MODELING OF A WIND ENERGY CONVERSION SYSTEM OF VARIABLE SPEED CONSIDERING THE BUCKLING PHENOMENON OF THE TOWER

Pablo Sánchez,

Nelson Aros

Universidad de La Frontera, Departamento de Ingeniería Eléctrica

Abstract

The effect of buckling of the tower of a system of wind energy conversion studies, of variable speed (WECSVV), on the production of electrical energy. The used model to describe the problem of buckling in WECSVV is based on the application of blade element momentum method, BEM, in stationary regime, the theory of electrics generators and the theory of structures type beams. The resulting model is multi-variate, nonlinear and with external disturbances. An analysis in open loop is realised and the results throw that variations in the entries exert different effects on the WECSVV when is had and the phenomenon of buckling of the tower does not consider. If the phenomenon is added in the calculations of power transference, then a percentage of electrical energy truly is not transferred to the network, whereas if it does not consider, the same percentage falsely is transferred to the network.

Key words: *Wind energy conversion; Model nonlinear; Hammerstein model.*

1. Introduction

Continuously the technology used in the different industrial processes has been evolving in efficiency to an increasing rate, which has implied the establishment of lines of work where the costs and the used energy are due to optimize (Sáez, 2000). According to it the processes of generation of electrical energy are not exempt, have been object of many studies, in particular the generation by means of wind energy, with a strong emphasis from 1980 - call modern period of the wind technology by his already very known kindness and disadvantages use, but at the same time applying a powerful technology still in maturation stage (Baker, 2007).

On the other hand, in Amirat (2009) it is realised a study of monitoring of conditions and diagnosis of faults of aerogenerators with productions of power of the order of the MW; and they are indicated that the most common faults are in the stages: electrical (17,5%), aerodynamics (13,4%), hydraulics (13,3%) and of control (12,9%), whereas in which less faults appear they are in the stages; structural (1,5%), restrained mechanic (1,2%) and in the axis of discharge and low speed (1,1%).

In Arifujjaman (2009) a study of realizability of the stages of signal conditioning by means of applied electronics of power to aerogenerators based on permanent magnet generators is realised, whose production of power does not surpass the 2 KW and mentions the percentage of faults of the stages, which reveals that the stages with greater amount of faults are: Aerodynamics (33,4%), electrical (20%), hydraulics (13,5%) and control (16,5%), whereas the stages with smaller amount of faults are: structural (1,9%), restrained mechanic (1,2%) and in the axis of discharge and low speed (1%).

In a system of wind energy conversion - WECS- one of the main problems is to obtain the optimal transference of energy from the wind field to the load, still more in a system of conversion of variable speed, the energy transfer coexists in a bilateral dependency, that is to say, kinetic energy absorption of the wind and delivery of electrical energy to a load (Steinbuch, 1989).

1.1. WECS models

The models that are used for the SCEVV are very defined. This must to that always the models have as bases the Newtonian Mechanics or the Methods of Energy based on the Hamilton's Theory.

Considering that the tower is a system of parameters distributed space and that the study of the buckling dynamics or flexion already is certain, then the main works carried out in this area appear: Several models possible exist to realise a study of the bending of a tower. In Meirovich (2001) it is mentioned the dynamic ones of cords in cross-sectional vibration. I sweep cylindrical in axial vibration, bars in torsion and beams in buckling. For all of them a proposed model is discretizado or of discrete masses, that consists of doing basically that the discreet masses divide the structure in n-sections, and the unions between those sections are called nodes. The forces are exerted with an intensity on each mass in a certain time. The movement is governed by ordinary differential equations and each equation is for a single mass. Those treat in independent form and later the effects produced by each are added to produce the total effect. The disadvantage is the computer effort because if increases the amount of nodes more equations are due to solve.

Another case for analysis of cords in cross-sectional vibration, I sweep cylindrical in axial vibration, bars in torsion and beams in buckling, is the model of energy through exposition of a Hamiltonian function by means of the Hamilton's extended principle (Meirovich, 2000), which leans of the concept of virtual work. The advantage of this exposition is not that it is not necessary to establish the direction of the forces consequently and, either are convention signs that to establish to determine the cross-sectional, axial vibration, or the torsion and the bending of a Girder.

Also in Meirovich (2000) and Timoshenko & Gere (1963) appears a model of distributed parameters where the bending of a tower is solved as an opposite problem of value for the static case and problem of an initial and opposite value for the dynamic case. It is possible to notice that in the dynamic case the problem to solve is by means of an equation of D'alembert, Which includes temporary as spatial dynamics.

A simpler model consists of a mass with spring and muffling, (MCK), where the main effect to analyze is the frequency and oscillation amplitude of a rigid solid.

Anyone of the explained models previously serves to analyze the frequency and the oscillation amplitude, nevertheless the main difference among them resides in the exactitude and complexity of the analysis. As in this work it interests to study the effect of bending of a tower in the production energetics, anyone of the explained previous models, serves for the analysis, then for effect to simplify the work and without loss of majority, model MCK is applied.

