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Recherche de zones éoliennes pour le développement et l'amélioration de l'efficacité énergétique éolienne

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Dedication

Every challenging work need self-efforts as well as guidance of elders especially those who were very close to our heart.

My humble effort I dedicate to my sweet and loving

Mather & Father

Whose affection, love, encouragement and prays of day and night make me able to get such success and honor,

Along with my brother, sisters, and my sister's children Mohammad, Roudyna, and Aroua, who brings joy and happiness to my life. All the hard-working and respected teachers.

Rafiq

Nomenclature

P_t	Mechanical power of the wind turbine (W)
A	Sweeping surface of the wind turbine blades(m^2)
R	Radius of the wind turbine blades (m)
C_p	Wind power coefficient (-)
λ	*Tip-Speed Ratio* TSR(–)
Ω	Wind turbine rotation speed (tr/mn)
v	Wind speed [m / s]
M	Transmission transmission ratio (-)
P_m	Generator electrical power (W)
e	Electromotive force of the generator (V)
u_s	Voltage across generator terminals (V)
i_s	Generator stator alternating current (A)
Ω_{G}	Generator rotation speed (tr/mn)
ω	Electric generator pulse (frequency) (rad/s)
ψ_r	Flux induced by the magnets of the generator (Wb)
p	Number of generator pole pairs (–)
Z_s	Generator impedance (Ω)
R_s	Resistance of generator stator winding (Ω)
L_s	Leakage inductance of the generator stator winding (H)
G	Gain coefficient of the function of C_p(–)
λ_0	maximum of the function ofduC_p(–)
a	Coefficient of the function of C_p(–)

Summary

Wind zone research for the development and improvement of wind energy efficiency.

Keyword:

Wind turbines, wind zone, wind speed, energy.

ملخص

أبحاث منطقة الرياح لتطوير وتحسين كفاءة طاقة الرياح.

الكلمة الرئيسية:

تور بينات الرياح ,منطقة الرياح ,سرعة الرياح والطاقة.

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General Introduction

The constant growth of energy consumption in all its forms and the associated polluting effects, mainly caused by the combustion of fossil fuels, are at the heart of the problem of sustainable development and care of the environment in a discussion for the future of the planet.

The electricity generation sector is the largest consumer of primary energy and two-thirds of its sources are fossil fuels. It is technically and economically capable of making significant efforts to reduce the effects of human activity on the climate and the environment. One possibility is to increase the rate of electricity production from non-fossil and renewable resources.

On the other hand, the process of liberalization of the electricity markets, which started a few years ago, allows the development of a new offer for the production of electricity. Some small producers cannot be connected to the electricity transmission network; the connection is then made directly to the distribution network. These particular behaviors have gradually developed and are now defined under the name of Decentralized Generation. The new situation created by this type of generation has made it one of the most studied subjects in the field of electrical power networks[1].

These findings indicate that renewable technologies have major advantages for developing their participation in the production of electricity and for intervening in the electric power market. Hydropower already has more than a century of development and its use is widespread worldwide. Today, the other sources of renewable generation, notably solar and wind, are the energies with the highest growth rate. Their development at the residential and industrial level is considerable, particularly in Europe and the United States. Wind energy systems represent the fastest growing technology. Among these wind technologies, many systems of different types have been designed and developed while extending experience in this field dating back several centuries.

Today, the most well-known and used form of wind technology is the wind generator; i.e. a machine that obtains energy from the wind to generate an electric current. The size of these modern wind turbines ranges from a few watts to several megawatts. The majority of current commercial systems are horizontal axis wind turbines (HAWT) with three-blade (three-blade) rotors. Turbines can transfer electrical energy to a power network through transformers, transmission lines and associated substations.

A large part of the current wind farm consists of systems connected to the public network. However, one of the areas where renewable technologies can develop in a substantial way is that of rural electrification or isolated sites. When conventional methods of supplying electricity such as extending the network and using diesel generators become too expensive or difficult to implement, renewable technologies, capable of generating electricity on site, are a very attractive possibility. , both technically and economically.

On the other hand, more and more individual (stand-alone) wind systems supply electricity to small communities. Due to the intermittent characteristic of wind, hybrid systems with diesel, photovoltaic and / or energy storage media are popular for remote areas. In the range of small wind turbines, the trend is to develop increasingly efficient controlled systems, using electronic switching conversion structures to widen the exploitable range of wind speeds.

In this context, this thesis works to present the best zone to install wind turbines in Algeria. So that we can benefit from this renewable energy. In this work, we chose threezones, compare the wind energy product form one-wind turbine, and chose the best zone from it.

In chapter 1 of this manuscript, we present the current wind turbine technology as a commonly used classification. The interest in implementing a gearbox for wind turbines is also demonstrated. The different types of electric generators present in wind turbines are exposed.

In the second chapter, a method without electronic control is presented and optimized, to provide the greatest amount of power possible. This results in an efficient system with very few components, which is another advantage for remote locations

The last chapter presents an improvement in the calculation of losses of static power converters for an application to a renewable hybrid energy system[2].

I.1 Introduction

Wind is a renewable source of energy, economical, exploitable with a good level of safety and respect for the environment. Around the world, wind energy resources are virtually limitless.

This chapter presents the current wind turbine technology as a commonly used classification. The interest of implementing a gearbox for wind turbines also demonstrated. The different types of electric generators present in wind turbines are exposed.

I.2 Wind

The wind resource comes from the wind, which is due indirectly to the sunshine of the Earth: a pressure difference is created between certain regions of the planet, depending on local warming or cooling, thus putting air masses in motion. Exploited since antiquity and long neglected, this energy knowssince about 30 years an unprecedented boom especially due to the first oil shocks. On a global scale, wind energy has been growing at a rate of 30% per year for the past decade. Europe, mainly under German, Scandinavian and Spanish impetus, had about 15,000 MW of installed capacity in 2000. This figure almost doubled in 2003, ie about 27,000 MW for 40000 MW of installed capacity worldwide. Forecasts for 2010 report wind power installed in Europe of around 70000 MW [1].

I.3 Classification of Wind Turbines

After its first use in ancient Persia, the technology that allows you to take advantage of wind energy has evolved into various forms and types of machines. The basic structure of wind turbines today consists of a rotor to capture wind energy by transforming it into rotational energy, a gear system to increase the rotational speed of the rotor, an electric machine to convert the wind. Mechanical energy in electricity. A schematic diagram is given in Figure I.1. There are different ways of classifying wind turbines, but these belong mainly to two groups according to the orientation of their axis of rotation: those with a horizontal axis and those with a vertical axis [1].

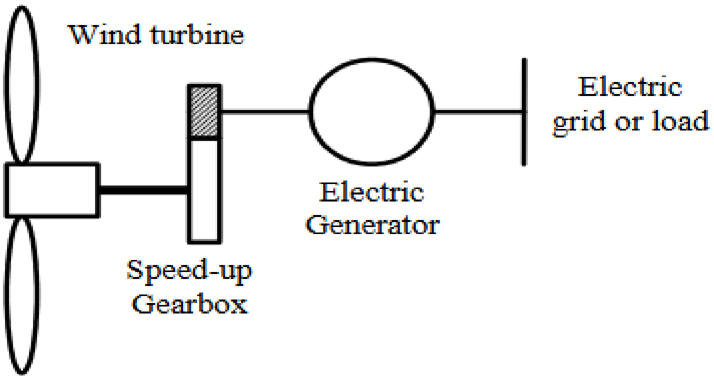


Figure I.1: Wind system diagram[1].

I.3.1 Horizontal Axis Wind Turbines (HAWT)

A turbine with a horizontal axis of rotation remains facing the wind, like the propellers of planes and windmills. It is attached to the top of a tower, which allows it to capture a larger amount of wind power. Most wind turbines installed are horizontal. This choice has several advantages, such as the low cut-in speed and a relatively high power ratio (ratio between the power obtained and the power of the moving air mass) . However, the gearbox and the electrical machine must be installed at the top of the tower, which poses mechanical and economic problems. Moreover, the automatic orientation of the windward propeller requires an additional organ ("tail", "yaw control" ...)[2].

Depending on its number of blades, an HAWT is called single-blade, two-blade, three-blade or multi-blade. A single-blade wind turbine is less expensive because the materials are smaller and, moreover, aerodynamic losses by push (drag) are minimal. However, a counterweight is needed and this type of wind turbine is not widely used because of this. Like single-blade rotors, two-bladed rotors must be equipped with a tilting rotor to prevent the wind turbine from receiving too strong shocks each time a rotor blade passes the tower . So, virtually all wind turbines installed or to be installed soon are of the three-bladed type. These are more stable because the aerodynamic load is relatively uniform and they have the highest power factor currently .

Depending on their wind direction, HAWTs are called upstream or downstream. Figure I.2 shows the two types mentioned. The first have the rotor facing the wind; since the flow of air reaches the rotor without obstacle, the problem of "tower shadow" is much less. Nevertheless, an orientation mechanism is essential to keep the rotor permanently facing the wind. Downstream rotor turbines do not need this steering mechanism but the rotor is placedon the other side of the tower: there can be an uneven load on the blades as they pass through the shadow of the tower. Tower. Of these two types of wind turbines, the upstream one is largely predominant[3].

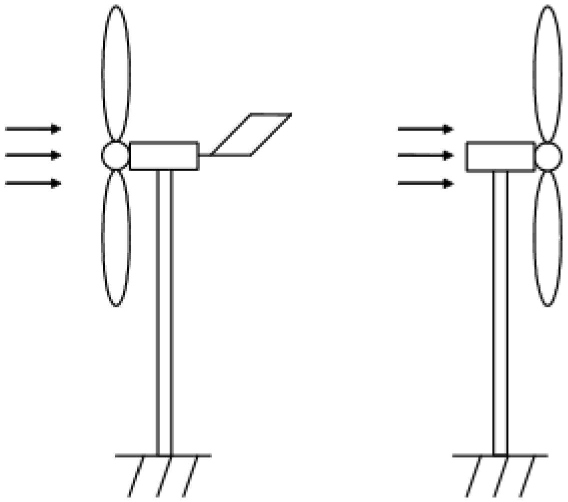


Figure I.2:Wind turbines upstream and downstream[3].

I.3.2 Vertical Wind Turbines (VAWT)

The axis of rotation of a VAWT is vertical to the ground and perpendicular to the direction of the wind. This type of turbine can receive wind from any direction, making any orientation device useless. The generator and the gearbox are located at ground level, which is simpler and therefore economical . System maintenance is also simplified as it is on the ground. These turbines do not have blade angle control like some HAWTs.

A disadvantage for some VAWTs is to require an auxiliary start device. Other VAWTs use thrust (drag) rather than aerodynamic lift (lift, an effect that allows an aircraft to fly), which results in a reduction in the power factor and a lower efficiency. The majority of VAWTs rotate at low speed, which is very disadvantageous in power generation applications with connection to the public network (50 or 60 Hz) because the gearbox must allow a significant reduction in power. The low aerodynamic efficiency and the reduced amount of wind they receive at ground level are the main handicaps of VAWT against HAWT[2].

I.4 The types of wind turbines

We have 2 different types of wind turbines

I.4.1 Earth Wind Turbines

The onshore wind turbines (Figure I.3) allow the production of electrical energy from the kinetic energy of the wind [4].

Figure I.3: Photograph of wind turbine fields[4].

This transformation of energy takes place in different stages [5]:

- The kinetic energy of the wind causes a rotation of the rotor of the three blades thus transforming the kinetic energy into mechanical energy.
- A multiplier is present on most wind turbines which accelerates the movement of the rotor to provide sufficient mechanical energy to the generator.
- The generator transforms the mechanical energy into electrical energy at about 690 V.
- The electricity produced is sent to a transformer increasing the voltage up to 20 000 V and distributed on the network.

The composition of the nacelle of the wind turbine is presented in Figure I.4.

