IMPACTS OF METEOROLOGICAL PHENOMENA ON THE PRODUCTION OF ELECTRICITY BASED ON AEROGENERATORS

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ABSTRACT

The purpose of this paper is to determine the wind energy production process, to determine the energy potential of a site and to see the impacts of meteorological phenomena on wind turbine-based power generation. We will choose three zones of study, chosen by their strong wind potential. We started by seeing generalities about the energy production process, we evaluated the wind potential and also the energy productions of three sites namely Vohemar, Taolagnaro and Antsiranana, and finally we will visualize the impacts of the meteorological parameters on the energy production.

Keyword: - *Wind turbine, energy, Weibull parameter, wind turbine, meteorological, phenomenon*

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1. Introduction

Wind energy results from the force exerted by the wind on the blades of an aerogenerator. The kinetic energy produced by the movement of the wind is transformed into mechanical energy. The generator transforms the mechanical energy thus created into electrical energy and adapts the electricity produced to the standards of the network. The estimation of wind energy resources presents a major difficulty. Unlike fossil fuel reserves, the amount of energy available varies with the season, the time of day and the topography of the place of production.

2. Wind energy production

2.1 Process of producing energy from the wind

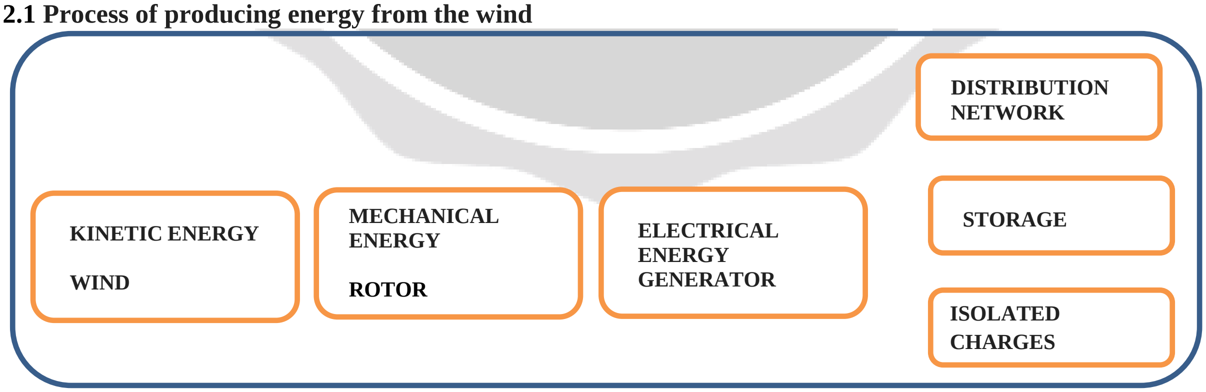

Fig -1: Process of producing energy from the wind

2.2 Geographic Constraints and Wind Turbine Operations

The production of wind turbines depends a lot on their location, they are implanted in areas where the wind is regular and frequent. Between the passes, at the top of the hills, near the sea, wind turbines are particularly effective. At high altitude, the air density is lower, but the winds are stronger, specific technologies of high altitude wind are then used.
Wind turbines do not produce electricity continuously, but intermittently, depending on the wind. Production is variable in quantity and over time, without necessarily adjusting to demand.

3. Mathematical modeling

3.1 Power of a moving air mass and kinetic power available

Considering a mass of air ma moving at velocity v through the surface A swept by the wind turbine, the expression of the kinetic energy of the air Ec as a function of the wind speed v (m / s) and my is:

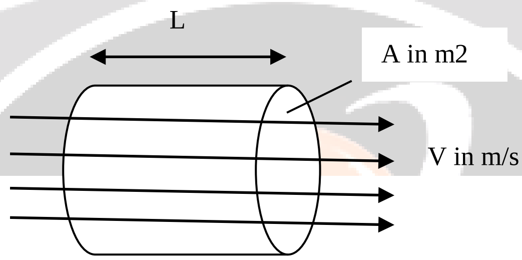

Fig -2: Tube swept by a moving mass of air

$$E_c = \frac{1}{2} m_a v^2$$

ρ: air density in kg / m3, A: swept area in m2, v: wind speed upstream of the rotor in m / s
Δma: quantity of mass of air passing through section A during a time Δt,

The amount of kinetic energy ΔEc of the air mass my view of the wind turbine is:

$$\Delta E_c = \frac{1}{2} \rho . A . v^3 . \Delta t \quad \text{with } \Delta ma = \rho . A\, v\, \Delta t$$

Wind power available before conversion is:

$$P_{dispo} = \frac{\Delta E}{\Delta t} = \frac{1}{2} \rho . A . v^3$$

3.2 The ideal wind rotor: the Betz limit

Albert Betz has demonstrated that in the case of a horizontal axis turbine operating in an open environment, the recoverable useful power on the motor shaft downstream of the rotor can not exceed 16 / 27th (59%) of the mechanical power maximum available, ie:

$$\mathbf{P_W = \frac{16}{27} . P_{dispo} = 0,5926\, P_{dispo} = \frac{1}{2} . C_p . \rho . A . v^3}$$

with Cp=0.5926

That is, an ideal wind rotor could exploit up to 16/27 of the wind energy. Cp decreases sharply as wind speed increases. If ρ = 1.25 kg / m³, by introducing this data into the equation above, for the maximum power of an ideal rotor, we obtain this simple relation:

$$P_{Wmax} = 0,37\ .A . v^3 \quad \text{in [W]}$$

The useful power per unit area or specific power is:

$$P_{max} = 0{,}37\,.v^3 \quad \text{in } [W/m^2]$$

$$A = \pi\, R^2 = \frac{\pi D^2}{4}$$

We can also write:

$$P_{Wmax} = 0{,}29.D^2.v^3 \quad in \;\; [W]$$

The maximum energy that could be extracted from a wind speed v with an ideal rotor is given by:

$$E_{max} = P_{max}.T = 0{,}37.v^3.T \quad in \;\; [WattHeure/m^2]$$

3.3 The non-ideal wind rotor: performance

Like any machine, a wind rotor has losses. There are mechanical, electrical and aerodynamic losses. Because of these losses it is impossible to reach the Betz limit.
The performance of a wind rotor can be defined in the following way:

$$\eta_w = \frac{P_W}{P_{Wmax}} = \frac{C_p}{0{,}5926}$$

$$P_W = 0{,}29.\eta_w.D^2.v^3 \quad in \;\; [W]$$

The output of an aerogenerator is given by:

$$\eta = \eta_1.\eta_2 \;....\eta_w$$

The wind turbine output is the product of the efficiencies of all system components.
The power factor cp of the plant can also be calculated with the following equation: $C_p = 0{,}5926.\eta$

3.4 Specific speed of a wind rotor

$$\lambda_0 = \frac{u_0}{v} = \frac{\pi.D.n}{60\;v}$$

$$u_0 = \frac{2.\pi.R.n}{60} \quad in \;\; [m/s]$$

u_0: speed of the blade tips and v wind speed in front of the rotor in m / s n is the rotational speed of the rotor in revolutions per minute [rpm] and R the radius [m].

3.5 Vitesse de rotation d'un rotor éolien

The optimal rotation speed, under which the rotor generates its maximum power, is:

$$n_{opt} = \frac{60.\lambda_d.v}{\pi.D}$$

λ_d : Rated rotor specific speed

3.6 Couple of a wind rotor

$$M_W = \frac{60.P_W}{2.\pi.n} = \frac{C_m.\rho.R.A.v^2}{2.}$$

$$C_m = \frac{C_p}{.\lambda_0}$$

And the starting torque coefficient of the rotor is calculated with:

$$C_{m0} = \frac{0{,}5}{{\lambda_d}^2}$$

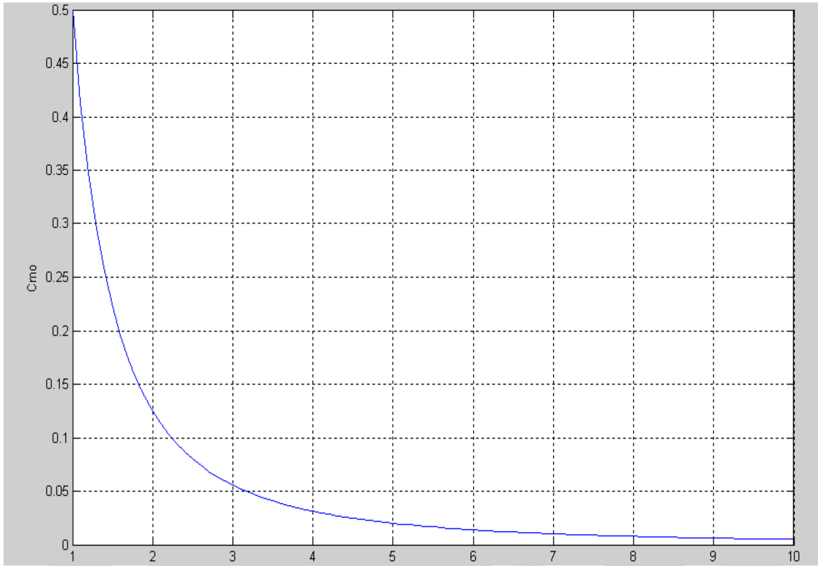

Chart -1: Starting torque coefficient of a rotor in function λ_d

3.7 Determination of the required area of the rotor

To obtain the power Pr the necessary rotor surface is equal to:

