, the mechanical power is expressed in the following Equation :

$$P_{mec} = \frac{1}{2}.C_p(\lambda, \beta).\rho.A.V_w^3 \tag{III.19}$$

where

- $C_p(\lambda, \beta)$ is the wind turbine$'$s power coefficient,
- ρ is the air density, ($\rho = 1.225kg/m^3$)
- V_w is wind speed ($m.s^{-1}$)
- A is the swept area given by the equation $A = \pi R^2$
- R is the radius of blade(m).

III.3.1 Aerodynamic model

Wind turbines transform the kinetic energy of the wind into mechanical energy. During this transformation, the wind turbine can only recover a fraction of the $wind^{'}s$ power. Therefore, the aerodynamic power available on the wind turbine's slow shaft can be expressed as:

$$P_{aer} = P_{mec} = \frac{1}{2}.C_p(\lambda, \beta).\rho.A.V_w^3 \tag{III.20}$$

with:

$\lambda = \frac{\Omega.R}{V_w}$ is defined the tip speed and β (in degree) is the pitch angle of the rotor blades. Where Ω is the rotational speed of a wind turbine (rad/s) and R is the length of the rotor blade. To studies the behaviour of the wind turbine, the mechanical torque is calculated practically from the mechanical power by using the wind turbine's rotational speed

$$T_{mec} = \frac{P_{mec}}{\Omega} \tag{III.21}$$

For the mechanical part, a mathematical representation of the multiplier is provided by the Equations (22) and (23):

$$\Omega_{mec} = G.\Omega \tag{III.22}$$

$$T_{mec} = G.T_g \tag{III.23}$$

Where: Ω_{mec} represents the angular speed of the generator (rad/s) or (rpm), and G is the speed multiplier gain.

$$J = \frac{J_{turbine}}{G^2} + J_g \tag{III.24}$$

The basic dynamic equation for determining how the mechanical speed evolves from the overall mechanical torque T_{mec} applied to the rotor is defined as:

$$J\frac{d\Omega_{mec}}{dt} = T_{mec} \tag{III.25}$$

Where; J denotes the total apparent inertia on the generator rotor.

The total mechanical torque depends on the load torque (T_g), the viscous friction torque (T_{vis}), and the electromagnetic torque (T_{em}) generated by the generator.

$$T_{mec} = T_g - T_{em} - T_{vis} \tag{III.26}$$

The viscous friction torque is modelled by:

$$T_{vis} = f.\Omega_{mec} \tag{III.27}$$

f Is the viscous friction coefficient.

Furthermore, the model of the turbine technologyŠs mechanical system is indicated by Fig.III.5.

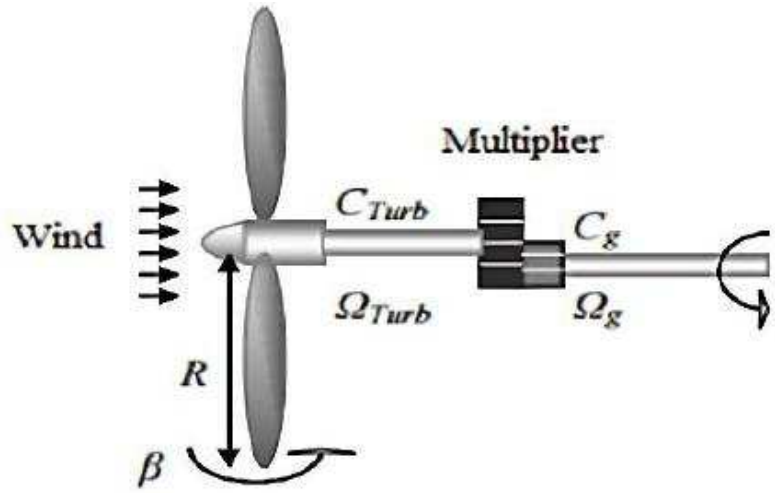


Figure III.5 : Wind energy scheme

.

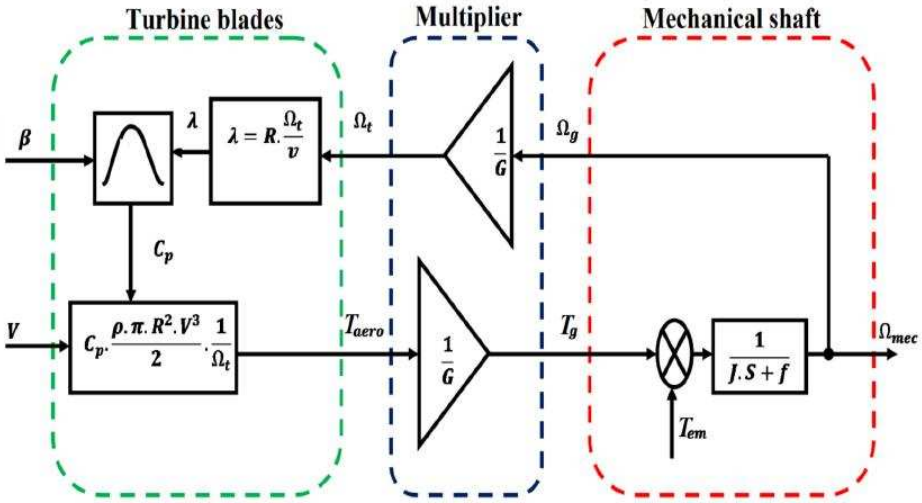


Figure III.6 : Block diagram of wind energy converter mechanical model.

III.4 The power curve of a wind turbine

The power curve of a wind turbine relates the speed of the wind flow intercepted by the wind turbine rotor to its electrical output. A power curve is needed at different stages of the lifetime of a wind farm. Prior to its market introduction, the power curve of a newly designed turbine must be assessed to validate its performance.
to monitor the state of the turbines and degradation due to ageing. Power curves are also used to estimate the aggregated power production of wind farms, and their integration into national power systems and electricity markets.

III.4.1 Operating regions of a wind turbine

Power curves are traditionally divided into four operation regions, as shown in Figure.7 and detailed below.
At very low wind speeds, the torque exerted by the wind on the blades is insufficient to bring the turbine to rotate. The wind speed at which the turbine starts to generate electricity is called cut-in wind speed and is typically between 3 and 4 m/s. **Region I** corresponds to wind speeds below this cut-in wind speed.
Above the cut-in wind speed, there is sufficient torque for rotation, and power production increases with the cube of wind speed before reaching a threshold corresponding to the rated power of the turbine (or nominal power) that is designed to not exceed. The lowest wind speed at which the nominal power is reached is called the rated (or nominal) wind speed and is typically between 12 and 17 m/s. **Region II** is delimited by the cut-in and the rated wind speed, and corresponds to an interval where the wind turbine 1operates at maximal efficiency.
For wind speeds above the rated wind speed, the wind turbine is designed to keep output power at the rated power, which cannot be exceeded. This can be achieved by means of a stall regulation or pitch control. The latter solution consists in adjusting the pitch angle of the blades to keep the power at the constant level and is overwhelmingly used in modern large turbines. **Region III** corresponds to wind speed values where the turbine operates at its rated power, and is bounded by the nominal wind speed and the cut-off wind speed.