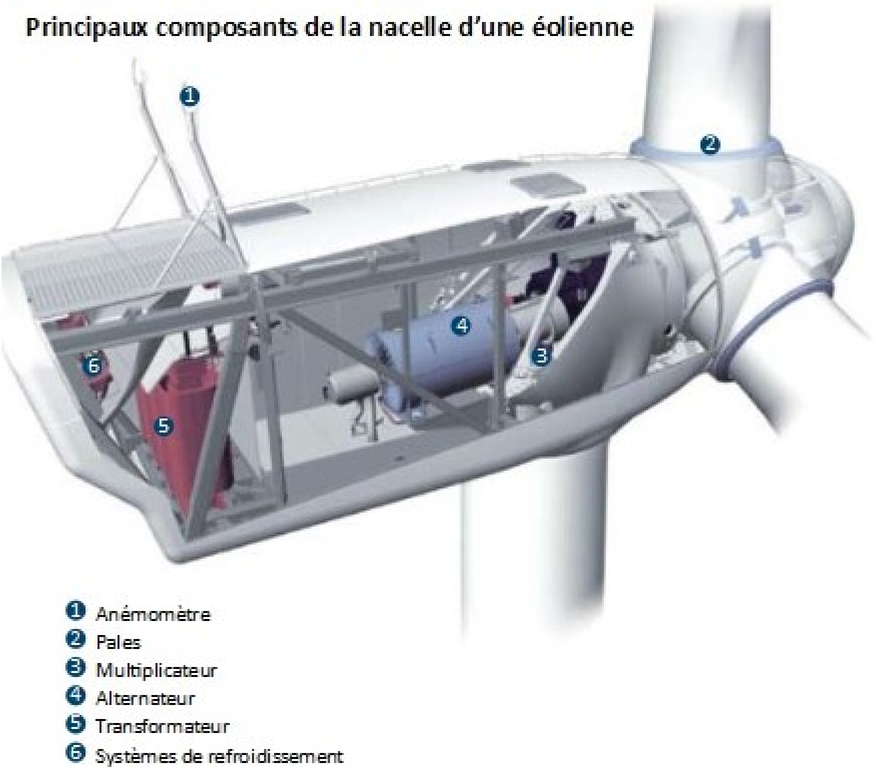


Figure I.4: Composition of the nacelle of a wind turbine [5].

The energy production of a wind turbine depends on many parameters: the length of the blades, the density of the air but especially the speed of the wind. Each wind turbine has power depending on the wind speed (Figure I.5). These are stopped for safety reasons if the speed is too high and do not work if the speed is too low.

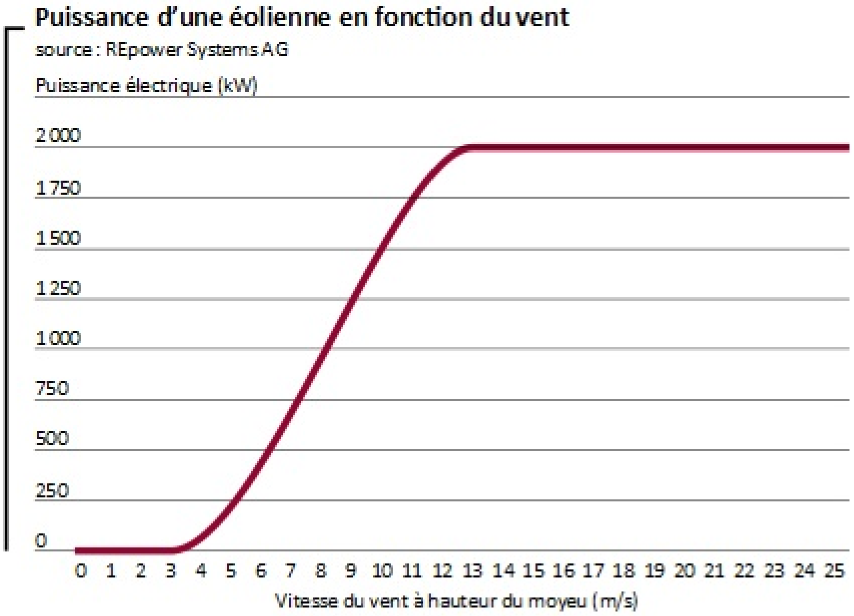


Figure I.5: Evolution of the power of a standard wind turbine according to the wind speed [5].

- Gearbox

The main shaft drives the multiplier, which by a complex system of gears will transform the slow and powerful movement of the main axis into a very fast movement but of weaker force.

The principle is identical to that of a bicycle equipped with pinion and chainring. When you put a large chainring for a small pinion, the force exerted on the pedals directly connected to the chainring will have to be very powerful the movement will there fore be quite slow, however, the movement transmitted through the chain to the gear of sprockets will be much faster but less strong[6].

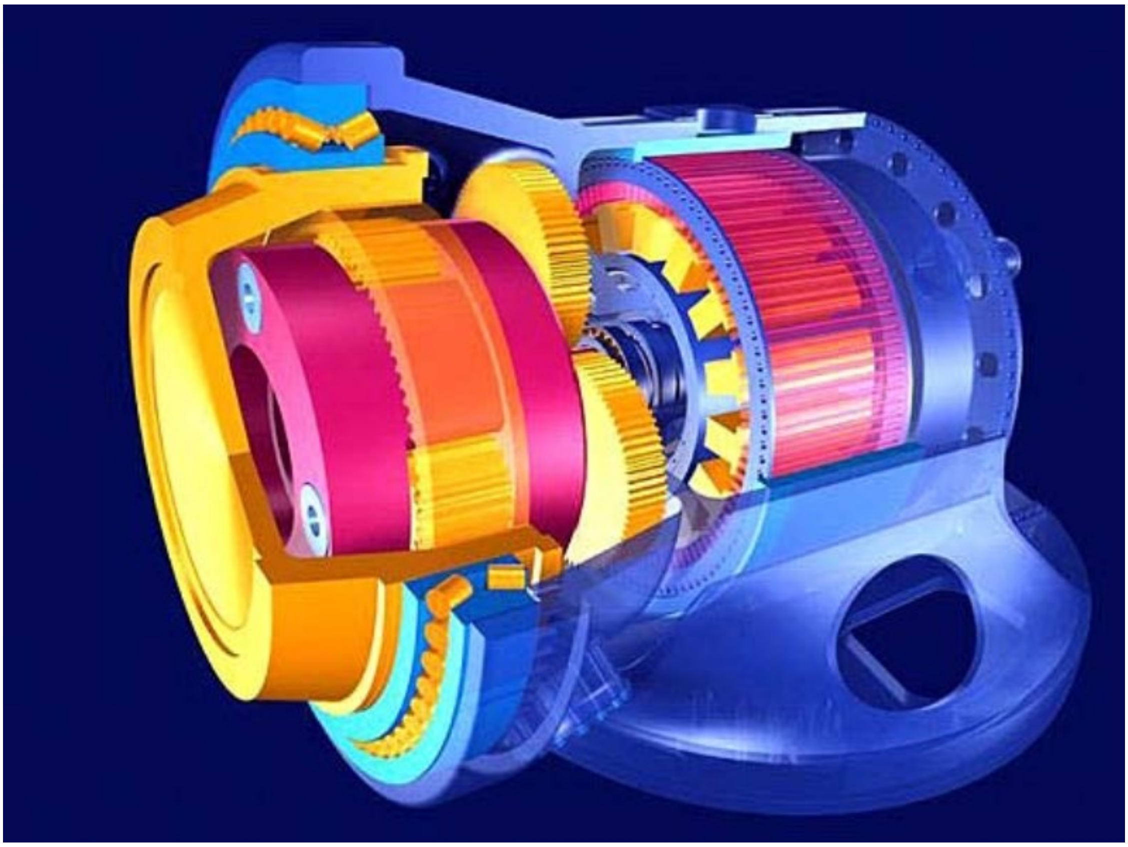


Figure I.6: Rotor bearing, gearbox and generator assembly of M5000 wind turbine[6].

I.4.2 Wind turbines atsea

There are different technologies for this type of wind turbines and each technology have its characteristic.

I.4.2.1 The installed windturbines

The wind turbines, whose first models have been in service in Denmark since 1991, operate more or less on the same general principle as the onshore wind turbines, and the main components remain relatively close to those used on land, but must be adapted to the marine environment. . Theirfoundations, theyfundamentallydiffer [7].

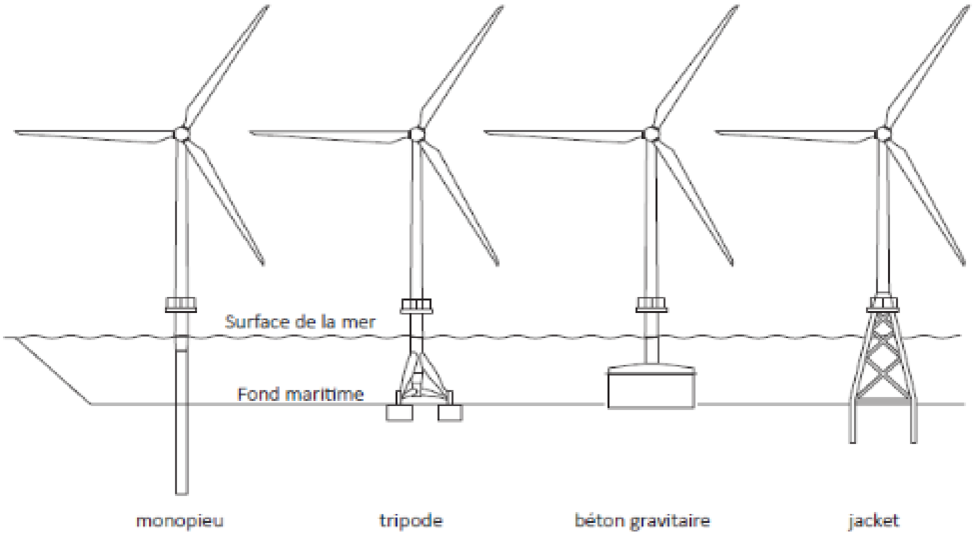


Figure I.7: Different types of laid wind turbine foundations[7].

Several types of foundations can be considered, depending on the water depth (bathymetry), as well as the characteristics of the seabed. They can be steel, concrete, or mixed. The steel foundation is fixed by a ("monopoly" foundation) or several (foundation "tripod" or "jacket") pieuxancrés in the marine soil (monopieu) .. The foundation in concrete, called "gravitaire", is simply put on the seabed .Joint foundation projects; wire mesh on gravity base appear. Thanks to this range of available solutions, and to the progress made in recent years, it is now possible to envisage settlements up to water heights of 50 m.

I.4.2.2 The floatingwind turbines

The use of floating foundations allows to significantly extend the potential of offshore wind, with the establishment of parks at heights greater than 50 meters, the current technical-economic limit of the offshore wind turbine installed, and up to water depths of 200 meters.Il will allow to exploit areas with a good wind farm today inaccessible to the technologies installed.

Several concepts of floating foundations are currently being studied. These include:

I.4.2.2.1 Platform with Tensioned Leg Platform (TLP)

Stability is achieved through a float held under the surface of the water by lines that pull it to the bottom. The vertical anchor lines must withstand significant stresses due to the pre-tension of the lines, to which are added the drifting forces.

I.4.2.2.2 The buoy type "SPAR"(buoy-pencil)

Balance is ensured by the weight of the float immersed on a great height. This concept can only be considered if the depth of water is sufficient, more than 100 meters in general.

I.4.2.2.3 The semi-submersible platform with catenary anchorage (Free Floating Platform or FFP)

The float is stabilized by its shape which has submerged volumes. Anchor lines must only withstand drifting forces.

The wind turbines used for the first floating wind turbine projects, although adapted because they are subject to particular constraints, in particular because of the effect of the swell and the current on the floating foundation, which have repercussions on the rest of the structure. Apparent machines used for wind turbines: horizontal axis, three-blade rotor, facing the wind ... Innovative technologies specifically adapted to the field of floating are also under development: two-bladed rotor, turbines with vertical axis lowering the center of gravity for example.

I.5 Applications of Wind Turbines

Unlike past centuries, it is no longer necessary to install wind systems precisely at the point of use of energy. Wind systems are now used to generate electrical energy that is transferred by an electric grid over a greater or lesser distance to users.

Stand-alone wind generation systems that provide electricity to small communities are quite common. The intermittent characteristic of wind is at the origin of hybrid systems with diesel and / or photovoltaic support for use in isolated locations. To increase power, wind turbines can be grouped into wind farms and transferred energy to the public grid through their own transformers, transmission lines and substations. Wind farms tend to move to offshore sites to capture more wind energy.