$$A = \frac{P_r}{0{,}37\ .\eta.v_r^3}$$

Pr is the useful power at the end of the chain formed by the wind rotor, the working machine, the transmission
The required diameter of the rotor is:

$$D \approx 2.\sqrt{\frac{P_r}{\eta.v_r^3}}$$

3.8 Characterization of the wind resource

The wind resource, especially the wind speed, is influenced by the topography: altitude, terrain profile (plain, hill, mountainous furrow) and roughness (type of vegetation, building, obstacle, ...).

The wind speed, which is zero on the ground, increases with altitude. It is generally modeled by the formula below which is verified all the better that the ground is flat (without "roughness"):

$$\frac{\mathbf{v}}{\mathbf{v_0}} = \left(\frac{\mathbf{h}}{\mathbf{h_0}}\right)^{\propto}$$

Vo and ho express wind speed and altitude at reference point
Vh is the estimated wind speed at rotor altitude h
α is the coefficient of roughness or vertical gradient coefficient of the wind speed, depends on the topography of the place.

3.9 Modeling of the local wind resource

The expertise of a site to develop a wind energy production facility requires the finest possible knowledge of the natural resource.
The Weibull distribution, given by the following equation, is a two-parameter distribution (λ and K), which allows to realize some important properties of the wind distribution according to these two parameters:

$$f(v) = \frac{k}{\lambda}\left(\frac{v}{\lambda}\right)^{k-1}.\exp\left(-\left(\frac{v}{\lambda}\right)^{k}\right)$$

f (v) is the frequency of occurrence (percentage of the analysis time generally related to the year) of wind speed v or Weibull function. λ is a scale parameter close to the average wind speed, in m / s k is a parameter of form representative of the more or less pronounced turbulence of the site (generally between 1 and 3), without unity and characterizes the distribution of the wind

4. Mathematical modeling of wind and the impacts of meteorological phenomena on wind turbine-based energy production

To model the wind parameters we used the Evertt C. Nickerson and Elmer L. Magaziner (1976) Model
This model is used to model wind parameters such as speed, force, pressure and direction. The model has been specially used to take into account the relief. The irregularity of the terrain has a great influence on the movement of the wind in the atmosphere and the precipitation in different places of a region. The flow on the island is influenced by the dynamic action of the relief playing a determining role on the types of time. These effects are seen on the precipitation regime; the direction and strength of the wind.

4.1 The equations of the model [8] [9] [10]

These equations (dynamic equations, thermodynamic equations) are expressed in the local coordinate system (x, y, γ).
γ was introduced to address the problem of boundary conditions in pressure coordinate
The vertical coordinate to be transformed γ is defined by the relation:

$$\sigma = \frac{4\gamma-\gamma^4}{3}$$

Where σ is the vertical coordinate
At the upper limit σ = γ = 0

On the ground σ = γ = 1
According to the conditions noted by DE RIVAS (1972); the values of dσ / dγ must be finite in all domains and zero for σ = γ = 1

The vertical coordinates can still be written according to the pressure:

$$\sigma = \frac{P-P_T}{P_S-P_T}$$

Or P: pressure on any level $\Pi = P_S - P_T$

P_S: Ground pressure
P_T: Pressure at the top of the domain to be studied or pressure at the upper limit taken equal to 100 mb

- **Dynamic equations**

The equations of motion for horizontal flow are written as follows:

$$\frac{\partial U}{\partial t} = -\frac{\partial(U_u)}{\partial x} - \frac{\partial(U_v)}{\partial y} - \frac{1}{\sigma'}\frac{\partial(\sigma' U\dot{\gamma})}{\partial \gamma} + fV + \left(\phi - \frac{RT^*\sigma\Pi}{P}\right)\frac{\partial \Pi}{\partial x} - \frac{\partial(\Pi\phi)}{\partial x} + F_U$$

$$\frac{\partial V}{\partial t} = -\frac{\partial(V_u)}{\partial x} - \frac{\partial(V_v)}{\partial y} - \frac{1}{\sigma'}\frac{\partial(\sigma' V\dot{\gamma})}{\partial \gamma} - fU + \left(\phi - \frac{RT^*\sigma\Pi}{P}\right)\frac{\partial \Pi}{\partial y} - \frac{\partial(\Pi\phi)}{\partial y} + F_V$$

The equations of horizontal motion are decomposed into zonal motion, carried by the parameter u and in meridian motion carried by the parameter v.

The generalized vertical velocity is obtained by:

$$\dot{\gamma} = -\frac{1}{\Pi\sigma'}\int_0^{\gamma}\sigma'\left(\frac{\partial\Pi}{\partial t}+\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right)d\gamma^*$$

The temporal derivation of the pressure is obtained by the integration with respect to the vertical of the continuity equation and one assumes as zero the pressure on the surface of the domain:

$$\frac{\partial\Pi}{\partial t} = -\int_0^1\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right)\sigma' d\gamma$$

The hydrostatic equation is:

$$\frac{\partial\phi}{\partial\hat{P}} = -C_p\theta\,(1+0{,}61\,q_v)$$

$$\hat{P} = \left(\frac{P}{P_0}\right)^k$$

$$k = \frac{R}{C_p}$$

$$\sigma' : \frac{d\sigma}{d\gamma}$$

$$U = \Pi\,\mathrm{u}$$

$$V = \Pi\,\mathrm{v}$$

$$\theta = T\left(\frac{P}{P_0}\right)^{-\frac{R}{C_P}}$$

$$T* = T\left[1+0.61q_V\right]$$

- **Thermodynamic equations**

Thermodynamic variables are entropy S and humidity W

$$S = \Pi\left(\ln\left(\frac{T}{\hat{P}}\right)+\frac{Lq_V}{C_P P}\right)$$

$$W = \Pi(q_V + q_{CW})$$

$$L = 597{,}3 - 0{,}566\,(T - 273{,}16)$$

The evolution equations of S and W are as follows:

$$\frac{\partial S}{\partial t} = -\frac{\partial(Su)}{\partial x}-\frac{\partial(Sv)}{\partial y}-\frac{1}{\sigma'}\frac{\partial(\sigma' S\dot{\gamma})}{\partial\gamma}+F_S$$

$$\frac{\partial W}{\partial t} = -\frac{\partial(Wu)}{\partial x}-\frac{\partial(Wv)}{\partial y}-\frac{1}{\sigma'}\frac{\partial(\sigma' W\dot{\gamma})}{\partial\gamma}+F_W$$

The temperature T is calculated from S and W but the following conditions must be respected:

If the air is saturated, the mixing ratio (ratio of the mass of water vapor to that of the dry air is associated) of the water vapor qv is a function of the temperature

If the air is not saturated, the mixing ratio of the non-precipitating cloud water is zero and the mixing ratio of the water vapor qv is replaced by $\frac{W}{\Pi}$

The temperature and mixing ratios of water vapor and cloud water have the following expressions:

$$W > \pi q_{vs} \quad \Longrightarrow \quad \begin{cases} q_v = q_{vs} \\ q_{cw} = \dfrac{W}{\pi} - q_{vs} \\ T = T_S \end{cases}$$

T_S is a saturated temperature

$$W \ \pi q_{vs} \quad \Longrightarrow \quad \begin{cases} q_v = \dfrac{W}{\pi} \\ q_{cw} = 0 \\ T = T_{inS} \end{cases}$$

T_{inS} is an unsaturated temperature

According to MURRAY (1967), the saturation water vapor mixing ratio qvs is easy to calculate using the expression of saturation vapor pressure with respect to water e_s .

$$q_{vs} = 0{,}622 \, x \, \frac{e_s}{P}$$

e_s = 6,11 exp (17,27 (T−273,16)/ (T − 35,86)),

4.2 Atmospheric boundary layer

- **The planetary boundary layer**

The planetary boundary layer is located between Z_B, altitude of the first grid point above the surface and Z_A, a given height where the wind is no longer influenced by the effects of the ground is 1 km.