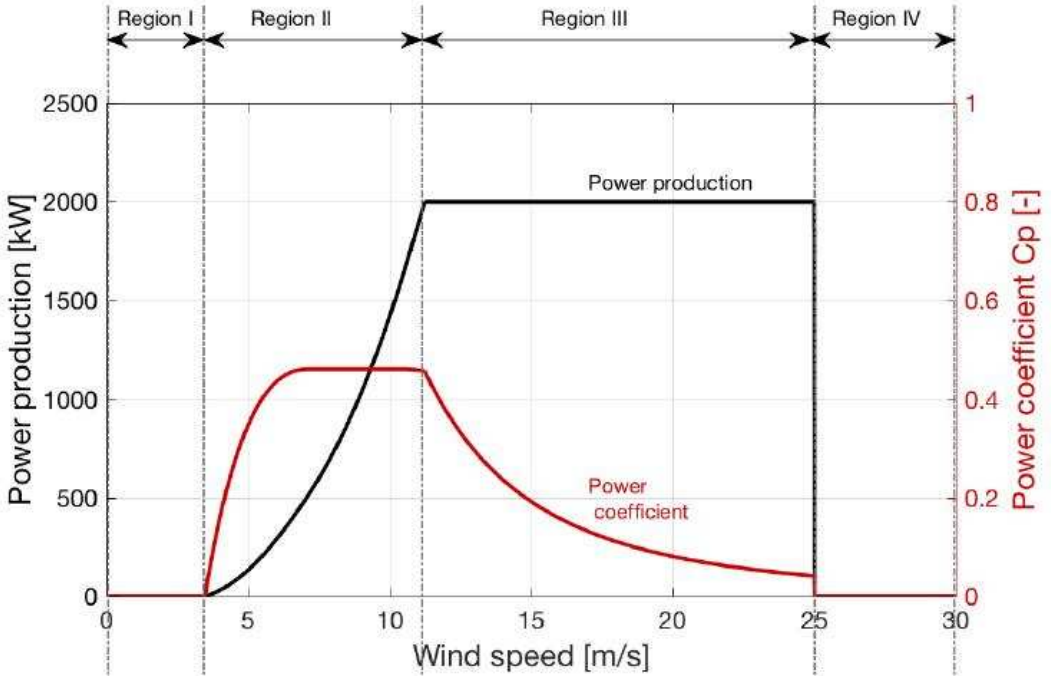


Figure III.7 : Operating regions of a wind turbine

The forces acting on the turbine structure increase with wind speed, and at some point the structural condition of the turbine can be endangered. To prevent damage, a braking system is employed to bring the rotor to a standstill. The cut-off wind speed corresponds to the maximum wind speed a wind turbine can safely support while generating power and is usually about $25m/s$. **Region IV** includes all wind speeds larger than the cut-off wind speed.

Some manufacturers have introduced storm control in larger-bladed turbine models, where the power is gradually reduced (from 21 m/s up to 25 m/s) to prevent such drastic loss of power at the cut-out speed. Figure 1 shows the different operating regions described above.

III.5 Estimation of wind potential energy

Given the need to convert the wind's kinetic energy into mechanical energy, the available potential undergoes a series of losses until the turbine exits (Betz limit, machine thresholds, and conversion losses). Indeed, only a portion of the wind power available at

a given site, known as useful power, is actually obtained at the end of the process at the turbine exit.

III.5.1 Average power density

The best way to assess the wind resource available at a given site is to calculate wind power density, which indicates the energy available at the site after conversion into electricity from a wind turbine.
Wind energy per unit area $\frac{P}{S}$ in $(\frac{W}{m^2})$ or wind energy density. Knowing that the power of the wind flowing at speed v through a sail is given by the following relationship [25]:

$$P(V) = \frac{1}{2}\rho V^3 \tag{III.28}$$

The wind potential available on a site per unit area can be expressed in the form [24]:

$$\bar{P}(V) = \frac{1}{2}\rho \bar{V}^3 \tag{III.29}$$

Generally, there are two ways to estimate the power density at a site. The first is based on measured data and the second on the probability distribution function.

- **First Method**

Using the arithmetic mean, the average power density is given by the following relationship:

$$\bar{P}(V) = \frac{1}{2}.\frac{1}{N}.\Sigma_1^N.\rho_i.V_i^3 \tag{III.30}$$

where ρ_i and V_i are respectively the air density and the wind speed measured at a moment i, and N the total number of measurements taken in a given period of time [26].

- **second Method**

Using the given definition of power per unit area, we can express the wind power density based on the Weibull distribution probability density function by the following relationship:

$$\bar{P}(V) = \frac{1}{2}.\rho.c^3.\Gamma.(1+\frac{3}{k}) \tag{III.31}$$

where k, c are parameters of weibull and Γ is function gamma [27].

III.5.2 Average available energy density

Furthermore, the average energy density that can be extracted from a given site over a defined period can be estimated using two methods:

- **First Method**

Whether daily, monthly or annual, the average energy density can be defined by the folowing relations [28]:

$$\begin{aligned} \bar{E_d} &= 24 \times \bar{P}\ (wh/m^2)/day \\ \bar{E_m} &= 24 \times d \times \bar{P}\ (wh/m^2)/month \\ \bar{E_y} &= \sum_{1}^{12} \bar{E_m}\ (wh/m^2)/year \end{aligned} \tag{III.32}$$

where $\bar{P}$ the average power density, and d the number of days considered in the month.

- **second Method**

Based on the number of days in a defined period, the average energy density is given as follows:

$$\bar{E_m} = 24 \times d_j \times \bar{P}\ (wh/m^2/period) \tag{III.33}$$

with d_j being the number of days included in the period we wish to study, For a month $d_j = 30$ and for a year $d_j = 365$.

Using the average power density as a function of the two Weibull parameters, equation (III.31) will be written in the following form: :

$$\bar{E_m} = \frac{1}{2}.\rho.c^3.\Gamma.(1 + \frac{3}{k}).T \tag{III.34}$$

where T is the number of hours included in a number of days of a defined period [29], [30]

.

III.5.3 Average power output from a wind turbine

There is a widely used expression for estimating the average power output of a wind turbine called the capacity factor C_f. It is represented by the ratio of the average power to the nominal power. The formula is given by the following relationship [31], [32]:

$$P_e = C_f.P_n \tag{III.35}$$

where the capacity factor C_f can be estimated based on the two Weibull parameters and the different operating speeds of a wind turbine (start-up, nominal and stop).
It is given by the following formula:

$$C_f = \left(\frac{e^{-(\frac{V_D}{c})^k} - e^{-(\frac{V_N}{c})^k}}{(\frac{V_N}{c})^k - (\frac{V_D}{c})^k} - e^{-(\frac{V_c}{c})^k}\right) \tag{III.36}$$

Thus, the average power output of a wind turbine can be written in the form:

$$P_e = \left(\frac{e^{-(\frac{V_D}{c})^k} - e^{-(\frac{V_N}{c})^k}}{(\frac{V_N}{c})^k - (\frac{V_D}{c})^k} - e^{-(\frac{V_c}{c})^k}\right).P_n \tag{III.37}$$

where

k and c are respectively the shape and scale parameters of the Weibull.

V_D : Wind turbine cut-in speed (m/s)

V_N : Wind turbine rated speed (m/s)

V_c : Wind turbine cut-out speed (m/s).

III.5.4 Extracted Wind Energy

Using the formula for estimating the average power output of a wind turbine P_e, the extracted wind energy can be calculated as a function of the number of hours in a period T using the following relationship [33]:

$$E_e = P_e.T \tag{III.38}$$

$$E_e = C_f.P_n.T \tag{III.39}$$

where:

T represent number of hours in a year $(T = 36524h = 8760h)$.