I.5.1 Isolated Power Systems and Wind Energy Utilization

Isolated power systems powered by wind power and other emerging forms of renewable energy are now technically reliable options. These systems are frequently perceived as more appropriate for local power supply in developing countries. Technological progress provides them with significant potential as distributed generation elements for large power grids in developed countries.

Significant efforts have been made to implement wind energy in local and regional power systems through the integration of small and medium-sized distribution systems . Many works have been published and there is abundant literature on the subject. Studies and development of wind energy systems for isolated customers are nonetheless mostly done on a case-by-case basis and it is difficult to generalize the results from one project to another. In the field of rural electrification, there are normally two methods of supplying electrical energy[8] :

a) Extension of the power network.

B) Use of diesel generators.

For remote locations these two solutions may be excessively expensive. The introduction of renewable technologies can help reduce energy supply costs for these isolated sites by reducing operating costs. Renewable technologies, other than biomass, are dependent on a non-fatal source (dispatchable); the combination of a low-cost renewable technology with a more expensive non-fatal technology is therefore an interesting option. Power systems that use multiple generation sources are called "hybrid power systems." To provide electricity to a remote community, these systems integrate different components: generation, storage, power conditioning and control systems.

Conventional hybrid systems consist of a DC bus for the battery bank and another AC power for the generator and distribution. However, recent advances in the fields of power electronics and control systems are reducing costs with a single AC bus structure. Renewable sources can be connected to the AC bus or DC bus, depending on the size and configuration of the system. Energy-producing systems for multiple homes and / or points of consumption usually provide AC power; some charges may still connect to the DC bus. This type of system can produce a few kilowatt hours (kWh) up to several megawatt hours (MWh) per day. Systems that feed small loads, of the order of a few kWh / day, preferably use the DC bus only. For larger loads, the systems instead use the AC bus as the primary point of connection. The tendency is then that each source has its converter with its own integrated control, which allows a coordination of the production. Large differences exist between the different possible configurations.

- *Wind Penetration Rate*

The amount of energy recovered from renewable source technologies in isolated power systems influences the structure, performance and economy of the system. The wind penetration rate connects the power produced by wind generation means and the total power of the power system.

The Instant Penetration Report (Pwind / Pload) is a technical measure that determines the structure, components, and control principles to be used for the system.The average penetration ratio (Ewind / Eload) is an economic-type measure that determines the energy cost of the system and indicates the percentage of generation that will be produced by the renewable source. Determining the optimum level of average wind penetration depends on the difference between the cost of installing wind power and the savings associated with replacing fuel with renewable energy.

I.5.1.1 HybridSystemswith Wind Technology

In systems using a DC bus, the battery group acts as a power reservoir that can dampen load flow fluctuations in the very short term and in the long term. The regulation is carried out autonomously, according to some specific parameters of the battery.

For AC systems, the goal is to achieve a balance of energy output, adjusting voltage and frequency. To obtain a voltage at a stable amplitude and frequency, various methods are used, such as synchronous capacitors, controllable battery banks, storage mechanisms, electronic power converters and control systems.

In some cases, small wind turbines up to 20 kW are directly connected to the load devices. The most common examples are for pumping water, but other applications such as ice making, battery charging and air compression are taken into account.

I.5.1.2 Hybrid Wind-Diesel Systems

In high-power insulated systems that combine wind turbines and diesel generators, the distribution is made in AC. This generation system association is named wind-diesel. These systems produce energy with one or more wind sources to reduce fuel consumption while maintaining acceptable energy quality. To be economically justified, the investment in equipment needed to take advantage of wind energy must recover through savings on fuel. Because of the large number of isolated mini-grids whose primary energy is oil, in developed countries or in developing countries, the market for readapting these systems to hybrid systems with low-cost renewable sources, like wind, is substantial.

One of the challenges presented by the incorporation of wind energy into diesel plants is the difficulty of regulating the voltage and frequency of the system, as the production of wind turbines is related to the random wind conditions. The problems of voltage and frequency stability increase with the relative amount of wind generation relative to the total power of the system. This illustrates how the wind penetration rate in the power system can strongly influence the design of the system and its components.

I.5.2 Aeolian Systems Connected to Large Networks

More than 95% of global wind energy capacity connected to large power grids. This is due to the many advantages of the operation of wind farms on the networks [5]:

a) The power of wind turbines need not necessarily be controlled according to the instant demand of a specific customer,
b) The lack of power delivered by wind turbines is offset by conventional power plants,
c) The grid frequency also maintained by the other plants and can be used to control the speed of wind turbines.

Thus, the operation of wind turbines connected to the networks is technically less complex than its individual isolated application.

I.5.2.1 DistributedSystems

The operation of one or a few wind turbines by private or industrial customers is the first field of application of wind turbines that has reached a commercial status. Firstly in Denmark, where legislation, subsidies for generation from renewable sources - mainly wind - and technical experience in the construction and operation of wind turbines made this development possible from 1978 onwards. , the significant progress of wind turbines in Germany is also due to laws that encourage the production of energy by renewable means [5].

The distributed installation of wind turbines is made almost exclusively in connection with the power grid of the electric companies. The consumption of the customer is recordedby a normal meter and the power produced by the wind turbine is injected into the public network and counted through another meter. Billing is done separately, depending on energy consumption and production.

I.5.2.2 AeolianParks

Even taking into account the largest current wind turbines, with a nominal power of a few megawatts, the power delivered by a single turbine remains a small amount compared to that of a conventional power plant. On the other hand, in most countries, areas with technically usable wind speeds are restricted to only a few regions. This creates the need to assemble as many wind turbines as possible, regardless of local energy demand. In this way, parks or wind farms, consisting of a concentration of many wind turbines in spatially organized and interconnected groups, appear. This group offers many technical advantages. In addition, from an economic point of view, it is more interesting in terms of cost of installation and connection to the grid, because long lines of interconnection to the network are justified only for a relatively large number of wind turbines.

- *Marine Parks (Off-Shore)*

It is expected that over the next decade, a 25% relative share of the new generation capacity will be wind-generated . However, it is difficult to find places to install large wind farms in developed regions. The development of off-shore wind systems avoids conflicts over land sites. This solution also has the advantage of counting with more consistent and less turbulent winds, which leads to greater production with lower peak mechanical forces in the turbines. Advances in technology make this option more and more interesting. The current conditions required for the installation of a wind farm are, according to Chen and Blaabjerg (2006) [9]:

a) Moderate wave height,

b) Shallow water,

c) An average wind of some 7 m / s.

I.6 Conclusion

In this chapter, the economic and environmental characteristics of the most commonly used forms of renewable energy and current wind technology have been shown. The different types of electric generators used in wind turbines and the main applications of wind turbines, with a segment specifically dedicated to isolated systems, were also presented.

II.1 Introduction

The most common application of small individual wind systems is to install them in isolated places or in places where the public electricity network does not arrive (Mathew, 2006; Hau, 2006) due to an extension of the network too expensive and for which the development of diesel systems is not justified economically and / or environmentally

In this chapter, a system without electronic control is presented and optimized, to provide the greatest amount of power possible. This results in an efficient system with very few components, which is another advantage for remote locations.

II.2 Wind Generation System Without Electronic Control

When using wind generation systems, the simplicity of the production system reduces maintenance costs and increases reliability. The system studied here is composed of a small wind turbine with a horizontal axis, a single-stage gearbox, a synchronous generator with permanent magnets, a bridge of diodes and a group of batteries.

Generally, structures operating at variable speed and controlled electronically allow to maximize the amount of energy produced by wind energy conversion systems (WECS, de Wind Energy Conversion System). These systems are complex, expensive and require additional electrical conversion stages associated with particularly suitable control structures.

In this part, the design of a simple wind conversion system based on the use of a minimum number of components is optimized. This system will be used for individual applications. From the system model, the equations of the mechanical power and the electric power of the generator are obtained. These expressions are dependent on the various parameters and variables of the generation system. The electric power delivered to the load is dependent on the rotation speed of the system in steady-state. In this fixed DC voltage system, the speed of rotation for each wind speed depends on a few system design parameters such as the gearbox transformation ratio and the battery terminal voltage. The objective here is to maximize the power obtained from the proposed system. The problem is solved by finding the optimal combination of gearbox ratio and battery voltage.

The static model of the system is described in the first part. The optimization problem is then presented and the resolution method exposed. The results are summarized and discussed at the end of this section [2].

II.3 System Model

The system studied is presented in Figure II.1. It is composed of a wind turbine with three-bladed horizontal axis which takes the energy of the moving air mass, an elevating gearbox which adapts the rotational speeds of the wind turbine and the generator, a synchronous permanent magnet machine for electromechanical conversion, a diode bridge for AC / DC electrical conversion and a group of batteries for energy storage. The load is assumed to consume all of the energy produced.

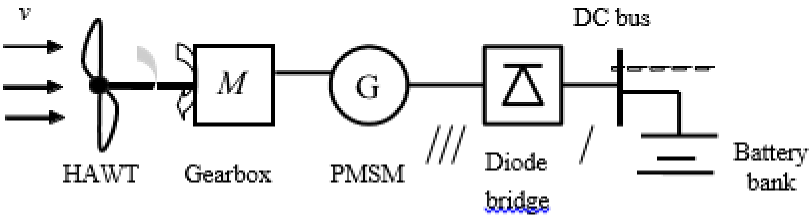


Figure II.1. Individual wind system with energy storage[2].

II.3.1 Mechanical_System

The mechanical power P_t that a wind turbine can extract from a mass of air crossing the surface swept by its rotor is[1]:

$$p_t = \frac{1}{2}\rho . A . C_p(\lambda) . v^3 \qquad (2.1)$$

P_t	Mechanical power of the wind turbine (W)
C_p	Wind power coefficient (-)
λ	*Tip-Speed Ratio* TSR(–)
ρ	Is the air density (Kg/m^3)$v$is the wind speed
A	is the area swept by the rotor of the wind turbine (m^2),

ρ is the air density (Kg/m^3), A is the area swept by the rotor of the wind turbine (m^2), v is the wind speed and C_p is the power coefficient of the turbine. The latter depends on the speed ratio λ (or TSR, tip speed ratio) (Mathew, 2006; Hau, 2006), and it is characterized by the properties of the wind turbine (horizontal or vertical axis, number and shape of the blades, etc.

$$TER = \lambda = \frac{\Omega R}{v} \qquad (2.2)$$

The nonlinear characteristic of the power coefficient $C_p$can be approximated either by a polynomial function (Borowy and Salameh, 1997), or by a rational function (Kariniotakis and Stravrakakis, 1995). The rational form proposed in equation (2.3) has the advantage of explicitly showing information such as the maximum TSR for a positive C_p, λ0 and the approximate value of the optimal TSR for maximum $C_p\lambda$ * ≈ (λ0 -at). A simple least squares regression can be used to adjust the coefficients *G and a*. (See Annex C).

$$C_p(\lambda) = \frac{G * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2} \qquad (2.3)$$

G Gain coefficient of the function of C_p(–)
a Coefficient of the function of C_p(–)

To adapt the relatively slow rotation speed of the wind turbine to that of the generator, a gearbox (gearbox) can be used. For reasons of simplicity, equation (2.4) is used as a model of this mechanical transmission system in which M represents the transformation ratio (or transmission) of the gearbox, Ω is the speed of rotation of the slow shaft of the wind turbine and Ω_G that of the electric machine (fast shaft).

$$\Omega_G = \mathrm{M}.\Omega \qquad (2.4)$$

Ω_G Generator rotation speed (tr/mn)
M Transmission transmission ratio (-)

The speed of rotation of the generator shaft and the speed of the electromagnetic fieldω (frequency or electrical pulsation) are linked by a relation involving the number of pairs of poles of the machine *p* ($\omega = p \cdot \Omega_G$). The mechanical power of the wind turbine can then be expressed as a function of the transmission ratio *M*, of the electrical pulsation ω and of the wind speed *v*:

$$P_t = \frac{\rho A\, R\, G}{2} \cdot \frac{\omega(\lambda_0\, p\, M\, v - R\, \omega)}{(a\, p\, M\, v)^2 + (\lambda_0\, p\, M\, v - R\, \omega)^2} \cdot v^3 \qquad (2.5)$$

R Radius of the wind turbine blades (m)
ω Electric generator pulse (frequency) (rad/s)

If we want to involve the turbine's rotation speedΩ, (2.5) also allows us to write the following relation:

$$P_t = \frac{\rho A\, R\, G}{2} \cdot \frac{\Omega(\lambda_0\, v - R\,\Omega)}{(a\ \ v)^2 + (\lambda_0\, v - R\,\Omega)^2} \cdot v^3 \qquad (2.6)$$

- **Monthly data for the area of Biskra:**

Table II.1. The average wind speed in m/s of Biskra.