According to O'Brien (1970), K represents the exchange coefficient; Ku is relative to the momentum and KT is relative to the exchanges of temperature and humidity, between levels Z_A and Z_B.

The expression of K is given by:

$$K = K_A + \left[\frac{([(Z_A - Z_B)]^2)}{\Delta Z^2}\right]\left[K_B - K_A + (Z - Z_B)\left(K'_B + 2(K_B - K_A)\right)/\Delta Z\right]$$

$\Delta Z = Z_A - Z_B$

K' : the derivation of K with respect to Z;

$K'_A = 0$;

$k\,(u)\ et\ k\,(t)$ are equal to zero for heights greater than Z_A .

The terms of the rubs are written as follows:

$$F_U = A\,\frac{\partial}{\partial_\gamma}\left(AK(u)\frac{\partial U}{\partial\gamma}\right)$$

$$F_v = A\,\frac{\partial}{\partial_\gamma}\left(AK(u)\frac{\partial V}{\partial\gamma}\right)$$

$$F_s = A\,\frac{\partial}{\partial_\gamma}\left(AK(T)\frac{\partial s}{\partial\gamma}\right)$$

$$F_w = A\,\frac{\partial}{\partial_\gamma}\left(AK(T)\frac{\partial w}{\partial\gamma}\right)$$

$$\text{With } A = -\frac{gP}{2T\pi\sigma'}$$

At the lower limit ($\gamma = \sigma = 1$) ;

$$AK(u)\frac{\partial U}{\partial \gamma} = \pi u^2 \cos \propto$$

$$AK(u)\frac{\partial V}{\partial \gamma} = \pi u^2 \sin \propto$$

$$AK(T)\frac{\partial S}{\partial \gamma} = \pi \left(\frac{Q_S P}{T} + \frac{LQ_e}{C_P}\right)$$

$$AK(T)\frac{\partial W}{\partial \gamma} = \pi Q_e$$

The heat flow πQ_s and the moisture flow πQ_e have the expressions below:

$$\pi Q_s = (\theta_0 - \theta_h)\sqrt{(U_h^2 + V_h^2)}/FG$$

$$\pi Q_e = (q_0 - q_h)\sqrt{(U_h^2 + V_h^2)}/FG$$

Tanα = $\frac{V_h}{Uh}$: report of the two horizontal components of speed at the level Z_B=h

- **Surface boundary layer**

This layer is the part of the atmospheric boundary layer directly in contact with the earth's surface. In this region, the effects of Coriolis force are negligible compared to the friction forces due to the ground, the wind direction is constant, and the wind structure is determined solely by the dynamic effects generated by the soil and thermal stratification. air. According to the formulation of BUSSINGED-DYER, (NICKERSON and SMILEY), the speed of friction u', and the sensible heat flow as well as the latent heat flow are given by:

$$\frac{u}{u^*} = F\left(\frac{Z}{L'}\frac{Z}{Z_0}\right)$$

$$\frac{(\theta - \theta_0)\,u^*}{-\overline{W'\theta_0}} = G\left(\frac{Z}{L'}\frac{Z}{Z_0}\right)$$

Where L: length of MONIN-OBUKHOV,

Z_0 : Roughness length,

F, G: stability functions that depend on thermal stratification.

The roughness length is obtained by a relationship between soil type and vegetation type. On this model, Z_0 is set to 0.01m.

By linking the theoretical formulation with the discretization scheme used on this model, the global Rihardson number for the surface layer is:

$$R_{tB} = \frac{hg(\theta_h - \theta_0)}{\theta_h u_h^2}$$

The length of MONIN-OBUKHOV has the following expression:

$$L = -\frac{u_*^3 \theta_h}{Kg\overline{W'\theta_0'}}$$

With K is a constant of VON KARMAN. The indices 0 and h are relative to the ground and to the altitude Z = h. To combine the given values of the Richardson number with the roughness length where Z becomes h, this equation becomes a transcendental equation in h / L that can be solved by Newton's method,

$$R_{tB} = \frac{Gh}{KLF^2}$$

$$G\left(\frac{h}{L'}\frac{h}{Z_0}\right) - KF^2\left(\frac{h}{L'}\frac{h}{Z_0}\right) R_{tB} = 0$$

Knowing $\frac{h}{L'}$', the speed of friction and the heat flux have the following relations:

$$u_* = \frac{u_h}{F\left(\frac{h}{L'}\frac{h}{Z_0}\right)}$$

$$\overline{W'}\overline{\theta_0'} = u_h(\theta_0 - \theta_h) / \left[F\left(\frac{h}{L'}\frac{h}{Z_0}\right) G\left(\frac{h}{L'}\frac{h}{Z_0}\right)\right]$$

$$\overline{W'}\overline{q_0'} = u_h(q_0 - q_h) / \left[F\left(\frac{h}{L'}\frac{h}{Z_0}\right) G\left(\frac{h}{L'}\frac{h}{Z_0}\right)\right]$$

u_* : speed of friction

u_h : horizontal wind speed at Z=h,

F, G : stability functions that depend on thermal stratification,

$\overline{W'}\overline{\theta_0'}$: sensible heat flux,

$\overline{W'}\overline{q_0'}$: latent heat flow.

According to these three conditions below, the functions F and G have the following expressions: - Unstable conditions:$\theta_0 - \theta_h > 0$

$$KF = ln\left[\frac{(\xi-1)(\xi_0+1)}{(\xi+1)(\xi_0-1)}\right] + 2\tan^{-1}\xi - 2\tan^{-1}\xi_0$$

$$KG = R_c ln\left[\frac{(\eta^2-1)(\eta_0+1)}{(\eta^2+1)(\eta_0^2-1)}\right]$$

$$\xi = \sqrt[4]{(1-\delta Z/L)}$$

$$\xi_0 = \sqrt[4]{(1-\delta Z_0/L)}$$

$$\eta = \sqrt[4]{1-\delta'' Z/L}$$

$$\eta_0 = \sqrt[4]{1-\delta'' Z_0/L}$$

ξ, ξ_0, η, η_0 : are surface layer functions

δ, δ'' : surface layer constants,

R_c : boundary layer constant,

$\gamma = 15$,

$\gamma'' = 9$, $R_c = 0{,}74$.

Conditions faiblement stables : $\frac{Z}{L} < 1$

$$KF = \ln(Z/Z_0) + \beta Z/L$$
$$KG = R_c \ln(Z/Z_0) + \beta Z/L$$

β= 4,7 is a surface layer constant

Very stable conditions: $\frac{Z}{L} > 1$

According to WEBB (1970),

$$KF = \ln(Z/Z_0) + (\beta lnZ/L) + \beta$$

$$KG = R_c \ln(Z/Z_0) + (1 + \beta - R)\ln(Z/L) + \beta$$

4.3 Digital processing of Evertt's model C. Nickerson and Elmer L. Magaziner (1976)

The model takes into account different boundary layers. The value of Z0 is introduced and takes a different value depending on the case where the field of study concerns the oceans or the terrestrial surface.
Temperature, wind components and humidity are relatively insensitive to Z0
At the upper limit, the vertical velocity is taken as zero and the pressure is 100 mb.

- **Initial conditions**

This model is initialized from the radiosonde data.
The moisture flow and the heat flow as well as the precipitation are initialized to zero. All microphysical variables and exchange coefficients are zero at the beginning of the simulation.

- **Conditions to the limits**

At the upper limit $\sigma = \gamma = 0$ and $\gamma = 0$ and = 0
At the upper limit and on the ground, the thermodynamic variables are specified.
On the lateral boundaries, the winds are specified by incoming flows and extrapolations from the inside values to the outflow. By incoming flow, the winds take their initial value, by outflow, they are calculated assuming that the normal derivative is equal to zero.