P_n Nominal power specific to the wind turbine.

III.6 Conclusion

A wind turbine is a device that transforms part of the kinetic energy of the wind (moving fluid) into mechanical energy available on a transmission shaft and then into electrical energy via a generator. In this chapter, we are mainly interested in the modeling of the small power wind turbine. An aerodynamic study of the turbine is presented, in

order to know its main operating parameters, namely the power coefficients, the torque, the BETZ limit, the capacity factor, the nominal power as well as the Estimation of the annual energy production of a small wind turbine with horizontal axis.

Chapter IV

Wind Turbine : Applications and Control

Large wind turbines are popular and are mostly responsible for the continued steady growth of wind technology in the past decade. These MW scale, grid connected turbines are installed in wind farms and in areas with high wind speeds. Small scale wind turbines on the other hand are different: they are mostly used for off-grid applications in remote areas. They also differ from large wind turbines in size, power rating, and types of generators and speed regulation used.

IV.1 Special Purpose Applications

Wind energy has historically been used for a wide range of special applications, ranging from grinding grain to sawing wood, and including many others as well. More recently, at least four special purpose applications have been used or investigated. These include: ***mechanical water pumping***, ***electric water pumping***, ***electricity generation.*** and ***hybrid system***.

IV.1.1 Mechanical water pumping

The wind energy can be used for pumping water and are particularly useful in remote locations where access to electrical utilities would be costly, different types of wind water pumps. Some are straight wind water pumps, while others are wind-electric pumps.

The farm windmill shown in Fig.(IV.1), is a mechanical system comprising of multi-bladed high solidity rotors (10 to 24 blades) connected to a positive displacement pump. The high number of blades is necessary to supply the high torque required by the pump for starting. A gearbox is often inserted between the turbine shaft and the crank shaft to achieve gear reduction and increase available torque. The turbine rotors have a peak efficiency of 10-15 percent at a tip speed ratio of around 1 while system average annual efficiency (wind to water pumped) is around 5 to 6 percent. Wind to pump efficiency is lower than turbine efficiency because the pump efficiency further reduces system performance [38]. They are commonly employed to:

• Pump groundwater for farm irrigation.

• Supply drinking water for the animals.

• provide water in remote or off-grid areas where electricity is unavailable.

IV.1.2 Electrical water pumping

Another type of wind powered water pumping is the use of electricity generating wind turbines to power an electric deep well pump. In this system Fig.(IV.2), the turbine is directly connected to a motor which is connected to a centrifugal pump. The advantages of the wind electric system over the mechanical system for water pumping application includes the following [14].

• It can be sited at a different location than the pump thereby providing the freedom to install the wind turbine at a windy site.

• Average annual system efficiency is double (12 to 15 percent) that of mechanical wind pumping system; therefore, wind electric systems can pump twice the amount of water from the same depth

• Larger sized wind electric systems can be used to implement a village water scheme or village irrigation scheme.

• It is a viable alternative solution to diesel powered generators in stand-alone high volume water pumping from deep wells.



Figure IV.1 : Mechanical wind pumping

.

IV.1.3 Electricity generation

Small wind turbines can be used to generate electricity to charge batteries, to power DC or AC loads and for grid connection. The electricity generated by small wind turbines can be used for either autonomous (off-grid) applications or grid connected applications as shown in Figures.(IV.3) and Figure.(IV.4) Off-grid systems are not connected to any larger generating system while grid-connected systems (distributed generation) are connected to a larger distribution (utility) network [16].

IV.1.4 Hybrid System

Small wind turbines can be combined with other generation sources such as photovoltaic systems or diesel generators Fig.(IV.5) and Fig.(IV.6). A hybrid system comprising wind and solar systems leads to a solution with increased availability due to the often complementary nature in the availability of wind and sun. In such a hybrid system, a diesel generator can also be included to supply back up power. Hybrid systems are traditionally used for village electrification but they are finding increasing importance in the



Figure IV.2 : Electric wind pumping

.

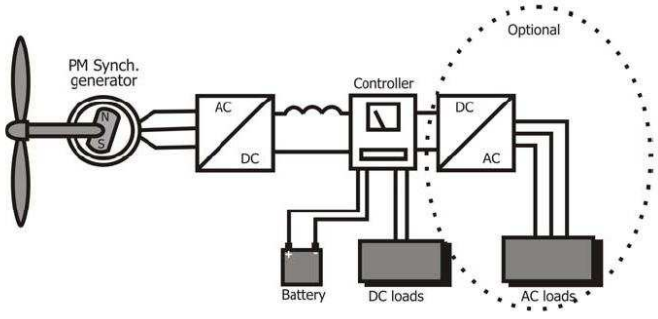


Figure IV.3 : Off-grid wind electricity generation

.

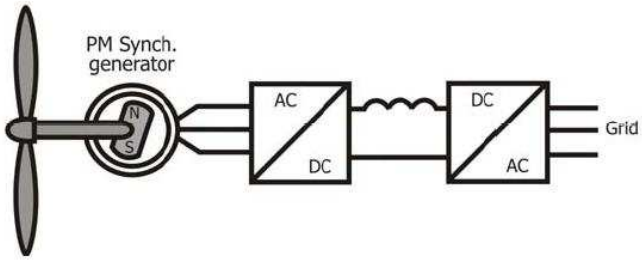


Figure IV.4 : Grid-connected wind electricity generation

.



Figure IV.5 : Hybrid wind-PV systems

.

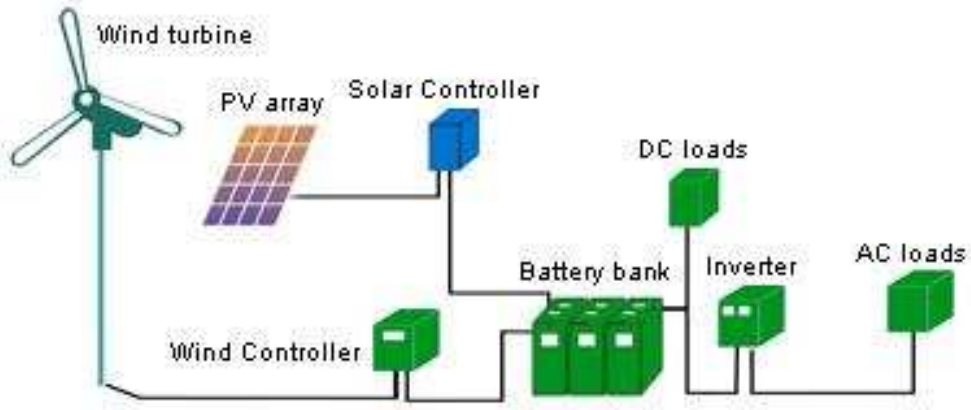


Figure IV.6 : Hybrid wind-PV systems

.

telecomm sector where they are used to power mobile phone base stations [34].

IV.1.5 Different applications of small turbine

Small wind turbines can be found among a broad range of users. In China and the USA, they are most commonly used for domestic energy supply, lighting, radio, TV, etc. In Europe, where the penetration of the utility grid is very high, there exists a market in the tourist industry, i.e. for use on boats, campers, etc. They also find application in telecommunication systems. A list of applications is given in Table1 [37].