January	February	March	April	May	June	July	August	September	October	November	December
5.6	4.9	2.9	6	5.2	2.9	3	3	3.8	4	3.8	5.4
4.8	3.4	4.7	5.9	5.2	3	2.8	3.5	3.3	2.9	3.4	4.2
4.6	3.9	4.2	5.3	3.7	4	3.5	3.4	3.5	2.1	3.7	3.1

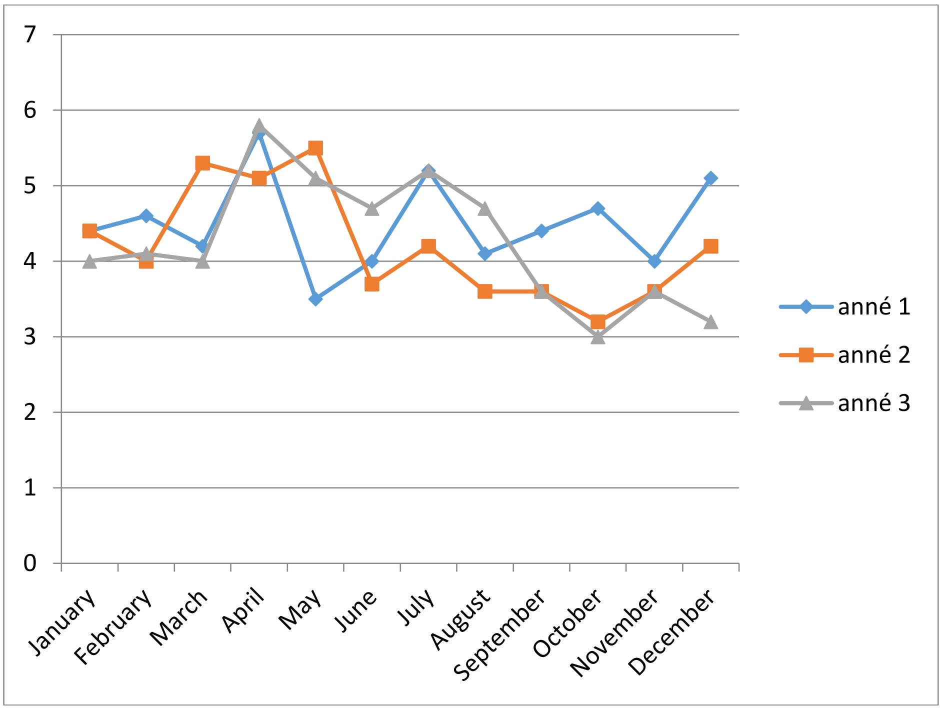


Figure II.2: Diagram of wind speed obtained from the data of Biskra By Excel.

Table II.2. The average monthly humidity in% of Biskra

January	February	March	April	May	June	July	August	September	October	November	December
62	52	45	39	35	30	23	27	41	57	58	61
56	47	48	46	43	33	29	31	37	42	59	67
53	51	41	32	28	29	26	29	46	51	54	66

Table II.3. The average atmospheric pressure in 1/10mb. Barometer altitude 88.9 m of Biskra

January	February	March	April	May	June	July	August	September	October	November	December
1007.8	1008.0	1010.5	1001.0	1003.4	1003.0	1003.0	1004.0	1005.0	1004.0	1007.0	1008.6
1007.4	1010.4	1008.5	1002.0	1002.5	1004.0	1003.0	1003.0	1007.0	1006.0	1007.0	1007.3
1013.6	1006.3	1006.4	1003.0	1004.4	1004.0	1002.0	1002.0	1005.0	1007.9	1007.0	1009.6

- **Monthly data for the area of Batna:**

Table II.4. The average wind speed in m/s of Batan.

January	February	March	April	May	June	July	August	September	October	November	December
4.0	3.3	2.4	3.1	2.5	2.9	2.8	2.5	2.4	2.6	1.7	2.3
1.8	2.7	2.9	2.6	3.3	2.1	2.6	2.7	2.0	2.0	1.7	2.4
1.9	3.2	2.7	3.1	3.5	3.9	3.8	3.4	2.7	2.3	2.8	2.5

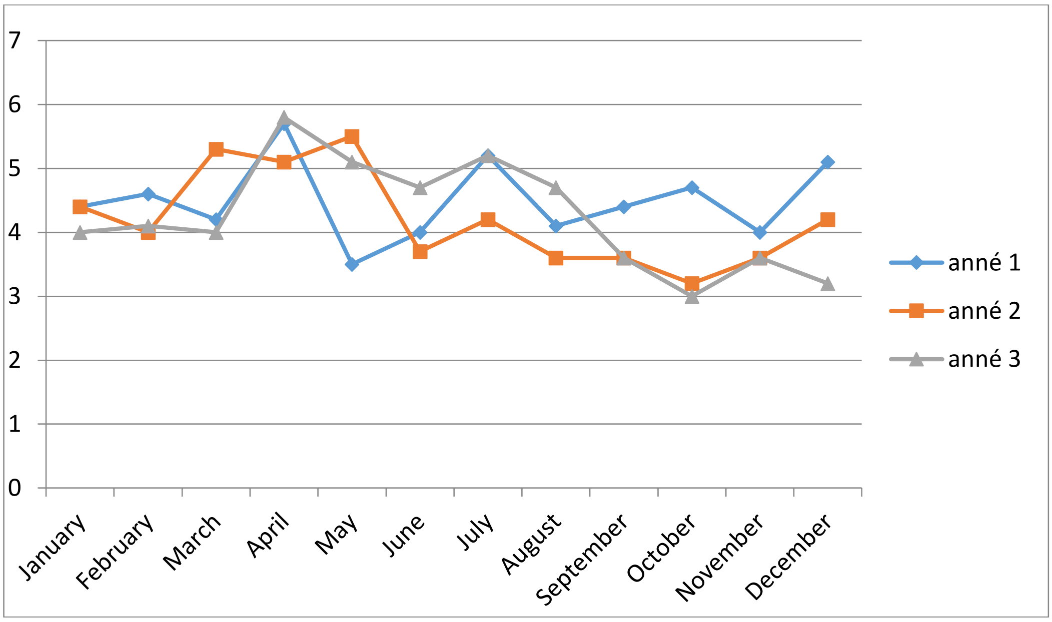


Figure II.3: Diagram of wind speed obtained from the data of Batan By Excel.

Table II.5. The average monthly humidity in% of Batna.

January	February	March	April	May	June	July	August	September	October	November	December
75	71	67	68	62	47	36	41	61	62	71	78
77	62	64	68	65	60	44	42	58	51	80	80
74	71	62	61	49	46	38	44	54	65	63	75

Table II.6. The average atmospheric pressure in 1/10mb. Barometer altitude 88.9 m of Batna

January	February	March	April	May	June	July	August	September	October	November	December
897.3	899.6	891.3	891.2	901.1	901.2	897.5	897.5	899.5	899.0	900.2	901.3
899.2	892.1	899.5	899.6	901.2	901.2	902.1	900.2	900.3	899.6	899.5	899.4
897.5	899.5	899.4	899.2	901.2	900.5	900.2	902.3	901.6	897.9	899.5	901.0

- **Monthly data for the area of Msila**

Table II.7. The average wind speed in m/s of Msila

January	February	March	April	May	June	July	August	September	October	November	December
4.4	4.6	4.2	5.7	3.5	4.0	5.2	4.1	4.4	4.7	4.0	5.1
4.4	4.0	5.3	5.1	5.5	3.7	4.2	3.6	3.6	3.2	3.6	4.2
4.0	4.1	4.0	5.8	5.1	4.7	5.2	4.7	3.6	3.0	3.6	3.2

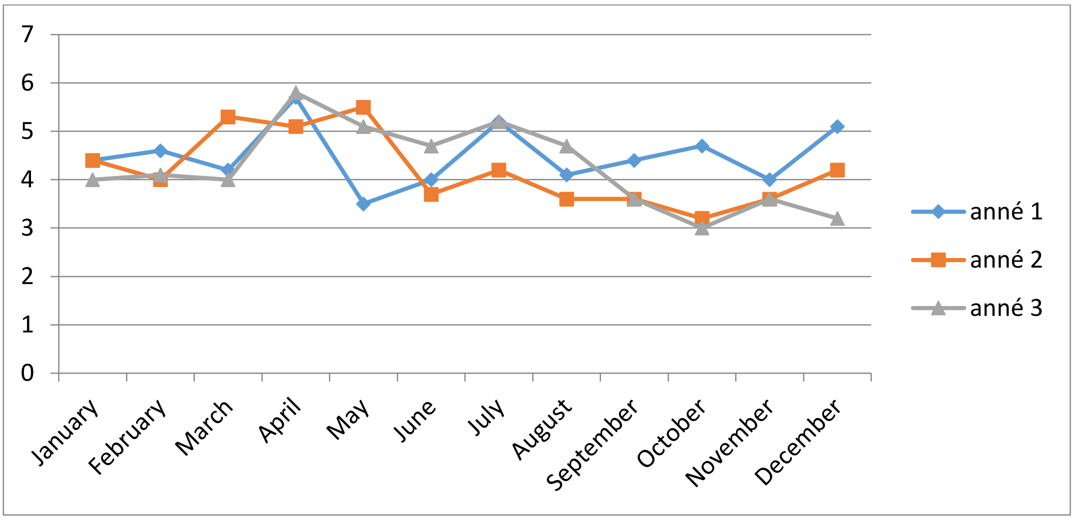


Figure II.4: Diagram of wind speed obtained from the data of Mesila By Excel.

Table II.8. The average monthly humidity in% of Mesila.

January	February	March	April	May	June	July	August	September	October	November	December
79	73	62	58	52	42	38	41	54	70	78	83
85	67	69	66	65	44	36	40	48	52	76	83
75	67	57	50	36	44	33	39	61	67	75	80

Table II.9. The average atmospheric pressure in 1/10mb. Barometer altitude 88.9 m of Mesila

January	February	March	April	May	June	July	August	September	October	November	December
965.2	966.0	965.3	965.4	965.8	965.6	966.2	966.1	965.2	965.1	965.3	965.2
965.1	965.6	966.2	966.1	965.2	965.1	965.3	965.2	966.0	965.3	965.4	965.8
966.0	965.3	965.4	965.8	965.6	966.2	966.1	965.2	965.1	965.3	965.2	965.6

II.4 Methods for quantifying the performance of a wind turbine

II.4.1 Availableenergy

We consider an air column of length dl, of section S, of density ρ animated with a speed V in accordance with the following figure[10]:

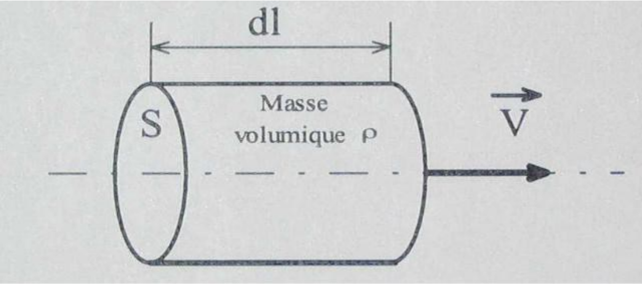


Figure II.5: Air column[10].