For the digital processing of the model, the atmosphere is divided into 15 levels in the γ coordinate system

Below the table of comparison between the coordinate systems σ and γ, it can be deduced that the coordinate γ makes it possible to have a resolution of the planetary boundary layer finer than the coordinate σ

Table-1: Coordinates σ and γ

γ	σ
0.0000	0.0000
0.0333	0.0444
0.1000	0.1333
0.1667	0.2220
0.2333	0.3101
0.3000	0.3973
0.3667	0.4829
0.4333	0.5660
0.5000	0.6458
0.5667	0.7212
0.6333	0.7908
0.7000	0.8533
0.7667	0.9071
0.8333	0.9504
0.9000	0.9813
0.9667	0.9978
1.0000	1.0000

5. Resolved by simulation

5.1 Wind parameter

Table-2: Average and maximum wind speeds in m / s and km / h and their directions for 3 sites

	MOIS	JANV	FEV	MARS	AVRIL	MAI	JUIN	JUIL	AOUT	SEPT	OCT	NOV	DEC	
ANTSIRANANA	Vmoy km/h	15	13	14	17	20	23	27	29	30	28	22	17	km/h
		4,17	3,61	3,89	4,72	5,56	6,39	7,50	8,06	8,33	7,78	6,11	4,72	m/s
	Direction	S	S	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	
	Vent Max	220	130	119	252	148	180	227	216	180	191	115	223	
TAOLAGNARO	Vent moy	21	22	17	16	14	14	16	19	21	23	19	19	km/h
		5,83	6,11	4,72	4,44	3,89	3,89	4,44	5,28	5,83	6,39	5,28	5,28	m/s
	Direction	E	NE	NE/E	NE/E	NE/E	NE/E	NE/E	NE/E	NE	NE	E	NE	
	Vent Max	119	151	144	112	126	162	94	104	126	155	126	108	
VOHEMAR	Vent moy	15	14	16	18	23	26	28	29	27	25	18	15	km/h
		4,17	3,89	4,44	5,00	6,39	7,22	7,78	8,06	7,50	6,94	5,00	4,17	m/s
	Direction	S	S/SE	S	S	S	S	S	S	S	S	S	S	
	Vent Max	220	68	104	86	94	104	101	101	97	97	68	119	

5.2 Graphs obtained after simulation

- **Maximum energy extracted per m2 and per hour for a wind speed v between 3.61 and 8.33 m/s**

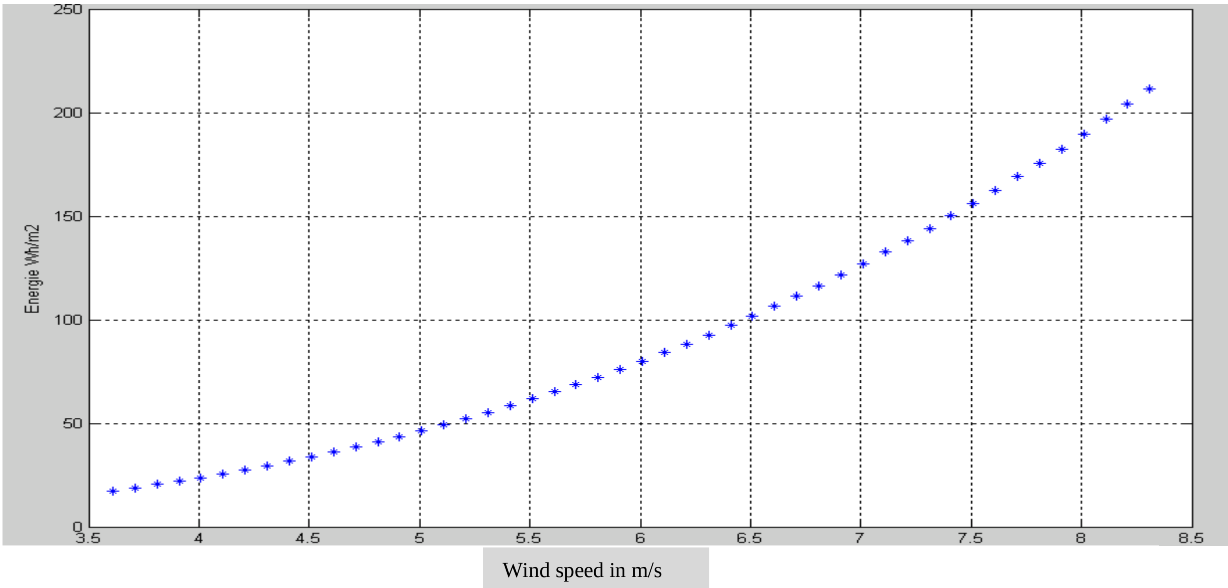

Chart-2: Maximum energy extracted per m2 and per hour for a wind speed v between 3.61 and 8.33 m/s

- **Wind power per unit area**

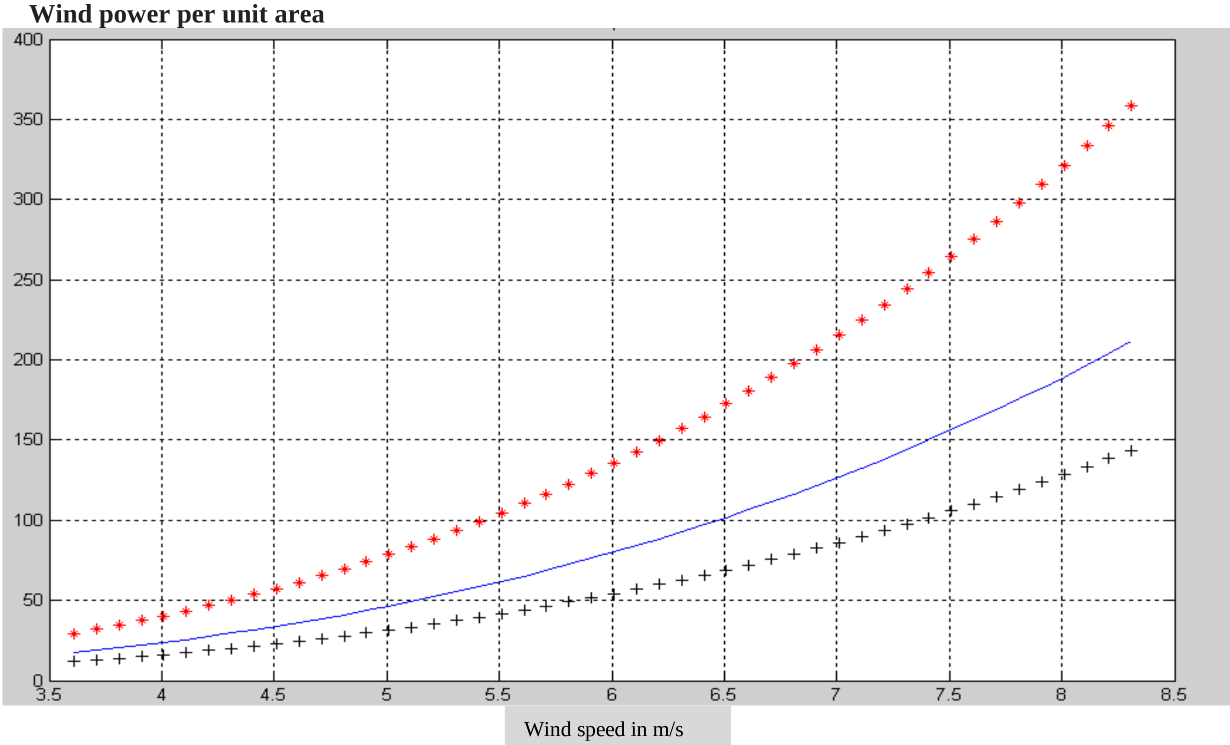

Chart-3: Wind power per unit area

<u>Legend</u>:

Vertical coordinate: P: wind power in Watt/m2
Curve 1 (left): Available power on the site (asterix curve)
Curve 2 (center): Maximum recoverable power (solid line)
Curve 3 (right): Power generally recoverable with Cp = 0.4 (curve in +)