• **Small wind turbine for Telecommunications**: the installation of solar panels and windmills:

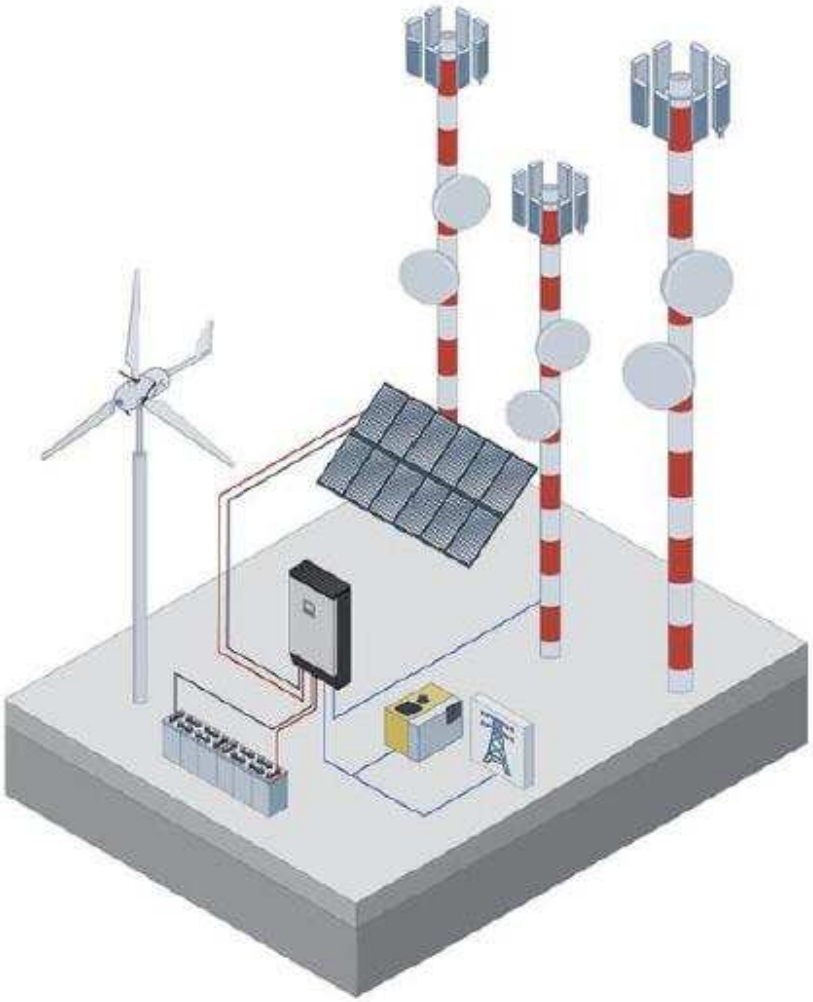


Figure IV.7 : Smal wind turbine for Telecommunications

.



Figure IV.8 : Smal wind turbine for Telecommunications

.



Figure IV.9 : Smal wind turbine for Telecommunications

.

Table IV.1 : List of Application of small wind turbines

Operation	Application
Domestic Power	Romote homes, farms offices, hospitals, Applications: TV, Radio, etc
Telecommunications	Rural radio systems, Small telephone systems
Agricultur2	Water pumping, Refregeration systems, Electric fencing
Navigation	Light or Radio beacons
Offshort platform	Cathodic protection
Village electrifications	Street light
Pleasure craft and boats	Power supply

For the wireless telecommunications it is necessary to place broadcast antennas in very remote places that are capable of transmitting the signals over great distances, so it is very common that these places are isolated.
If they are isolated and need electricity, the best option is to complement renewable energy sources . The installation of solar panels and windmills allows to generate energy in cycles of 24 hours , during the day , mainly with solar energy and night with wind power.
Combining solar and wind energy has many advantages, including the following:

1. Reduction of size of batteries
2. Increase the battery life
3. Reduce the number of solar panels
4. Divide dependency from a single power source (only the Sun or just the Wind
5. Reduce or eliminate diesel expense if it exists

- **Small wind turbine : Residential or residential areas**

Residential facilities or residential areas are mainly used to save on electricity bill costs in some of the network sales, self-consumption or net balance modes. These types of installations are very interesting not only because of the cost saving of their installation but also because of the reduction of CO2 emissions to the atmosphere.

- **Hospitality, rural tourism and leisure**



Figure IV.10 : Smal wind turbine : Residential or residential areas

.

Rural tourism, hiking, horseback riding, mountain biking, etc. are sports and leisure activities that are often located in places where the network is weak and sometimes require power to be able to supply the energy needs Typical of any public service establishment. For these cases, professional equipment is used to guarantee the electrical supply , which is usually in three-phase, commonly smart grid installations are made to the alternating bus.

If the characteristics of the location allows this type of facilities like the previous ones the ideal is always to use a combination of complementary energies, installing Solar and Wind Energy . However, it is essential for this type of installation, to carry out a correct study of resources, sizing and design of the installation so that the integration of technologies, generation by renewable sources and performance End of the installation fulfills its task perfectly.



Figure IV.11 : Smal wind turbine : Residential or residential areas

.



Figure IV.12 : Smal wind turbine : Residential or residential areas

.



Figure IV.13 : Smal wind turbine : rural tourism and leisure

.



Figure IV.14 : Smal wind turbine : rural tourism and leisure

.

IV.2 Wind Systems Control

The purpose of the control system of a wind turbine is to manage the safe, automatic operation of the turbine. This reduces operating costs, provides consistent dynamic response and improved product quality, and helps to ensure safety. This operation is usually designed to maximize annual energy capture from the wind while minimizing turbine loads.

Control systems may dynamically adjust blade pitch settings and generator torque to control power in high winds on variable-speed wind turbines.Without some form of control system, a wind turbine cannot successfully and safely produce power.

Wind turbine control systems vary significantly from turbine to turbine. The choice of control system components and configurations depends significantly on the specific wind turbine design [36].

IV.3 What does wind turbine control mean

Wind turbines are essentially flexible structures in stochastic wind and we expect them to produce maximum power as long as the wind speed is below the rated value, and regulate their outputs, namely the rotational speed of the rotor and the generated power, when the wind speed goes beyond rated value. Finally they should shut down when wind speed passes a certain value called cut-out wind speed [35].

The configuration of wind turbines determines their speed and power regulation capabilities. The nature of their electrical components and their grid connection determine whether the wind turbine is fixed-speed or variable-speed. As for the rotor, its nature determines the power regulation method: passive aerodynamic stall, active aerodynamic stall, and variable blade pitch.

Mainly there are two types of systems used in wind energy conversion system :

IV.3.1 Fixed-speed wind turbine

A fixed-speed wind turbine design means that its rotor always has the same operating angular speed, regardless of wind speed. This operating speed depends on the design of the turbine itself and the frequency of the electrical grid.

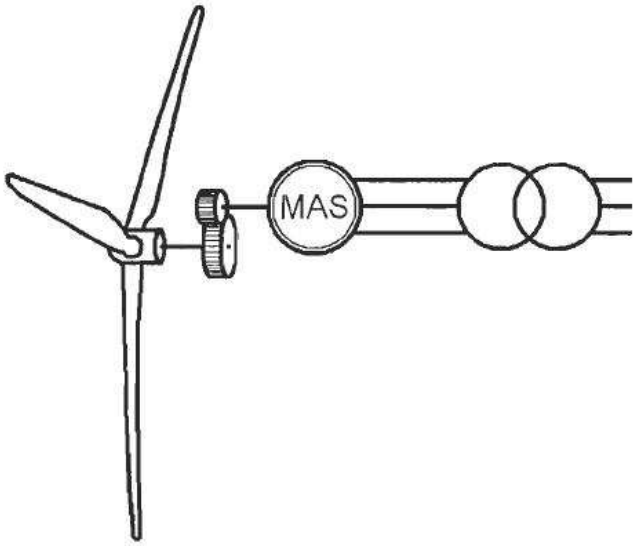


Figure IV.15 : Fixed speed wind turbine using a cage asynchronous generator

.