The kinetic energy of this column of air is therefore:

$$dW_c = 1/2\ dm\ V^2 \quad \text{with} \quad dm = \rho\ S\ dl$$

Now we know that dl = V dt because

V = dl / dt Hence:

$$dW_c = 1/2\ \rho\ S\ V^3 dt$$

We thus deduce the expression of the available power:

$$P_d = \frac{dW_c}{dt} = 1/2\ \rho\ S\ V^3 \qquad (2.7)$$

The available power per m2 then becomes:

$$P_d = 1/2\ \rho\ S\ V^3 \qquad (2.8)$$

The maximum available power is obtained when the kinetic energy of air rotation after passing through the wind turbine is low, i.e. for a high angular speed of rotation ω and a low torque on the tree.

Note: We recall that the angular speed of rotation ω is defined by ω = 2π n with n the number of revolutions per second.

II.4.2 Recoverableenergy

We define a coefficient of performance Cp specific to each wind turbine, comparable to the efficiency of a heat engine, which directly depends on the characteristics of the wind turbine.

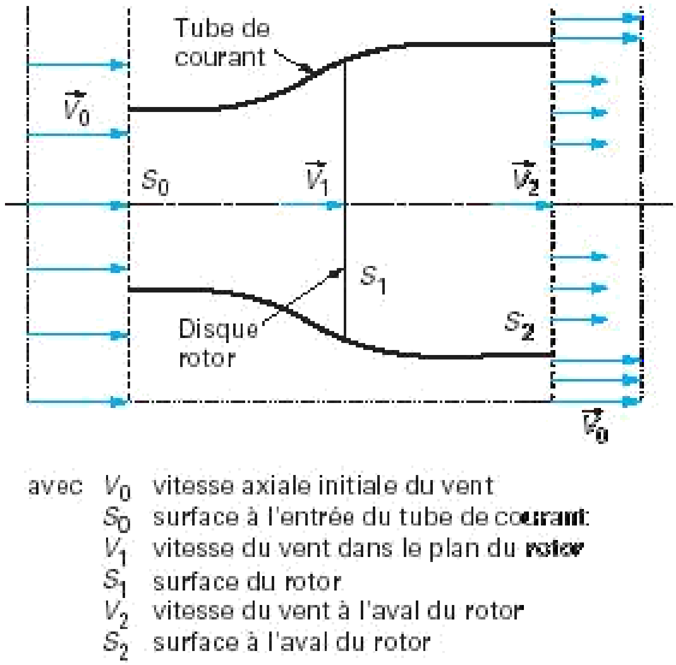
Thus this coefficient of performance varies with the wind, as shown in the graph opposite, corresponding to the high performance wind turbine NORDEX S77 / 1500kW whose characteristics are:

- rotor diameter: 77m with 3 blades,
- rotation speed: 9.6 to 17.3 rpm,
- nominal power: 1500kW (for a wind of 13m / s),
- weight 88,000 Kg (without the tower).

The recoverable power Pr on the wind turbine is then defined by:

$$P_r = C_p P_d \qquad (2.9)$$

Where Pd is the available power.



FigureII.6: Wind vein at the crossing of the aeromotor [10].

II.4.3 BETZ theory

Energy is produced by taking kinetic energy when it crosses the aeromotor.

II.4.4 Wind vein at the crossing of the aeromotor

We will assume the incompressible air, which will allow us to write the conservation of the volume flow:

$$S_0V_0 = S_1V_1 = S_2V_2 \qquad (2.10)$$

Euler's theorem (variation of the momentum of the windstream between upstream and downstream of the propeller) allows us to write that the force F exerted on the blades of the air motor is given by the expression:

$$F = \rho S_1V_1(V_0 - V_2) \qquad (2.11)$$

This gives the expression of the mechanical power supplied to the aeromotor:

$$P = F\,V_1 = \rho S_1V_1^2(V_0 - V_2) \qquad (2.12)$$

In addition, the elementary air mass dm crossing the wind turbine during the time dt is:

$$dm = \rho\, S_1\, V_1dt \qquad (2.13)$$

The variation of kinetic energy of this mass dm when the speed passes from the value V0 to the value V2 is defined by:

$$dW_c = 1/2\, dm\, (V_0^2 - V_2^2) \qquad (2.14)$$

The variation of the kinetic energy per second of the air mass is:

$$P_c = \frac{dW_c}{dt} = 1/2\, \rho\, S_1V_1(V_0^2 - V_2^2) \qquad (2.15)$$

by expressing that Pc = P, we deduce that:

$$V_1 = \frac{V_0 + V_2}{2}$$

Thus the recoverable power according to Betz's theory is stated:

$$P\,r = 1/4\, \rho S_1(V_0 + V_2)^2(V_0 - V_2) \qquad (2.16)$$

II.4.5 The BETZ limit

The relation having to exist between V0 and V2 so that this power Pr goes through a maximum is:

$$dP_r / dV_2 = 0 \text{ is } \quad V_0 = 3 V_2$$

Under these conditions the maximum power is written:

$$P_{max} = (8/27)\rho \, S \, V_0^3 = (16/27)(1/2 \, \rho \, S \, V_0^3)$$

$$P_{max} = \frac{16}{27} P_d \qquad (2.17)$$

which means that the maximum recoverable power can never represent more than $\frac{16}{27}\times 100 = 59.26\%$ of the available power due to the wind, this is the Betz limit

In reality the power recovered is less than this maximum power because "from the wind to the light bulb" in our case, or "from the wind to the electricity grid" on a national scale there are several stages of energy conversion, each with its own efficiency (for example the efficiency of a propeller is around 85%). In addition, in practice all the organs are not at their maximum efficiency at the same time, which further reduces the overall efficiency. Thus an industrial wind turbine will have an overall yield of between 50 and 55%, an artisanal wind turbine between 25 and 40%.

II.5 Conclusion

A method for optimizing an isolated small wind conversion system is presented and studied. The goal is to maximize the power produced by a simple system without mechanical or electronic control. The method is based on a simple model without losses in the mechanical transmission with which one obtains the expressions of the mechanical power of the wind turbine and electric of the machine. The equation of mechanical power is obtained through the approximation of the power coefficient of the wind turbine by a rational function proposed.

III.1 Introduction

This chapter is devoted to the result of the calculation of the production power of the wind and the energy of the wind speed, using a scripting language to make the calculation efficiency and comprehensive.

III.2 Tools of calculation

For the calculation of the power produced by a wind and energy of wind speedwe used:

- MATLAB (“matrix laboratory”) and it is a scripting language1 emulated by a development environment of the same name; it is used for numerical calculation purposes. Developed by The MathWorks, MATLAB allows you to manipulate matrices, display curves and data, implement algorithms, create user interfaces, and can interface with other languages such as C, C ++, Java, and Fortran. MATLAB users (around 4 million in 20192) are from very different backgrounds such as engineering, science, and economics in an industrial as well as a research context. Matlabcan be used alone or with toolboxes ("toolbox").

Previously, we have seen that the power produced by a wind crossing a surface S depends on the cube of the wind speed V and the density of the air p. This power is given by:

$$p_t = \frac{1}{2}\rho . A . C_p(\lambda) . v^3 \quad (3.1)$$

We find in the literature several types of power coefficient modelling, generally valid for a particular turbine: each turbine has a specific behaviour. Thus, everyone confronted with this problem of modelling the power coefficient. However, the modelling used in this work appears in other references. It has the advantage of being presented in the form of a single equation, valid whatever the setting angle pet whatever the speed ratio.

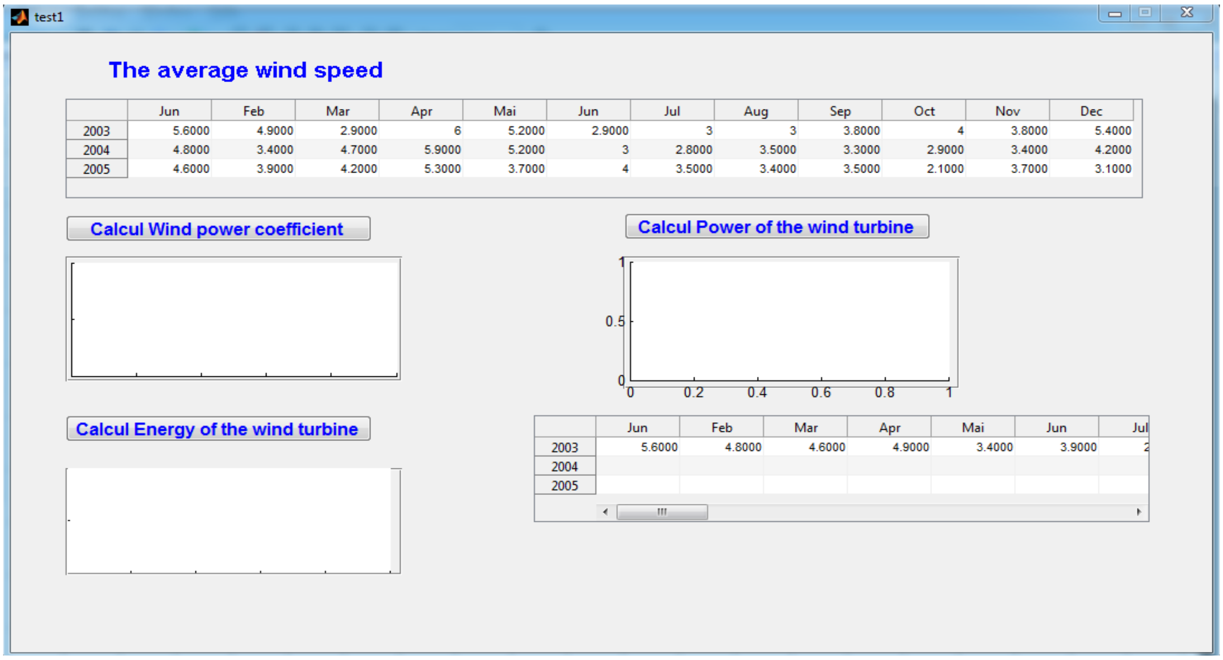
$$C_p(\lambda) = \frac{\mathrm{G} * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2} \quad (3.2)$$

Energy of wind speed

$$E_t = P_t * T_i \quad (3.3)$$

III.3 Result

The first image is the Graphical program interface that we create in MATLAB to have the results.

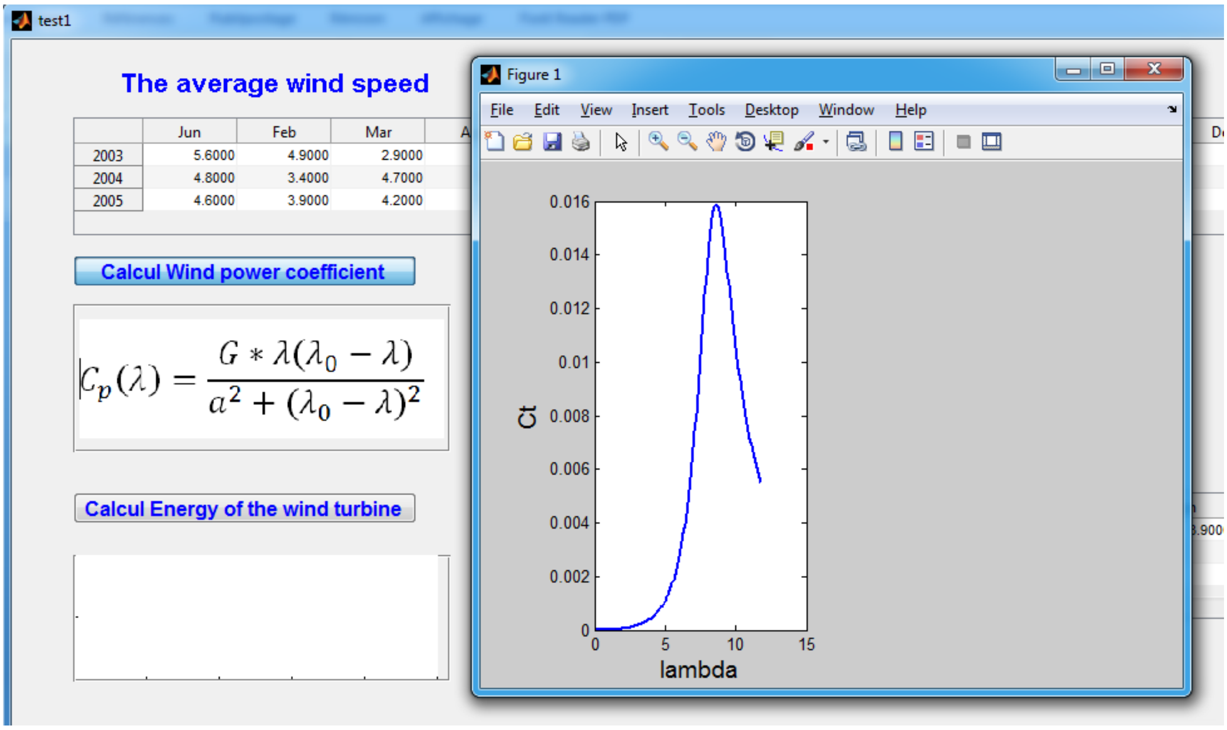


	Jun	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	5.6000	4.9000	2.9000	6	5.2000	2.9000	3	3	3.8000	4	3.8000	5.4000
2004	4.8000	3.4000	4.7000	5.9000	5.2000	3	2.8000	3.5000	3.3000	2.9000	3.4000	4.2000
2005	4.6000	3.9000	4.2000	5.3000	3.7000	4	3.5000	3.4000	3.5000	2.1000	3.7000	3.1000

	Jun	Feb	Mar	Apr	Mai	Jun	Jul
2003	5.6000	4.8000	4.6000	4.9000	3.4000	3.9000	2
2004							
2005							

Figure III.1: Graphical program interface that we create in MATLAB.