- **Density of wind speeds in 3 sites**

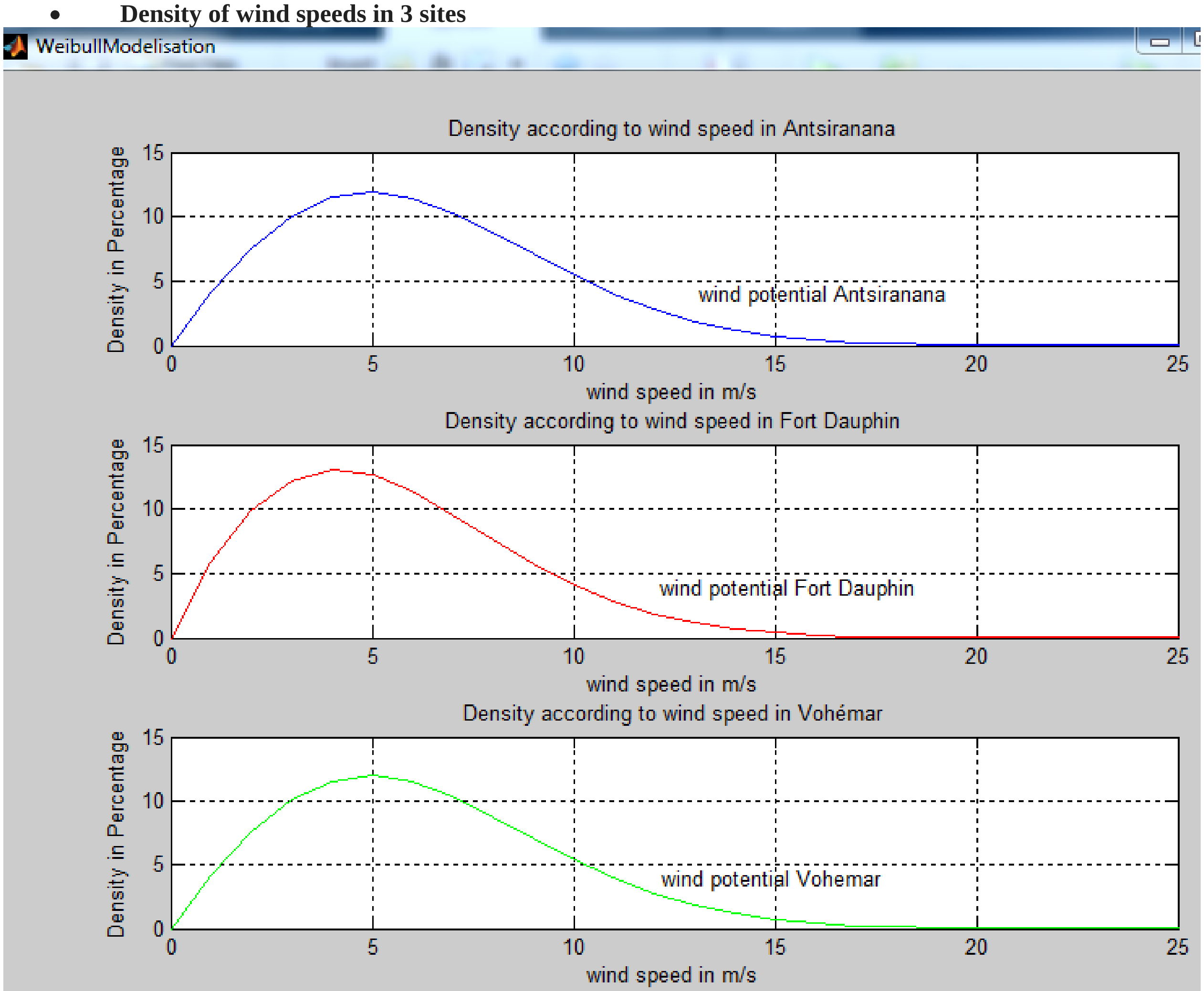

Chart-4: Density of wind speeds in 3 sites

We know that wind turbines rotate for wind speeds between 4 and 25 m / s. These curves show that these sites have interesting wind potentials.
Since vertical axis wind turbines can run even at relatively low wind speeds, production at these sites is attractive.

- **Variation in temperature and pressure as a function of altitude**

The variation of the atmospheric pressure with the altitude is the change of the pressure according to the altitude in the particular case of an object located in the open air above the terrestrial ground. The earth's atmosphere is never in equilibrium because of the solar warming of the soil. However, one can define a normalized atmosphere, supposedly in equilibrium and where the atmospheric pressure decreases with the altitude according to a law with the power 5.25. The pressure is reduced by a factor of 2 at the altitude 5 500 m and a factor of 10 at 16 km.
By taking the sea level as the reference altitude z0, and assuming for the atmosphere an average state defined by the standard ICAO type atmosphere (Temperature 15 ° C = 288.15 K, pressure 1013.25 hPa, vertical gradient

temperature 0.65 K per 100 m), we obtain the international formula of barometric leveling giving the pressure p (z) expressed in hectopascals (or millibars) at the altitude z expressed in meters

$$p_h = 1013 \cdot 25 \left(1 - \frac{0{\cdot}0065\, h}{288{\cdot}15}\right)^{5{\cdot}255}$$

We can therefore model the variations by the function p of the real variable h, defined on the interval [0; 11,000 m]; limit of the troposphere
In the troposphere; the atmospheric pressure varies between 1013.25 hPa on the ground (altitude = 0m) to 226.51 hPa on the upper limit of this zone (altitude = 11km)

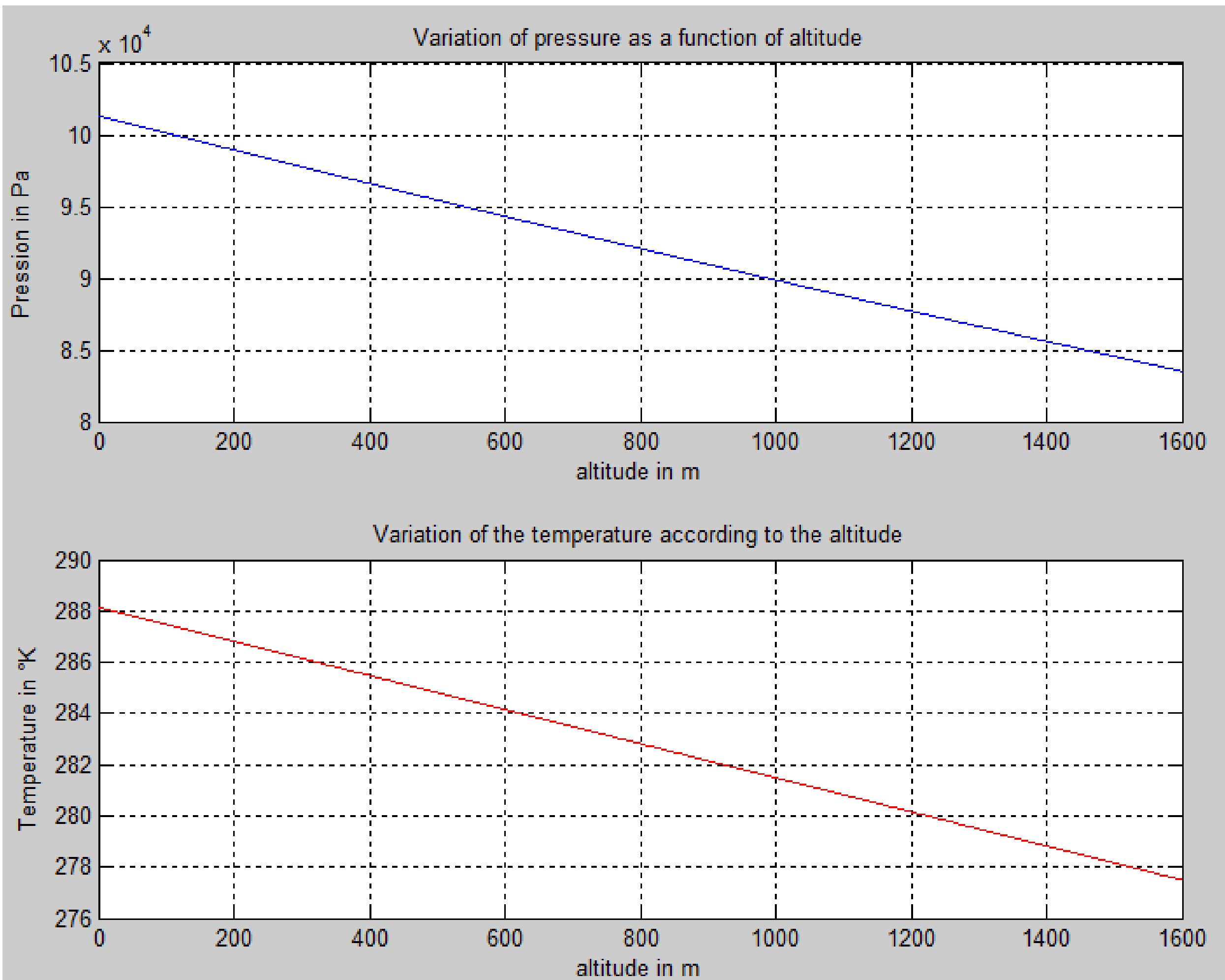

Chart-5: Variation in temperature and pressure as a function of altitude

We can see that temperature and pressure are two decreasing functions of altitude.

- **Simulation of impacts Pressure, temperature and humidity on wind power**

The following simulations show the impacts of meteorological parameters on wind power
First, we will give formulas linking meteorological parameters with wind power.

In the first case, we will simulate with the assumption that the wind is dry.