For this configuration, the stator of the asynchronous machine is connected directly to the network via a transformer (see Figure.IV.15). In addition, this configuration couples the wind turbine rotor to the rotor of the asynchronous machine via a gearbox [35]. Fixed-speed wind turbines do, however, have several advantages: simplicity, the use of inexpensive technology, and low maintenance requirements.

IV.3.2 Variable-speed wind turbine

Variable-speed wind turbines are currently the most widely used in industry. The term variable speed refers to the fact that the turbines speed is independent of the power grid frequency. The main advantage of operating a turbine at variable speed is to maximize the capture of available wind energy.

The generators used for this type of configuration are [35]:

• the cage asynchronous machine (Figure.IV.16) : In cage induction machines, the rotor of the machine is coupled to the rotor of the wind turbine via a gearbox.

• the synchronous machine with a high number of poles or not (Figure.IV.17): For synchronous machines with a high number of poles, the machine rotor is directly coupled to the turbine rotor. This is called a direct-drive transmission. The generator can have

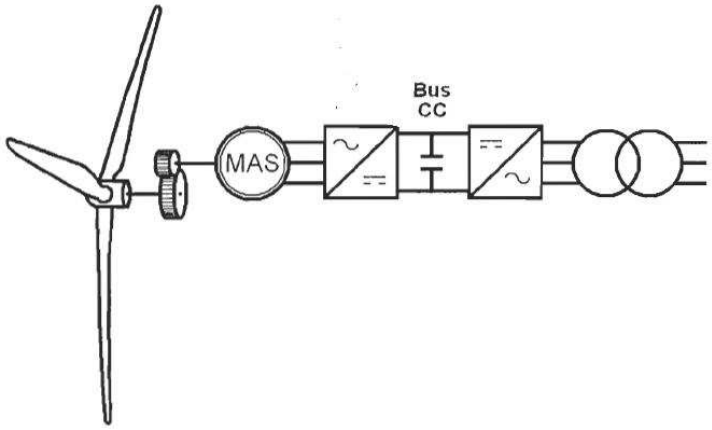


Figure IV.16 : Variable-speed wind turbine using a cage induction generator and a full-power converter

.

an external excitation circuit or be self-excited. This type of turbine is available from Enercon.

• the permanent magnet synchronous machine with a high number of poles (Figure.IV.18) : Conventional synchronous machines must consist of a gearbox between the machine rotor and the turbine rotor.

• Variable-speed wind turbine using a doubly-fed asynchronous generator: Variable-speed wind turbines with partial power converters are composed of doubly-fed induction generators (DFIGs) Fig.(IV.19) This configuration is also known as double-fed induction generators (DFIGs). This technology first emerged in the wind energy sector in the early 1990s with Vestas Wind Systems. It is now the most widely used technology for large-scale wind turbines [35].

IV.4 Maximum Power Point Tracking MPPT

Due to the nature of the wind that is instantaneously changing, hence, there is only one optimal generator speed is desirable at one time that ensures the maximum energy is harvested from the available wind. Therefore, it is essential to include a controller that is able to track the maximum peak regardless of any wind speed. The available maximum

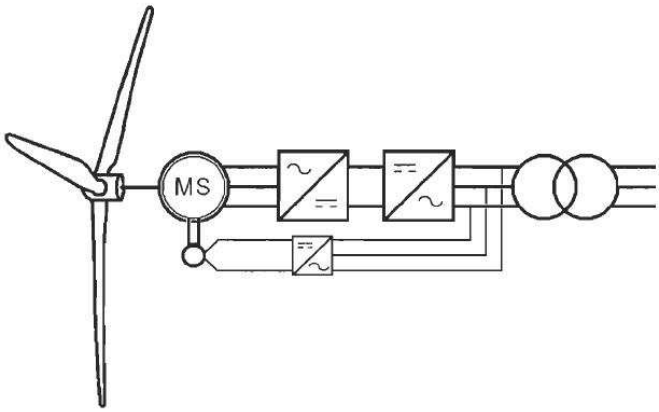


Figure IV.17 : Variable-speed wind turbine using a high-pole synchronous generator and a full-power converter

.

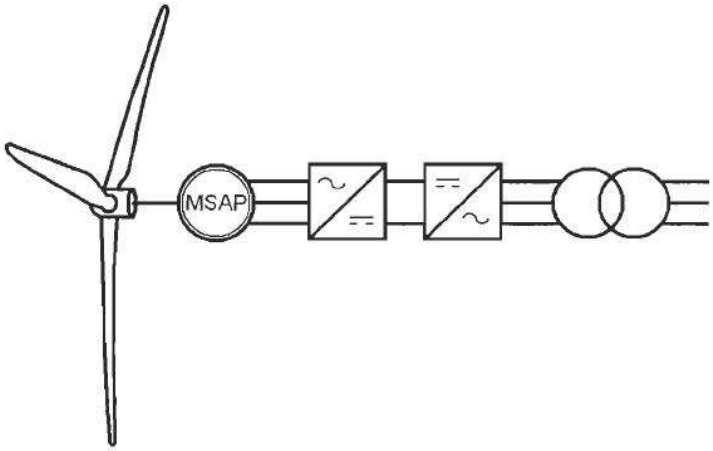


Figure IV.18 : Variable-speed wind turbine using a synchronous generator and a full-power converter

.

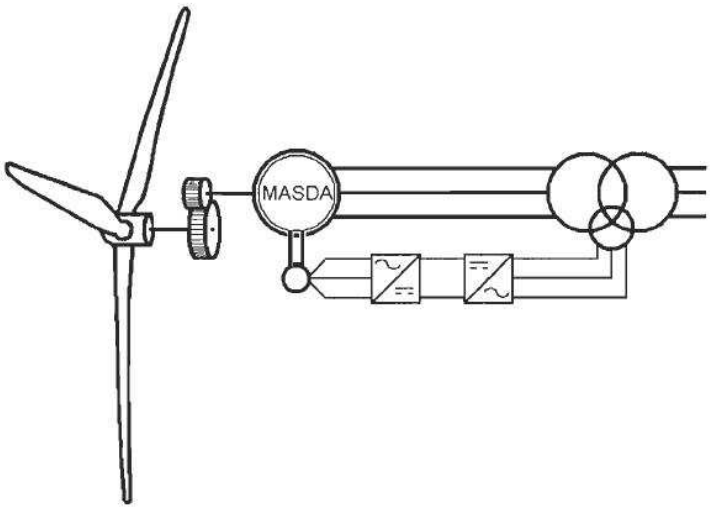


Figure IV.19 : Variable-speed wind turbine using a synchronous generator and a full-power converter

.

power point tracking (MPPT) algorithms can be classified according to the control variable, namely with and without sensor, and also the technique used to locate the maximum peak.

As shown in Fig.(IV.20), for each wind speed, there is only one rotor speed that allows the wind turbine to operate at the maximum power point. Unlike fixed-speed operation, which rarely allows wind turbines to operate at the optimum point, variable-speed operation allows us to regulate the rotation speed in such a way as to place the wind turbine at the optimum operating point.