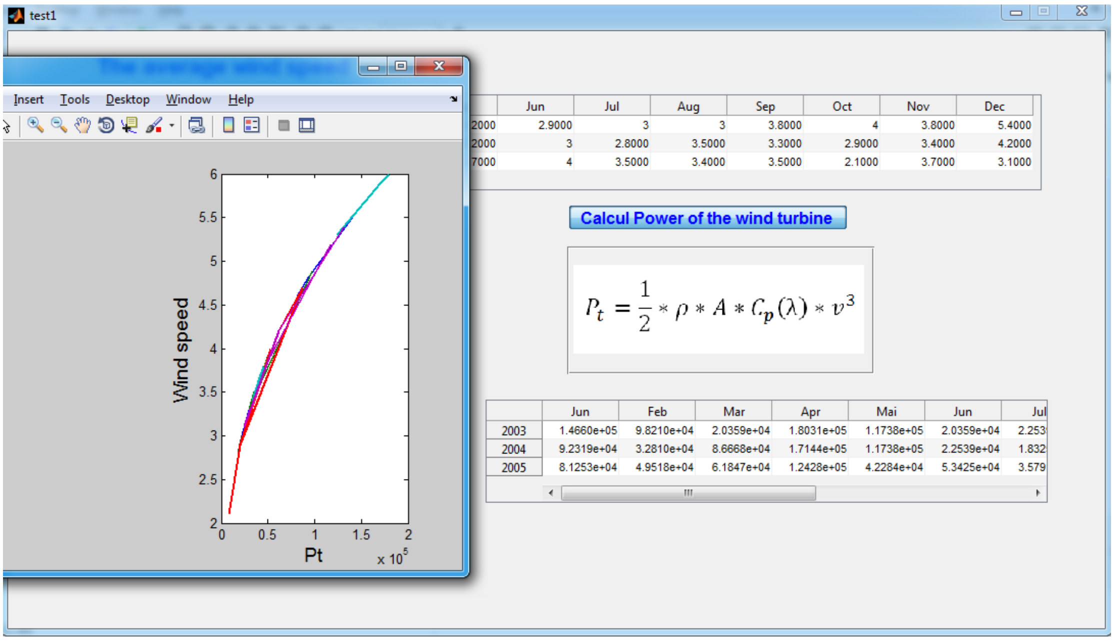
III.3.1 Result of the Biskra region



	Jun	Feb	Mar
2003	5.6000	4.9000	2.9000
2004	4.8000	3.4000	4.7000
2005	4.6000	3.9000	4.2000

$$C_p(\lambda) = \frac{G * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2}$$

Figure III.2: Calculof the wind power coefficient of Biskra using MATLAB.

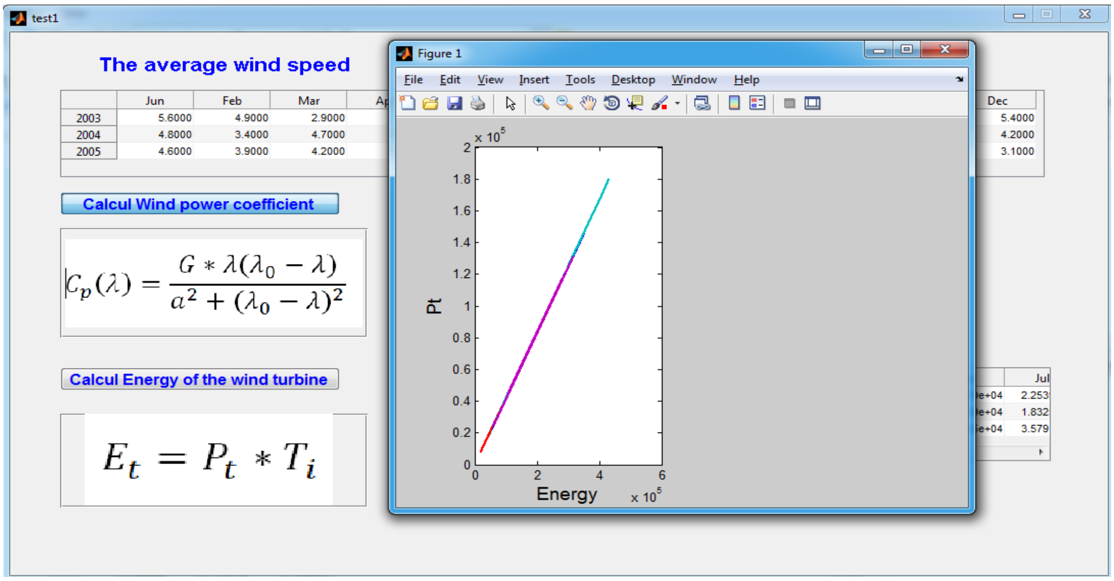


	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	2.9000	3	3	3.8000	4	3.8000	5.4000
2000	3	2.8000	3.5000	3.3000	2.9000	3.4000	4.2000
7000	4	3.5000	3.4000	3.5000	2.1000	3.7000	3.1000

$$P_t = \frac{1}{2} * \rho * A * C_p(\lambda) * v^3$$

	Jun	Feb	Mar	Apr	Mai	Jun	Jul
2003	1.4660e+05	9.8210e+04	2.0359e+04	1.8031e+05	1.1738e+05	2.0359e+04	2.253
2004	9.2319e+04	3.2810e+04	8.6668e+04	1.7144e+05	1.1738e+05	2.2539e+04	1.832
2005	8.1253e+04	4.9518e+04	6.1847e+04	1.2428e+05	4.2284e+04	5.3425e+04	3.579

Figure III.3: Power calculation of the wind turbine of Biskra using MATLAB.



The average wind speed

	Jun	Feb	Mar	Ap
2003	5.6000	4.9000	2.9000	
2004	4.8000	3.4000	4.7000	
2005	4.6000	3.9000	4.2000	

Dec
5.4000
4.2000
3.1000

$$C_p(\lambda) = \frac{G * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2}$$

	Jul
e+04	2.253
e+04	1.832
e+04	3.579

$$E_t = P_t * T_i$$

Figure III.4:Energy Calculation ofwindturbine of Biskra using MATLAB.

- ***Consul result***

```
Et =

  1.0e+005 *

  Columns 1 through 8

    3.9699    2.6595    0.5513    4.8828    3.1785    0.5513    0.6104    0.6104
    2.2157    0.7874    2.0800    4.1147    2.8170    0.5409    0.4398    0.8590
    2.4238    1.4771    1.8449    3.7072    1.2613    1.5937    1.0676    0.9787

  Columns 9 through 12

    1.2404    1.4468    1.2404    3.5596
    0.7200    0.4886    0.7874    1.4843
    1.0676    0.2306    1.2613    0.7418
```

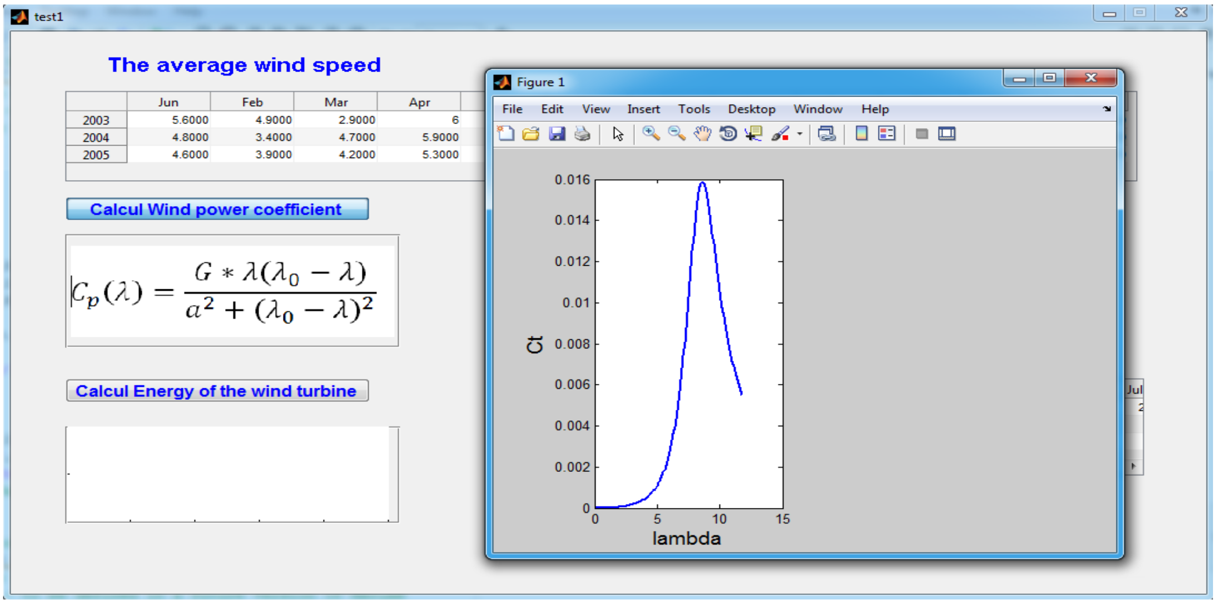
Result of Energy Calculation ofwindturbine of Biskra using MATLAB.

Through the results, it shows by MATLAB in the command window.We find the energy produced in each year by one wind turbine is:

Table III.1. YerlyEnergy Calculation ofwindturbine of Biskra.