As the wind power is a function of the wind density, we will see the expression of the latter as a function of pressure and temperature, this is given by:
Demonstration:

$$\rho(\mathrm{P},\mathrm{T}) = \frac{P}{287{\cdot}06\,T}$$

$$T = 273\cdot 15 + \theta$$

P represents the atmospheric pressure in (Pa) and θ the temperature in (° C), T the temperature in (K).
Wind power under dry air conditions per unit area is given by

$$P_{eol}(\mathrm{P},\mathrm{T}) = \frac{1}{2}\,\frac{P}{287{\cdot}06\,T}\,v^3$$

Let $\varphi_1(\mathrm{P},\mathrm{T})$ be the coefficient that reflects the influence of pressure and temperature on wind power, it is given by

$$\varphi_1(\mathrm{P},\mathrm{T}) = \frac{P_{eol}(\mathrm{P},\mathrm{T})}{P_{dispo}}$$

Normally $\varphi_1(\mathrm{P},\mathrm{T})$ must be less than Un (01) because $P_{dispo} \geq P_{eol}(\mathrm{P},\mathrm{T})$
With P_{dispo} wind power available dry air on a site, under normal conditions of pressure and temperature, per unit area,

$$P_{dispo} = \frac{1}{2}\rho_0 . v^3$$

v^3 the cubic mean wind speed, ρ_0 is the constant density of dry air.

$$\varphi_1(\mathrm{P},\mathrm{T}) = \frac{\frac{1}{2}\frac{P}{287{\cdot}06\,T}\,v^3}{\frac{1}{2}\rho_0 . v^3}$$

$$\varphi_1(\mathrm{P},\mathrm{T}) = \frac{P}{287{\cdot}06\,T\rho_0}$$

Evolution of the coefficient $\varphi_1(\mathrm{P},\mathrm{T})$ as a function of the atmospheric pressure and temperature

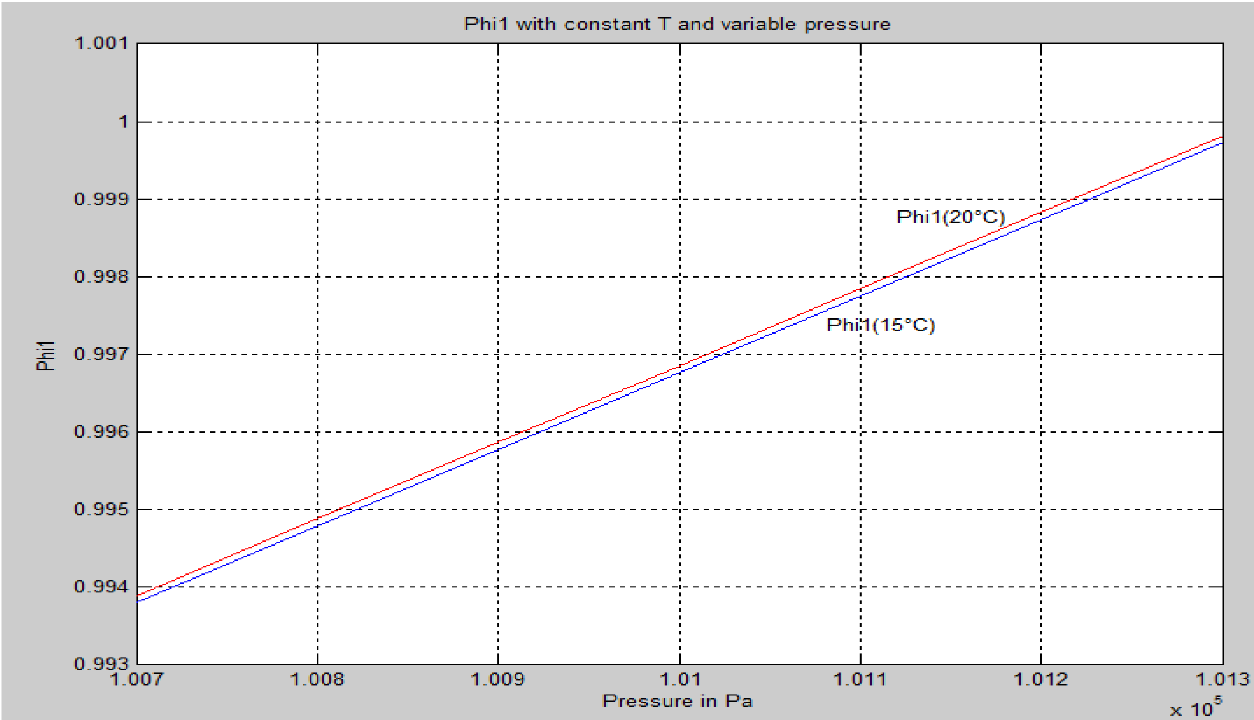

Chart-6: Evolution of phi 1 for two temperature values

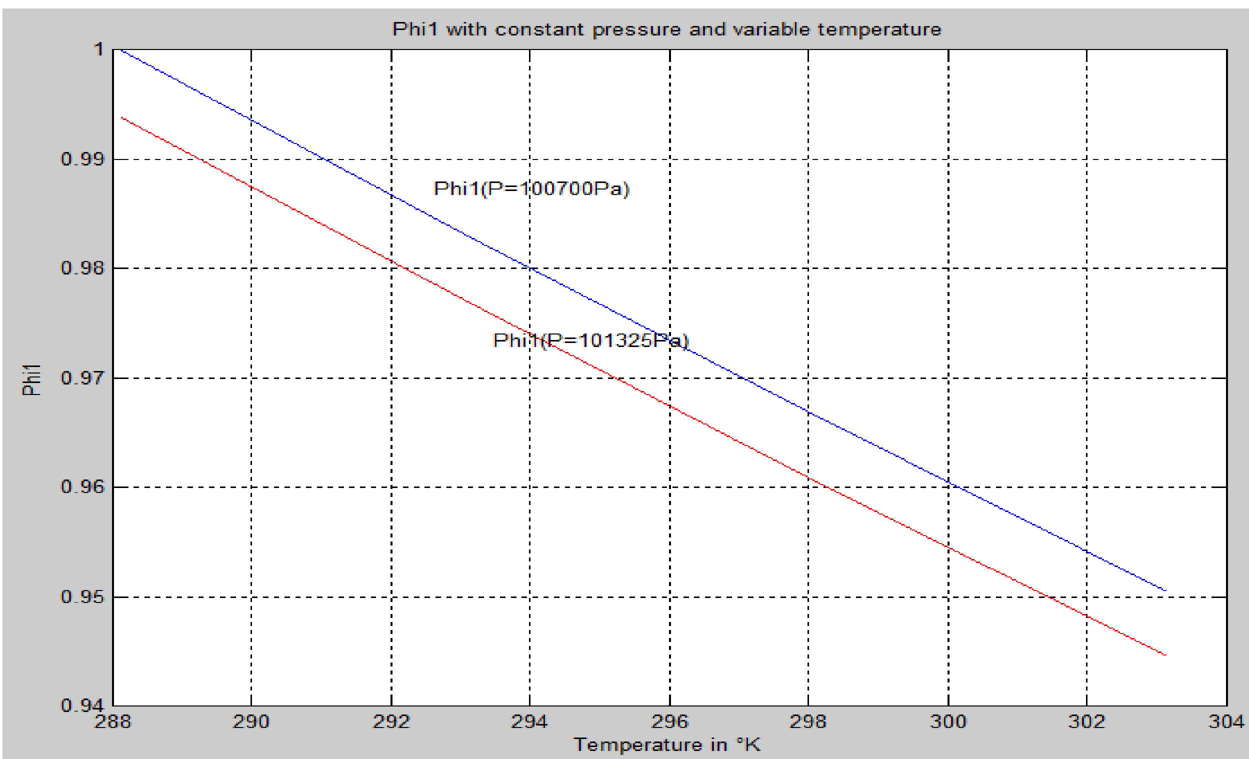

Chart-7: Evolution of phi 1 for two pressure values

Wind power is a decreasing function of temperature. It is found that the two curves are parallel, this figure demonstrates our previous theory with respect to the fact that the pressure increases; more production increases. For the same value of the temperature, the higher the pressure, the more the production ncreases.