IV.4.1 Operating regions

The characteristic of a variable-speed WT has four main operating zones, which can be distinguished in Fig.IV.21 Elaboration of this characteristic is necessary to identify the type of control required by each zone. In region I, the turbine cannot start because the wind speed is very low and insufficient (less than V_{cut-in}), and as a result, the rotational speed and the mechanical power are equal to zero. Once the wind speed exceeds the V_{cut-in} value and remains below a nominal speed V_n, we move to the second operating

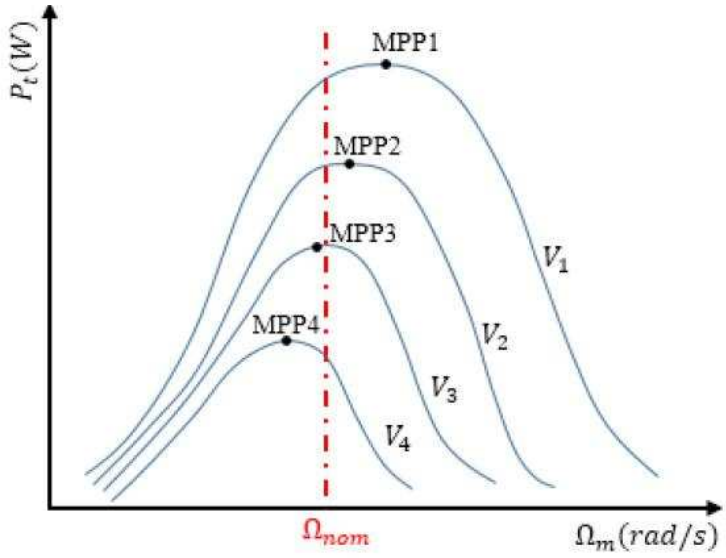


Figure IV.20 : Characteristics of turbine power as a function of the rotor speed for a series of wind speeds

.

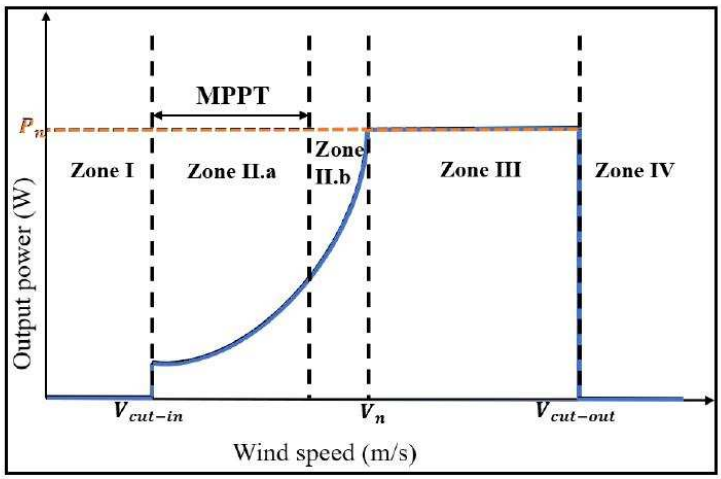


Figure IV.21 : Operating regions of a variable speed wind turbine

.

region, where the objective is to ensure the extraction of maximum power available to have optimal operation by acting on the electromagnetic torque until the wind reaches the nominal speed V_n corresponding to the nominal values of the mechanical power P_n and the nominal rotation speed w_n. This phenomenon is known as MPPT [17].

IV.4.2 Maximum power point tracking (MPPT) control strategy

Different algorithms and techniques for tracking the maximum power point of wind energy conversion systems (WECs) for different variable speeds. as illustrated in Fig.IV.25,

- **MPPT controls depend on turbine characteristics**:

- Algorithms do not require wind speed measurement like:

⋆ *Optimal Torque Control (OTC),*

⋆ *Power Signal Feedback control (PSF),...:*

- Algorithms require wind speed measurement or estimation like the :

⋆ *Tip Speed Ratio TSR method*

A. The Optimal Torque Control (OTC) Method:

The OTC method [39], [40] aims to force the wind turbine to operate at its maximum power point without measuring wind speed, by controlling only the torque on the turbine shaft, as illustrated in Fig.(VI.22). This technique, a priori, remains simple and easy to implement in practice, but it is linked to the characteristics of wind turbines. And since variations in wind speed are not directly taken into account, this technique remains slower than the TSR technique.

B. Power Signal Feedback control (PSF):

The "PSF" method is a control technique close to the "OTC" method, where the control of the torque on the turbine shaft is replaced by the control of the power transmitted to the load [41], as illustrated in Fig.(VI.23). The power setpoint is determined using a table previously constructed using readings taken for different wind speeds over the entire operating range intended for the wind turbine. This method does not require knowledge of the wind speed, but it requires a lot of testing on the turbine in order to fill the table with the necessary information on power and rotation speed, and when the turbine changes or ages, you have to study a new table [41].

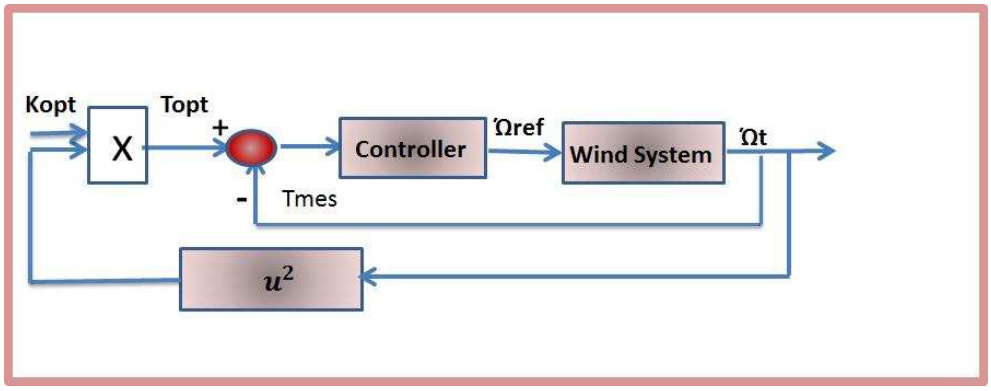


Figure IV.22 : OTC

.

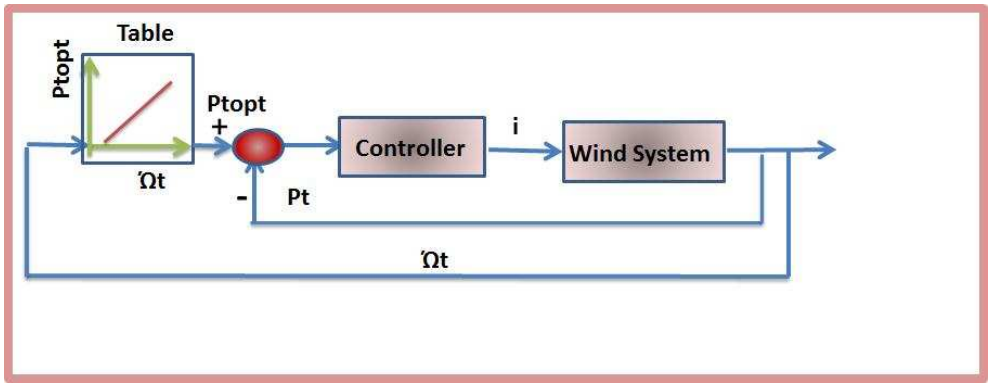


Figure IV.23 : PSF

.