Year	**2003**	**2004**	**2005**
Energy [MW]	2.45073	1.73348	1.76556

III.3.2 Result of the Batna region

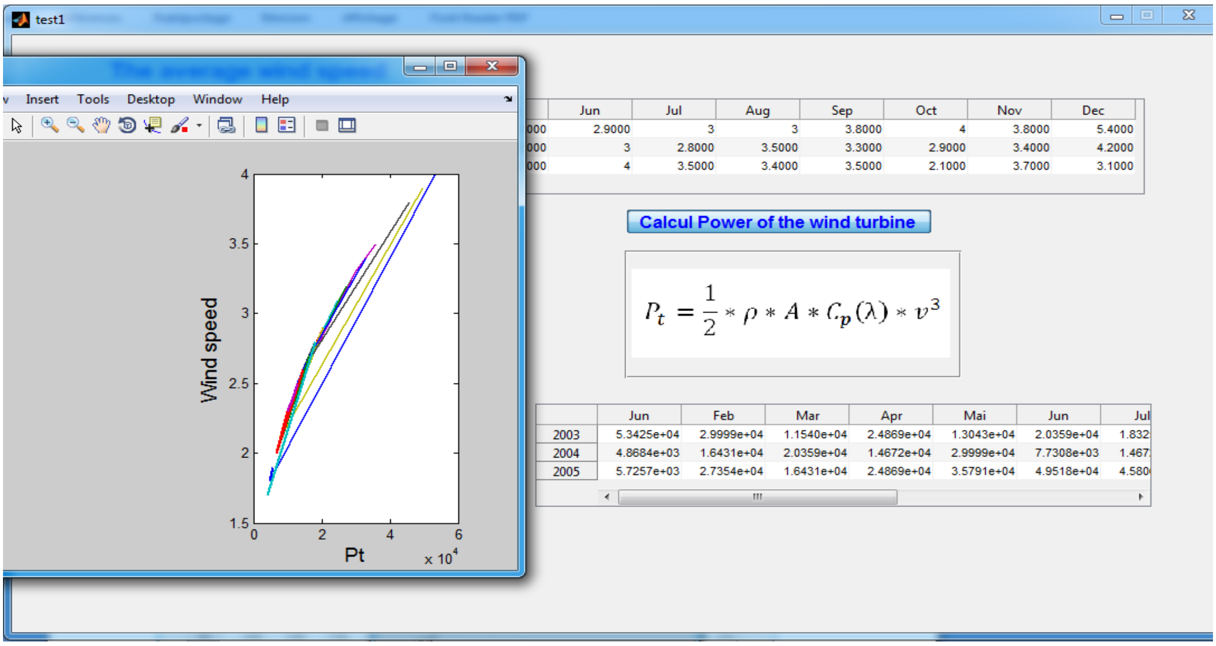


The average wind speed

	Jun	Feb	Mar	Apr
2003	5.6000	4.9000	2.9000	6
2004	4.8000	3.4000	4.7000	5.9000
2005	4.6000	3.9000	4.2000	5.3000

$$C_p(\lambda) = \frac{G * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2}$$

Figure III.5: Calculof the wind power coefficient of Batna using MATLAB.

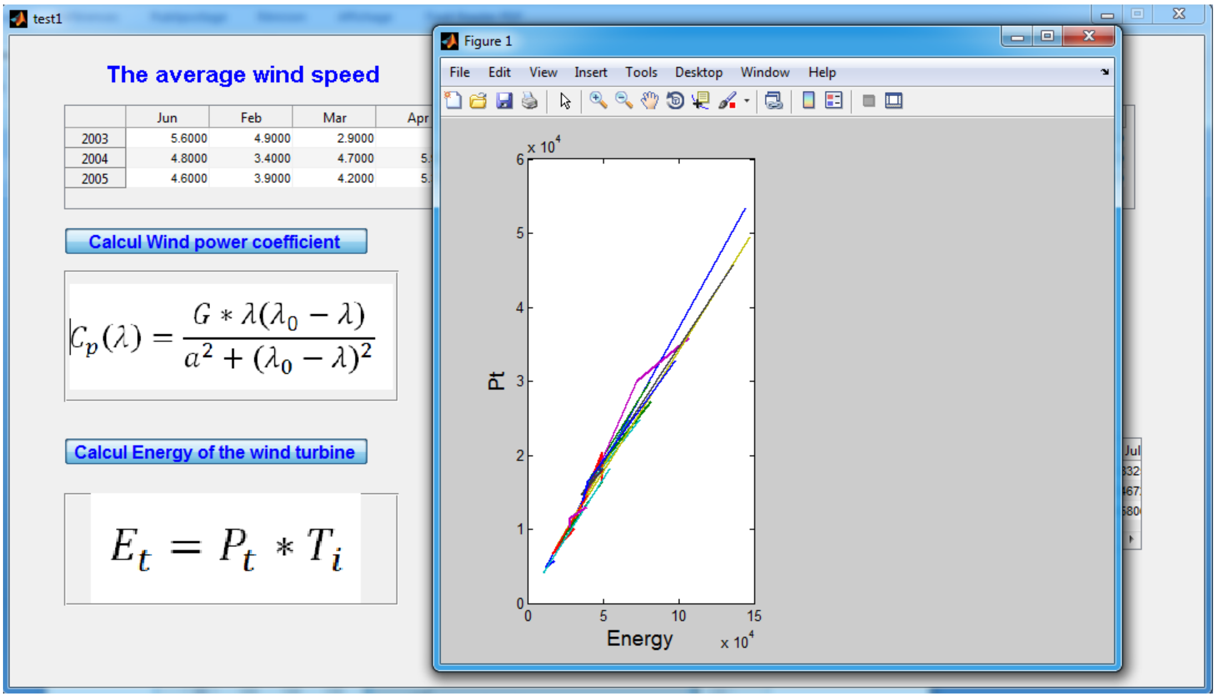


	Jun	Jul	Aug	Sep	Oct	Nov	Dec
000	2.9000	3	3	3.8000	4	3.8000	5.4000
000	3	2.8000	3.5000	3.3000	2.9000	3.4000	4.2000
000	4	3.5000	3.4000	3.5000	2.1000	3.7000	3.1000

$$P_t = \frac{1}{2} * \rho * A * C_p(\lambda) * v^3$$

	Jun	Feb	Mar	Apr	Mai	Jun	Jul
2003	5.3425e+04	2.9999e+04	1.1540e+04	2.4869e+04	1.3043e+04	2.0359e+04	1.832
2004	4.8684e+03	1.6431e+04	2.0359e+04	1.4672e+04	2.9999e+04	7.7308e+03	1.467
2005	5.7257e+03	2.7354e+04	1.6431e+04	2.4869e+04	3.5791e+04	4.9518e+04	4.580

Figure III.6: Power calculation of the wind turbine of Batna using MATLAB.



The average wind speed

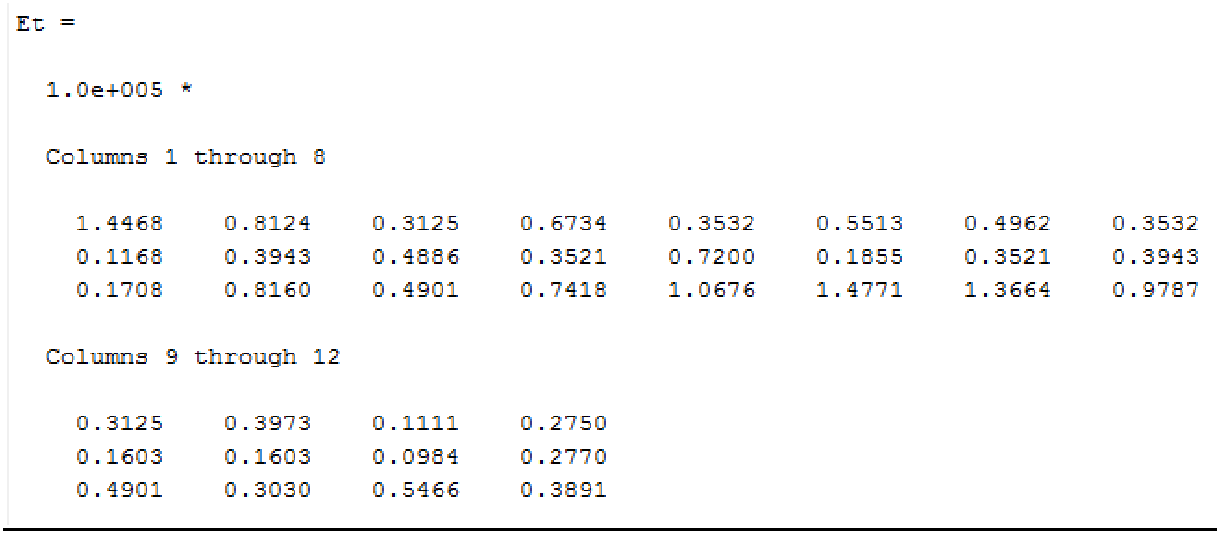
	Jun	Feb	Mar	Apr
2003	5.6000	4.9000	2.9000	
2004	4.8000	3.4000	4.7000	5.
2005	4.6000	3.9000	4.2000	5.

$$C_p(\lambda) = \frac{G * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2}$$

$$E_t = P_t * T_i$$

Figure III.7:Energy Calculation ofwindturbine of Batna using MATLAB.

- ***Consul result***



```
Et =

   1.0e+005 *

   Columns 1 through 8

     1.4468    0.8124    0.3125    0.6734    0.3532    0.5513    0.4962    0.3532
     0.1168    0.3943    0.4886    0.3521    0.7200    0.1855    0.3521    0.3943
     0.1708    0.8160    0.4901    0.7418    1.0676    1.4771    1.3664    0.9787

   Columns 9 through 12

     0.3125    0.3973    0.1111    0.2750
     0.1603    0.1603    0.0984    0.2770
     0.4901    0.3030    0.5466    0.3891
```

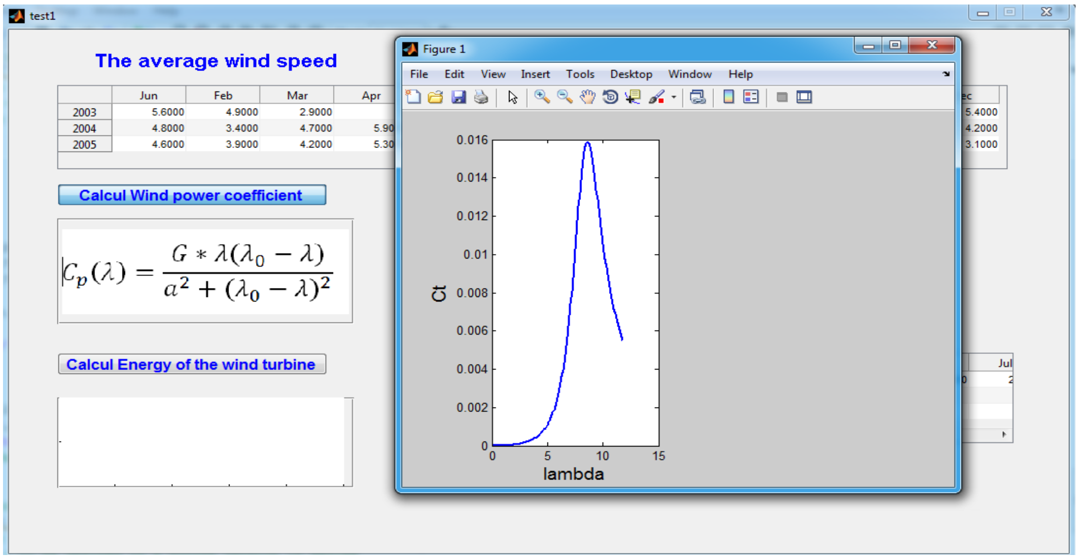
Result of Energy Calculation ofwindturbine of Batna using MATLAB.

Through the results, it shows by MATLAB in the command window. We find the energy produced in each year by one wind turbine is:

Table III.2. YerlyEnergy Calculation ofwind turbine of Batna.