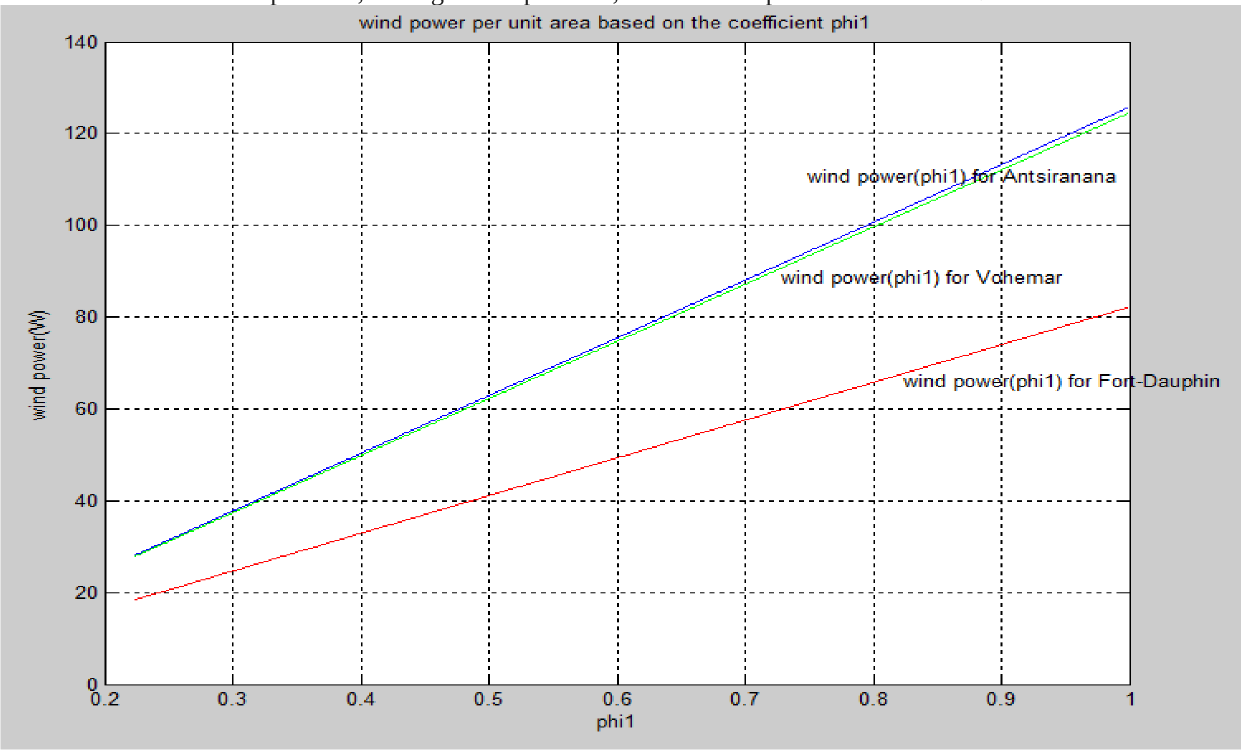

Chart-8: Evolution of wind power per unit area according to the coefficient phi 1

We can see that wind power increases with $\varphi_1(\mathrm{P,T})$

$\varphi_1(\mathrm{P,T})$varies from 0.22 to 1, which means that on the ground, for a normal atmospheric pressure, one can capture all the available energy but at the limit of the troposphere only 22.2% of the available energy can be extracted. Power increases proportionately with increasing wind speed

In the second case, we will simulate with the assumption that the wind is wet.
The goal here is to show the effects of air humidity on wind power

Demonstration:
The density of the wet wind is given by:

$$\rho(\mathrm{P,T},H_r) = \frac{P}{R_h\,T}$$

$$\mathrm{R_h} = \frac{\mathrm{R_s}}{1-\left(\mathrm{H}\,\frac{\mathrm{P_{sat}}}{\mathrm{P}}\right)\left(1-\frac{\mathrm{R_s}}{\mathrm{R_v}}\right)}$$

$R_s = 287 \cdot 06J\ /\mathrm{kg}\,.\,\mathrm{K}$ is the specific constant of the air

Rv=461 J/kg.K

$$H_r = \frac{P}{P_{sat}}\ x\,100$$

Hr is the relative humidity in%
P is the pressure and Psat is the saturation pressure

$$P_{sat} = 6110 \cdot 213\, exp\left(\frac{17 \cdot 5043\, \theta}{\theta + 241 \cdot 2}\right)$$

With -30< θ<70˚C

Density finally gives,

$$\rho(\mathrm{P}, \mathrm{T}, H_r) = \frac{P}{287 \cdot 06\, T}\left(P - 230 \cdot 617 H_r\ exp\left(\frac{17 \cdot 5043\, \theta}{\theta + 241 \cdot 2}\right)\right)$$

The power of the wet wind is given by,

$$P_h(\mathrm{P}, \mathrm{T}, H_r) = \frac{1}{2}\,\frac{P}{287 \cdot 06\, T}\left(P - 230 \cdot 617 H_r\ exp\left(\frac{17 \cdot 5043\, \theta}{\theta + 241 \cdot 2}\right)\right) v^3$$

That is $\varphi_2(\mathrm{P}, \mathrm{T}, H_r)$, the coefficient that reflects the influence of the pressure, the temperature and the humidity on the wind power, it is given by,

$$\varphi_2(\mathrm{P}, \mathrm{T}, H_r) = \frac{P_h(\mathrm{P}, \mathrm{T}, H_r)}{\boldsymbol{P_{dispo}}}$$

Replacing $P_h(\mathrm{P}, \mathrm{T}, H_r)$ *and* $\boldsymbol{P_{dispo}}$ with their expressions, we have,

$$\varphi_2(\mathrm{P}, \mathrm{T}, H_r) = \frac{\frac{1}{2}\frac{P}{287 \cdot 06\, T}\left(P - 230 \cdot 617 H_r\ exp\left(\frac{17 \cdot 5043\, \theta}{\theta + 241 \cdot 2}\right)\right) v^3}{\frac{1}{2}\rho_0 . v^3}$$

After simplification, we find,

$$\varphi_2(\mathrm{P}, \mathrm{T}, H_r) = \frac{1}{351 \cdot 6485\, T}\left(P - 230 \cdot 617 H_r\ exp\left(\frac{17 \cdot 5043\, \theta}{\theta + 241 \cdot 2}\right)\right) v^3$$

After simulation; we obtain the graph above:

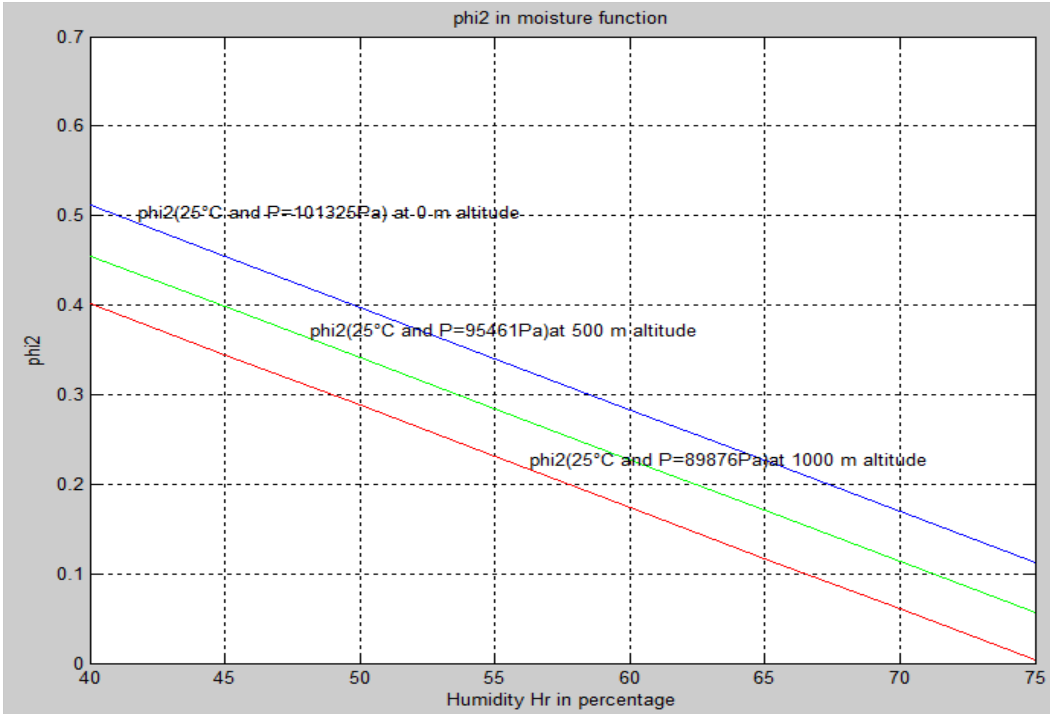

Chart-9: Graph of the effect of humidity on wind power at constant temperature and variable pressure

It is advantageous to put the blades in a low altitude; in order to have higher atmospheric pressures; in humid regions to achieve optimal production