C. The Tip Speed Ratio (TSR) Method:

The TSR method aims to operate wind turbines at their maximum power point by constantly monitoring the relative speed λ. This process requires measuring rotational speed, wind speed, and prior knowledge of the optimal relative speed value λ_{opt}, as illustrated in Fig.(VI.24). This seemingly simple control strategy requires the presence of an anemometer near the wind turbine, which is difficult to install in reality due to the frequently changing wind direction. Therefore, the use of this type of sensor increases the cost and complexity of the wind turbine system [21], [22].

• **MPPT controls do not depend on turbine characteristics** :

- Iterative search technique MPPT methods such as: Perturbed and Observed (P and O)

- Advanced control techniques: algorithms that involve the use of intelligent algorithms

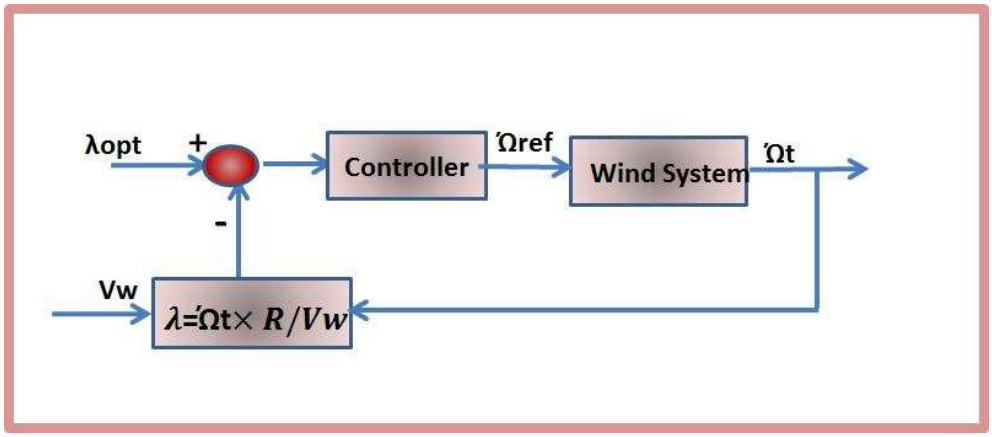


Figure IV.24 : TRS

.

like

: ⋆ neural networks (NN)

⋆ fuzzy logic controllers (FLC) [42].

- Hybrid algorithm using Smart algorithm.

IV.5 Conclusion

This chapter discusses the applications of small wind turbines for electricity production are primarily used as battery chargers on locations without electricity grid. Applications can be energy supply for houses (lighting, TV, refrigerator), offices, hospitals and farms (water delivery, electrical fencing). Other applications are telecommunication and navigation. The technology of small wind turbines differs on a number of aspects from the technology of large turbines and is discussed in this contribution. Small wind turbine systems typically operate in a stand-alone mode, sometimes in parallel with diesel sets or PV systems.

In addition to all this, we also cited the main categories of MPPT techniques used in wind turbines. to ensure the production of power at optimal levels.

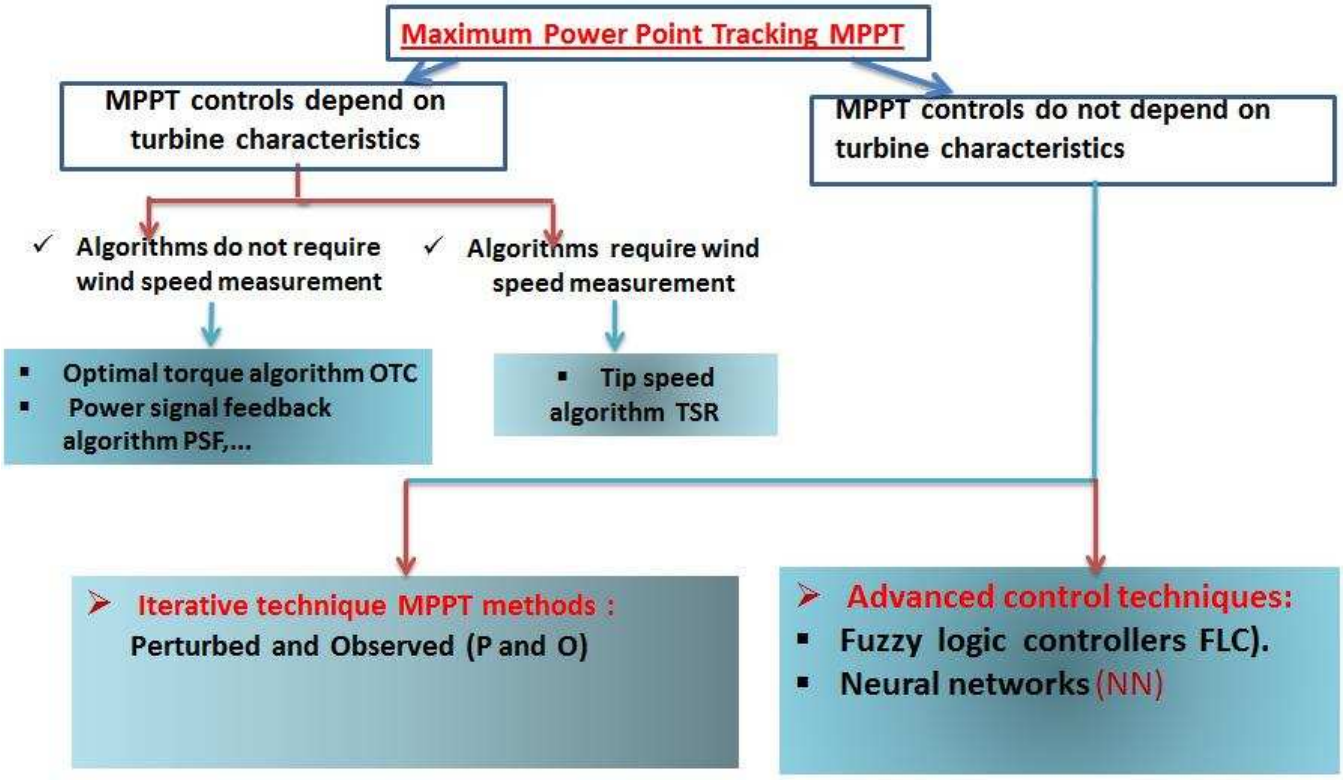


Figure IV.25 : Classification of different MPPT algorithms

.

Bibliography

[1] Meadows, D. H., Meadows, D. L., Randers, J. and Behrens III,W.W. (1972) The Limits to Growth. Universe Books, New York.

[2] Paraschivoiu, I. (2002) Wind Turbine Design: With Emphasis on Darrieus Concept. Polytechnic International Press, Montreal.

[3] McGowan, J. G. and Connors, S. R. (2000) Windpower: a turn of the century review. Annual Review of Energy and the Environment, 25, 147 − 197.

[4] N. Kasbadji-Merzouk, M. Merzouk and B. Benyoucef, Model of Vertical Wind Speed Extrapolation in a Semi-Arid Region, Proceeding du World Renewable Energy Congress-IX, Florence, Italie, 19-22 Août 2006.

[5] C.G. Justus and A.S. Mikhail, Height Variation of Wind speed and Wind Distributions StatisticsŠ, Geophysical Research Letters, Vol. 3, $N5$, 1976.

[6] A.S. Mikhail and C.G. Justus, Comparison of Height Extrapolation Models and Sensitivity AnalysisŠ, Wind Engineering, Vol. 5, Nř2, 1981.