Year	2003	2004	2005
Energy [MW]	0.66349	0.36997	0.88373

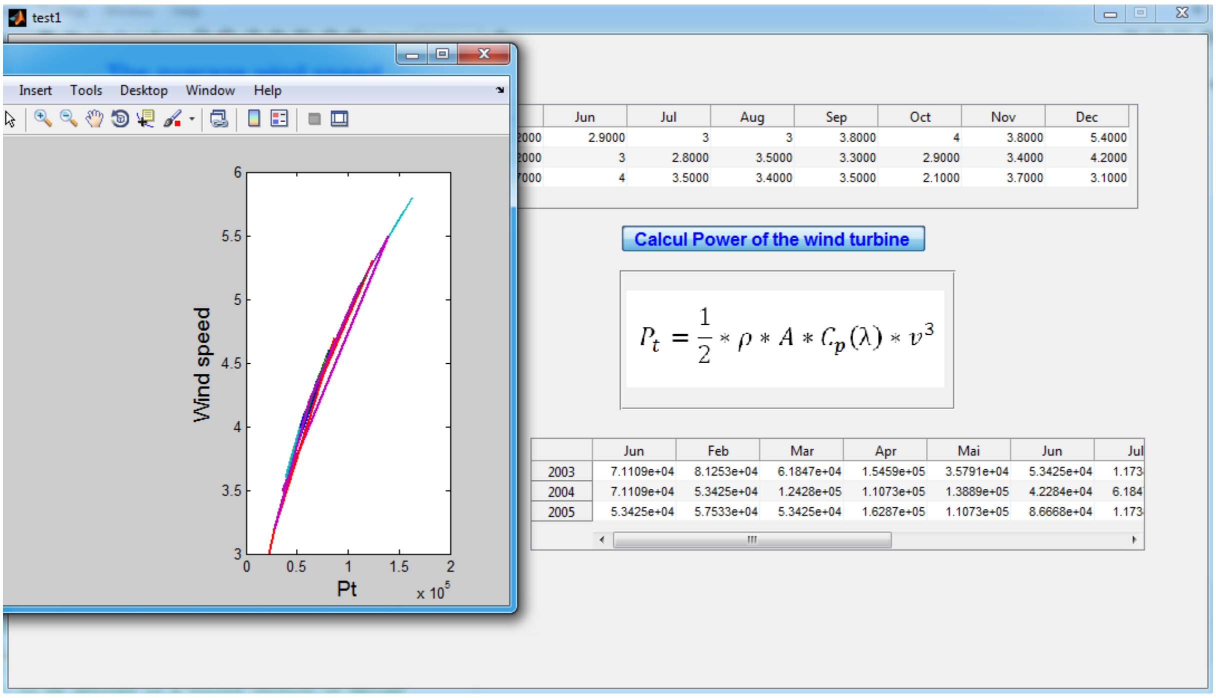
III.3.3 Result of the Mesila region



	Jun	Feb	Mar	Apr	ec
2003	5.6000	4.9000	2.9000		5.4000
2004	4.8000	3.4000	4.7000	5.90	4.2000
2005	4.6000	3.9000	4.2000	5.30	3.1000

$$C_p(\lambda) = \frac{G * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2}$$

Figure III.8: Calculof the wind power coefficient of Mesila using MATLAB.

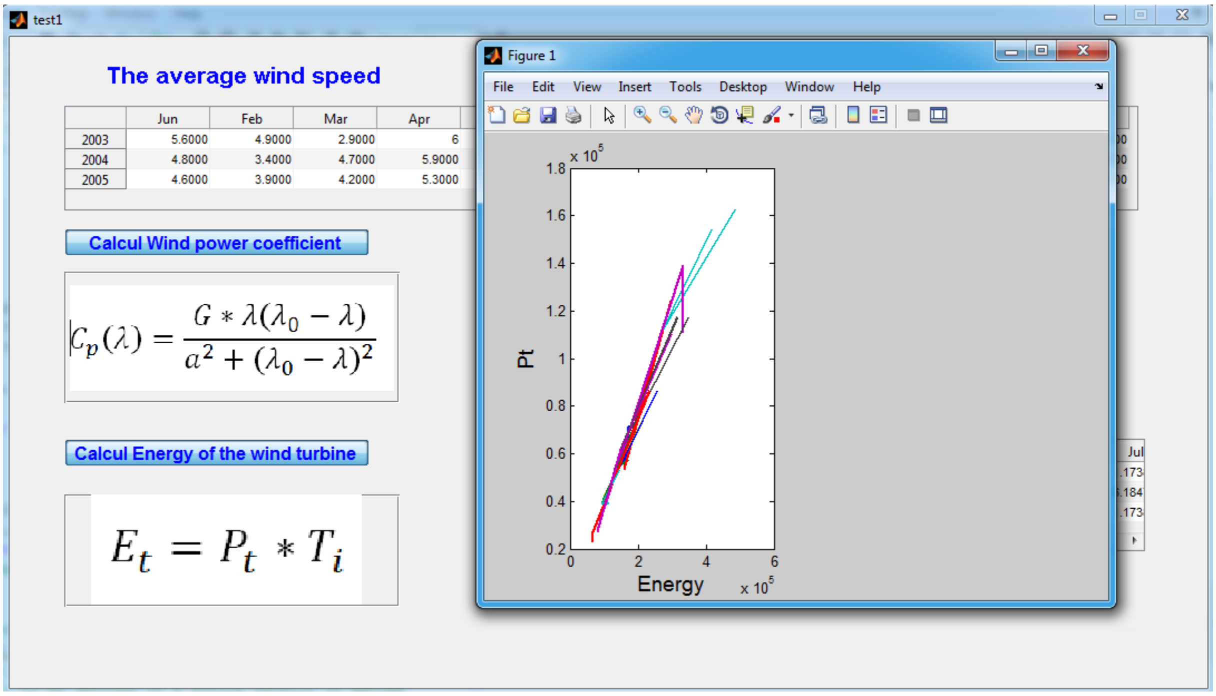


	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	2.9000	3	3	3.8000	4	3.8000	5.4000
2000	3	2.8000	3.5000	3.3000	2.9000	3.4000	4.2000
7000	4	3.5000	3.4000	3.5000	2.1000	3.7000	3.1000

$$P_t = \frac{1}{2} * \rho * A * C_p(\lambda) * v^3$$

	Jun	Feb	Mar	Apr	Mai	Jun	Jul
2003	7.1109e+04	8.1253e+04	6.1847e+04	1.5459e+05	3.5791e+04	5.3425e+04	1.173
2004	7.1109e+04	5.3425e+04	1.2428e+05	1.1073e+05	1.3889e+05	4.2284e+04	6.184
2005	5.3425e+04	5.7533e+04	5.3425e+04	1.6287e+05	1.1073e+05	8.6668e+04	1.173

Figure III.9: Power calculation of the wind turbine of Mesila using MATLAB.



The average wind speed

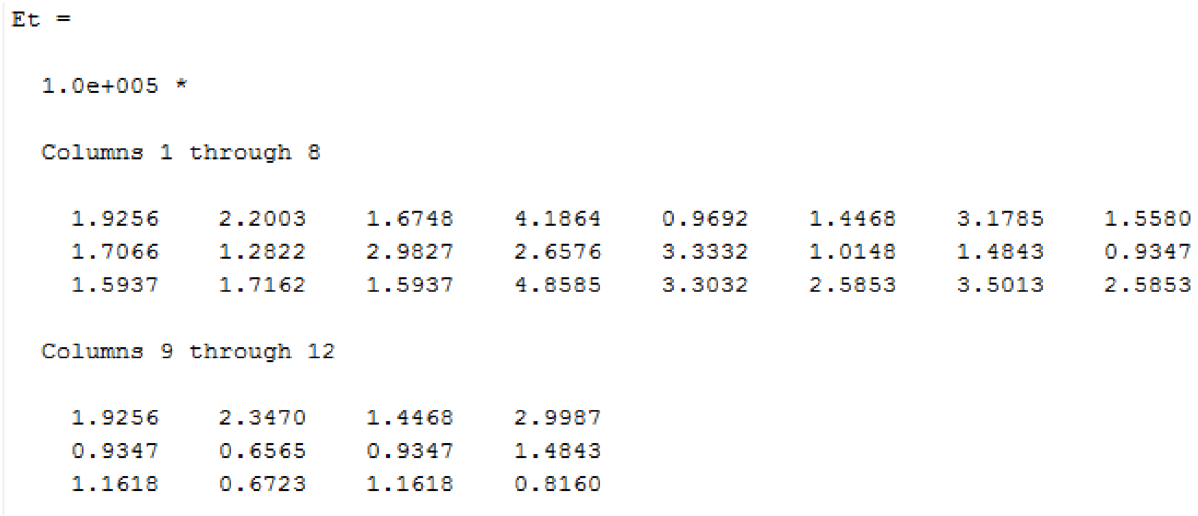
	Jun	Feb	Mar	Apr
2003	5.6000	4.9000	2.9000	6
2004	4.8000	3.4000	4.7000	5.9000
2005	4.6000	3.9000	4.2000	5.3000

$$C_p(\lambda) = \frac{G * \lambda(\lambda_0 - \lambda)}{a^2 + (\lambda_0 - \lambda)^2}$$

$$E_t = P_t * T_i$$

Figure III.10:Energy Calculation ofwindturbine of Mesila using MATLAB.

- ***Consul result***



```
Et =

  1.0e+005 *

  Columns 1 through 8

    1.9256    2.2003    1.6748    4.1864    0.9692    1.4468    3.1785    1.5580
    1.7066    1.2822    2.9827    2.6576    3.3332    1.0148    1.4843    0.9347
    1.5937    1.7162    1.5937    4.8585    3.3032    2.5853    3.5013    2.5853

  Columns 9 through 12

    1.9256    2.3470    1.4468    2.9987
    0.9347    0.6565    0.9347    1.4843
    1.1618    0.6723    1.1618    0.8160
```

Result of Energy Calculation ofwindturbine of Mesila using MATLAB.

Through the results, it shows by MATLAB in the command window. We find the energy produced in each year by one wind turbine is:

Table III.3. YerlyEnergy Calculation ofwind turbine of Mesila.

Year	**2003**	**2004**	**2005**
Energy [MW]	2.58577	1.94063	2.19638

III.4 Conclusion

We concluded that the best zone to insert the wind turbine from the zones that we study is: Mesila, and that is because it has the highest production of wind energy. The next zone is Biskra and then Batna with the lowest production of wind energy.

General conclusion

The research done in this thesis work led to several results, the most important of which are summarized here.

The formulation of an optimization method made it possible to find the optimal values of the gearbox transformation ratio and the battery voltage for a simple structure of isolated and small wind power conversion system. A mechanical model of the wind turbine and another electrical model of the machine were used to obtain equations that formalize the optimization problem.

Perspective

The following future work could be pursued on the basis of the results and research carried out in this thesis work.

For the optimization problem, it is possible to include other components of the conversion system in the proposed problem. For example, the machine; dimension a system without gearbox, seeking the optimal number of poles and the characteristics of the machine for an optimal adaptation to the wind conversion system.

Other resolution techniques, such as Gradient Descent, Neural Networks, Genetic Algorithms, etc., can be useful for verifying the results of the optimization problem already solved by the Monte-Carlo Method or for solving new optimization problems that the wind generation system can offer.

For well-defined sites, it is possible to resume the optimization of the system with an adaptation of it to the wind conditions of the location.

For the controlled system, it is possible to design a control system specially adapted to the wind power application of the cascade converter. Include a part of simultaneous control of the two converters, for the area where the input and output voltage values are similar and thus avoid an operating region without regulation.

A command in power factor corrector mode can also be studied and verified taking advantage of the proposed cascade structure. This would allow the machine to operate with almost sinusoidal currents, reducing the detrimental effects of current harmonics in the machine.

For the method of calculating losses in converters, a possible inclusion of the loss equations in the dimensioning procedure of the hybrid power system to carry out a more precise calculation of the losses and of the energy not supplied in order to improve the dimensioning.

Develop a calculation method for other types of losses from electronic and electrical converters in order to complete the procedure for estimating losses in power systems, especially for hybrid systems[1].

Bibliography

[1] Mirecki, A. (2005). Etude comparative de chaînes de conversion d'énergie dédiées à une éolienne de petite puissance, Institut National Polytechnique de Toulouse, France.

[2] Mathew, S. (2006). Wind Energy: Fundamentals, Resource Analysis and Economics, Springer, Germany

[3] Windpower (2006), Site Web de la Danish Wind Industry Association, http://www.windpower.org

[4] hmf.enseeiht, Site Web de Département de formation MÉCANIQUE DES FLUIDES, ÉNERGÉTIQUE&ENVIRONNEMENT,http://hmf.enseeiht.fr/travaux/bei/beiere/book/export/html/1331

[5] Hau, E. (2006). Wind Turbines: Fundamentals, Technologies, Application, Economics, Springer, Germany

[6] Ragheb, A., &Ragheb, M. (2010, March). Wind turbine gearbox technologies. In 2010 1st International Nuclear & Renewable Energy Conference (INREC) (pp. 1-8). IEEE.

[7] Lopez, M. (2008). Contribution à l'optimisation d'un système de conversion éolien pour une unité de production isolée (Doctoral dissertation).

[8] Ackermann, T. (2005). Wind Power in Power Systems, John Wiley&Sons, England

[9] Chen, Z. and Blaabjerg, F. (2006). "Wind Energy – The World's Fastest Growing Energy Source", IEEE Power Electronics Society Newsletter, 3, 15-18

[10] Pierre Boscq, Baptiste Dumortier, Aurore Dutin and Kevin Friry (2005/2006) graduation project.