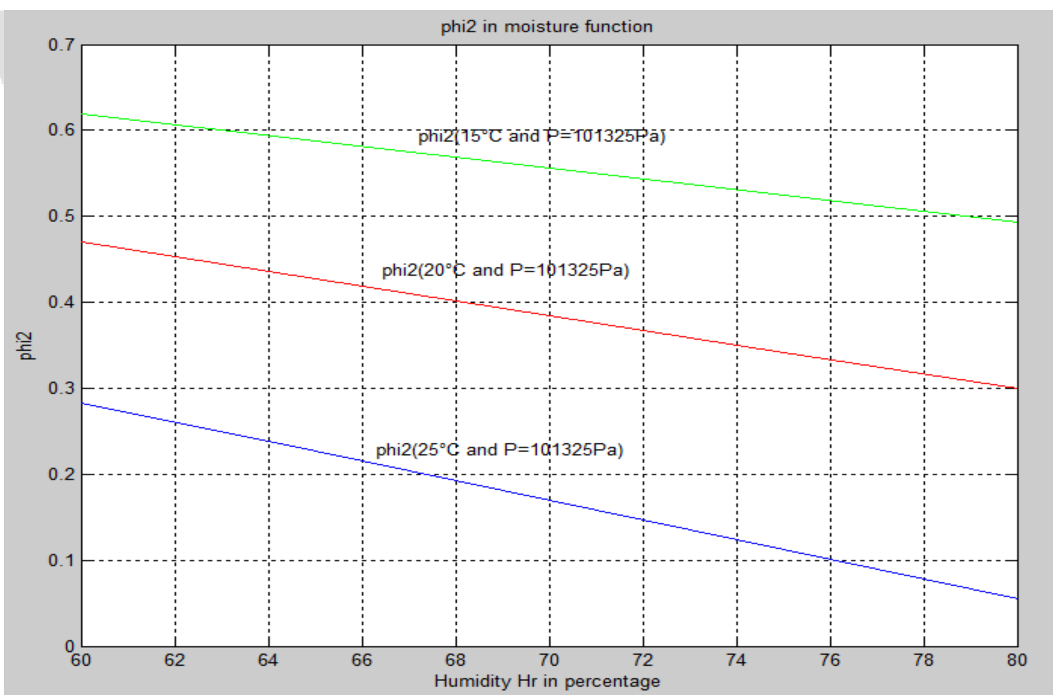

Chart-10: Graph of the effect of humidity on wind power at constant pressure and variable temperature

It can be seen that at constant pressure, the higher the temperature, the lower the value of $\varphi_2(P,T,H_r)$, so the energy production decreases.
Then the value of $\varphi_2(P,T,H_r)$decreases, the humidity increases.
Humidity thus slows down the production of wind energy; winter is not conducive to wind energy production.
During this period ; it is more interesting to combine the production of energy with other energy sources.

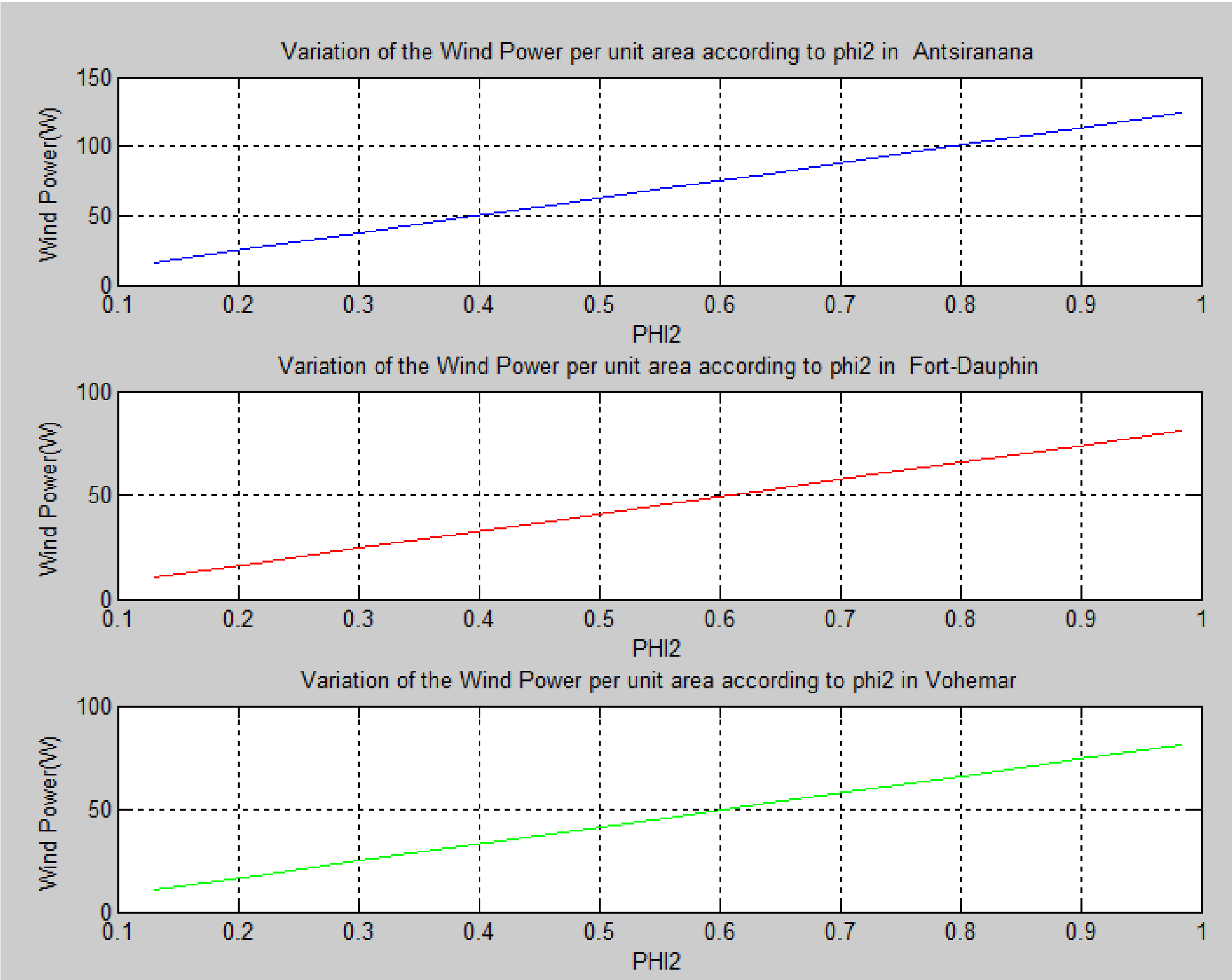

Chart-11: Variation of the wind power as a function of $\varphi_2(P,T,H_r)$

According to this figure, the wind power increases proportionally with the values of $\varphi_2(P,T,H_r)$and the wind speed.

6. Energy planning proposal

The objective of this section is to make a proposal for energy planning for wind energy production.
After performing several simulations with meteorological parameters; we can say that the wind energy produced is more interesting from the month of May to the month of October because during this period the pressure and the wind speed reach their maximum values compared to the rest of the year, moreover as winter is the temperature and humidity are lower.
We know from the previous results that increasing wind pressure and wind speed, as well as decreasing air temperature and humidity are favorable for extracting the maximum amount of wind energy.
Therefore, from the month of November to the month of April, it is recommended to combine the wind energy installation with other energy sources or to increase the infrastructures to be able to obtain the same quantity of

energy as during the winter because all meteorological parameters have values that do not favor production during this period.

7. CONCLUSIONS

This simulation allowed us to understand that meteorological parameters have significant effects on wind energy production.
Using the model of Evertt C. Nickerson and Elmer L. Magaziner (1976), it was possible to model the values of wind parameters in the three sites studied.
Atmospheric pressure, outdoor temperature, wind speed and humidity influence wind energy production
The temperature decreases by 6.5 K per kilometer; pressure also decreases with altitude as the wind speed increases with this same altitude
The values of these parameters are very dependent on the weather conditions
The more you increase the height of the nacelle; the higher the wind speeds and the lower temperatures; which favors the production of energy. On the other hand in this case, the pressure decreases which slows the production.
It is therefore important to perform the studies well in order to identify the optimal values of these meteorological and geographical parameters in order to produce the maximum wind power in a given site.
On the variability of wind speeds and wind power, it has been confirmed that the sites have a huge wind potential.
The wind is unevenly distributed over the surface of the globe. The geography of a site can vary wind speeds significantly only a few kilometers away. However, it is fundamental to know precisely the wind power site, since it is from him that depends the economic viability of a wind project. It is therefore necessary to set up beforehand a measuring mast which will record the behavior of the wind for several months, or even several years. The wind power available is mainly a function of the cube of the wind speed. This means, for example, that a 10% increase in wind speed increases the available wind energy by 30%.
Given the problem of energy supply in Madagascar, and the frequent cut of electricity because supply can no longer meet the demand, the state must consider using other energy sources such as wind.

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