[7] N. Kasbadji-Merzouk, M. Merzouk and B. Benyoucef, ŚModel of Vertical Wind Speed Extrapolation in a Semi-Arid RegionŠ, Proceeding du World Renewable Energy Congress-IX, Florence, Italie, 19-22 Août 2006.

[8] N. Kasbadji-Merzouk, Evaluation du Gisement Energétique Eolien. Contribution à la Détermination du Profil Vertical de la Vitesse du Vent en Algérie, Thèse de Doctorat en Physique Energétique et Matériaux, Université de Tlemcen, 2006.

[9] N. Kasbadji-Merzouk, Wind Energy Potential of Algeria, International Journal of Renewable Energy, Vol. 21, pp 553 - 562, 2000.

[10] Burton, T., Sharpe, D., Jenkins, N. and Bossanyi, E. (2001) Wind Energy Handbook. John Wiley Sons, Ltd, Chichester.

[11] Pedersen, T. F. et al. (2006) ACCUWIND Ű Accurate Wind Speed Measurements in Wind Energy: Summary Report. Risø National Laboratory Report: Risø-R-1563(EN).

[12] McGowan, J. F. Manwell et J. G, WIND ENERGY EXPLAINED Theory, Design and Application, Massachusetts, USA: WILEY, 2009.

[13] Wind Power Generation and Wind Turbine Design Par Wei Tong WIT Press, 30 avr. 2010

[14] B. D. Vick, B. A. Neal et R. N. Clark, PERFORMANCE OF A SMALL WIND POWERED WATER PUMPING SYSTEM, USDA-Agricultural Research Service, Bushland (Etats Unis), 2008.

[15] F. Nabah, A. Ettaouil, and N. Guennoun. Calcul du sillage d'un rotor éolien à axe horizontal calculation of wake of an horizontal axis wind rotor. Forum International sur les Energies Renouvelables (FIER), Tétouan-Maroc, 2002).

[16] G.A. Smith, K.A. Nigim, Wind-energy Recovery by a Static Scherbius Induction Generator", Proc. IEE, 1981, 128, pp. 317-324.

[17] K. Eftichios, K. Kostas, Design of a maximum power tracking system for windenergy- conversion applications, IEEE transaction on industrial electronics, vol. 53, no. 2, April 2006.

[18] K. Tan and S. Islam, Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors, IEEE Transaction on energy Conversion, vol. 19, no. 2, pp. 392-399, June 2004.

[19] . G. Abo-Khalil, D.C. Lee, MPPT Control of wind generation Systems based on estimated wind speed using SVR, IEEE Transaction on industrial electronics, vol. 55, no. 3, Mars 2008.

[20] D. Schreiber, State of art of variable speed wind turbines, 11th International symposium on power electronics, Oct.-Nov. 2001, CDROM proceedings.

[21] I. Yazici and E. K. Yaylaci, Improving efficiency of the tip speed ratio-MPPT method for wind energy systems by using an integral sliding mode voltage regulator, Journal of Energy Resources Technology, vol. 140, no. 5, 2018.

[22] K. Kumar, N. R. Babu, and K. R. Prabhu, Design and analysis of RBFN-based single MPPT controller for hybrid solar and wind energy system, IEEE Access, vol. 5, pp.15308-15317, 2017.

[23] M. A. Abdullah, A. H. M. Yatim, C. W. Tan and R.Saidur, A review of maximum power point tracking algorithms for wind energy systems, Renewable and Sustainable Energy Reviews, vol. 16, pp. $3220 - 3227, 2012$.

[24] Manwell JF, McGowan JG, Rogers AL. Wind energy explained: theory, design and application. Amherst, USA: John Wiley and Sons; 2002.

[25]]A.S. Ahmed, Wind energy as a potential generation source at Ras Benas, Egypt, Renewable and Sustainable Energy Reviews. $14, 2167 - 2173$. (2010)

[26] Z. Durisic, J. Mikulovic, A model for vertical wind speed data extrapolation for improving wind resource assessment using WAsP, Renewable Energy $41407 - 411$. (2012)

[27] Jamil M, Parsa S, Majidi M. Wind power statistics and an evaluation of wind energy density. Renewable Energy $6(5) : 623 - 628$. 1995

[28] Tchinda R, Kendjio J, Kaptouom E, Njomo D. Estimation of mean wind energy available in far north Cameroon. Energy Convers Manage $2000; 41 : 1917 - 1929$.

[29] Keyhani A, Ghasemi-Varnamkhasti M, Khanali M, Abbaszadeh R. An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. Energy $2010; 35(1) : 188 - 201$.

[30] M.R. Islam, R. Saidur, N.A. Rahim, Assessment of wind energy potentiality at Kudat and Labuan, Malaysia using Weibull distribution function, Energy 36 (2011) $985 - 992$

[31] Akpinar EK, Akpinar S. An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics. Energy Convers Manage 2005; 46 : 1848 − 1867.

[32] Ucar A, Balo F. Evaluation of wind energy potential and electricity generation at six locations in Turkey. Appl Energy 2009; 86 : 1864 − 1872.

[33] A.W. Dahmouni, M. Ben Salah, F. Askri, C. Kerkeni, S. Ben Nasrallah, Assessment of wind energy potential and optimal electricity generation in Borj-Cedria, Tunisia, Renewable and Sustainable Energy Reviews 15(2011)815 − 820.

[34] L. Stoyanov, Étude de différentes structures de systèmes hybrides à sources d'énergie renouvelables, Thèse de Doctorat, Université de Corse Pasquale Paoli (France) et l'Université Technique de Sofia (Bulgarie), 2011.

[35] Samuel Ofordile ANI, Low Cost Small Wind Turbine Generators for Developing Countries. Master of Engineering (Electrical Engineering), University of Nigeria, Nsukka geboren te Ikem, Nigeria.

[36] S. Heier, Grid Integration of Wind Energy Conversion Systems, 2nd ed, Chichester: Wiley, 2006.

[37] R. Ramakumev and W. C. Hughes, Renewable energy sources and rural development in developing countries, IEEE Trans. on Education vol. E42, no. 3, pp. 242 − 251, Aug. 1981.

[38] R.N. Clark, Comparison of two mechanical windmills for water pumping, in Proc. Windpower 95, Washington, DC, March 26030, 1995, pp.457 − 463.

[39] M. E. Haque, M. Negnevitsky and K. M. Muttaqi, A novel control strategy for a variable speed wind turbine with a permanent-magnet synchronous generator, IEEE Trans. Ind. Electron., vol. 46, no. 1, pp. 331 − 339, 2010.

[40] M. Yin, W. Li, C. Y. Chung, L. Zhou, Z. Chen and Y. Zou, Optimal torque control based on effective tracking range for maximum power point tracking of wind turbines under varying wind conditions, IET Renewable Power Generation, vol. 11, no. 4, pp. 501 − 510, 2017.

[41] C. Huang, F. Li and Z. Jin, ŞMaximum power point tracking strategy for large-scale wind generation systems considering wind turbine dynamics, IEEE Trans. Ind. Electron., vol. 62, pp. 2530 – 2539, 2015.

[42] R. M. Hilloowala and A. M. Sharaf, A rule-based fuzzy logic controller for a PWM inverter in a stand alone wind energy conversion scheme, IEEE Transactions on Industry Applications, vol. 32, no. 1, pp. 57 – 65, 1996.