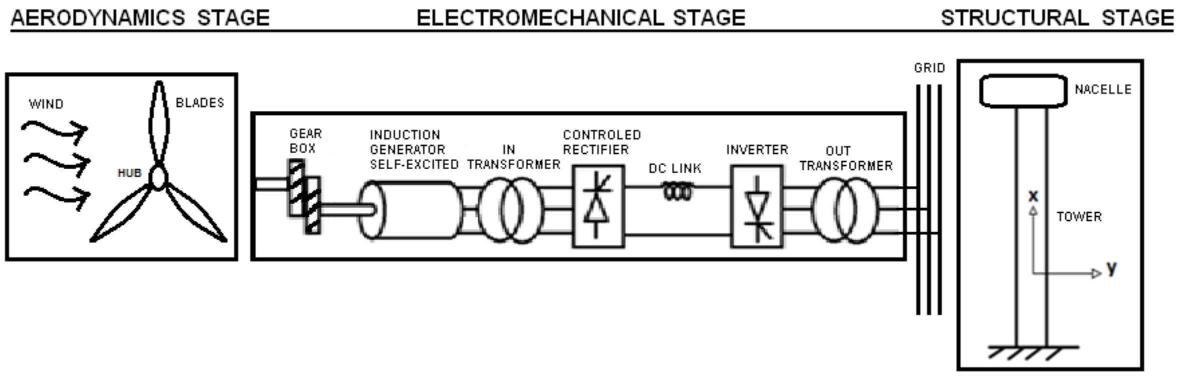
In order to understand the effect of torque and it forces of the vanes, exerted on the nacelle of a WECSVV, in Hansen (2008) and Burton (2001) is an exhaustive analysis on the aerodynamics of vanes, the types of generators commonly used and the applied methodologies of control on the WECSVV, thus also study the effects on the performance of the WECSVV due to the phenomena of shade of the vanes, turbulence and bending of the vanes. The elements that conform to the theory of blades of a WECSVV are: Blade element momentum method (BEM), moment method (M), Element of blade method (EB) and Vortex method (V) among others. In particular the analysis in this work is through the theory of the BEM in stationary state.

Though it is true, a slightly frequent phenomenon in the WECSVV is the structural fatigue (Amirat, 2009; Arifujjaman, 2009), the effect that it produces in the WECSVV has been investigated. Therefore according to the realised bibliographical study, investigations that they look for to analyze the effect of bending of a wind tower, against the power production are not detected. In such a way that the study to realise has by primary target, the evaluation of the effects of buckling of the tower of the WECSVV, in the production of electrical energy.

2. WECS proposed model

In this work the WECSVV with the following components is used: Blades, rotor of low speed, multiplying box, rotor of high speed, self-excited induction generator, rectifier controlled, dc link, inverter, load and tower; see Figure 1.

Figure 1. WECS components

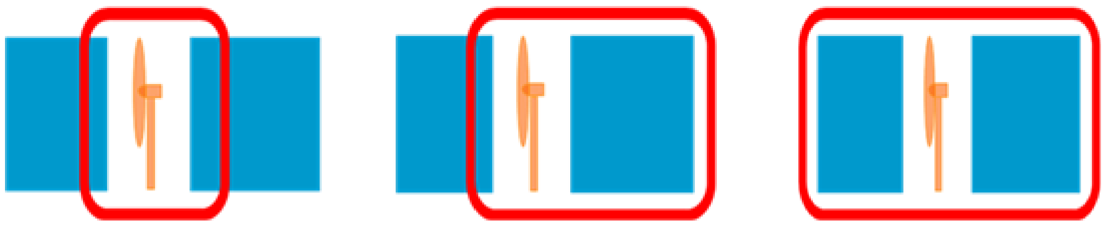


2.1. Aerodynamic stage

This stage essentially is made up of the blades and the Hub - the data are in Hansen (2008, page 59). Different types from analysis exist to study the aerodynamic phenomena in the wind turbines, which generally are classified according to the zone of work: a) Local zone, it is at the BEM, b) Semi-Global Zone, Estela's Theory of Vortexes is in use, and c) Global Zone, Navier-Stokes's Theory is in use for dynamics of fluids. In Figure 2 the zones of work and the theory are appraised with which they are analyzed (Munduate, CENER, 2007).

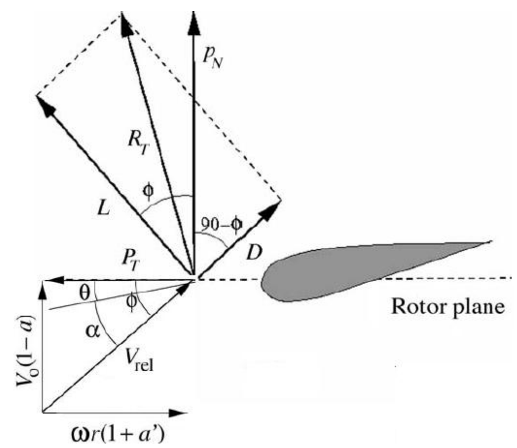
The aerodynamic analysis applied in this work is based on the theory of the classical blade element momentum method, BEM, in stationary regime (Burton, 2001; Hansen, 2008). Of this theory it is possible to obtain torque and the axial force when the wind hits with the blades. This is obtained by means of the knowledge of basic the structural data of the vane (Hansen, 2008). Basic the structural data of the blades, are: cord, , angle of flow, , length, , coefficients of elevation, , and drag . The Theory is based on the resolution of an iterative algorithm that allows finding the values of the factors of axial and tangential induction, since they are possible to determine torque, the axial force and the power coefficient of the turbine (see figure 3).

Figure 2. Zones of work for aerodynamic analysis of a wind turbine



Local zone: BEM   Semi-global zone: Stela of Vortexes   Global zone: Navier-Stokes

Figure 3. Diagram of torque and forces in l outline station of vane submissive a wind field



The existing connection between the aerodynamic stage and the electromechanical stage is by means of torque, the angular velocity of the axis of low speed generated by the turbine, and the power coefficient of the turbine. The existing connection that with the structural stage, is the total axial force, exerted by the turbine on the gondola. Total the axial force, is defined as sum of the axial forces, each station of vane (Burton, 2001), see figure 3.

2.2. Electromechanical Stage

This stage is in charge to perceive the movement of the axis from the box of gears and by means of magnetic induction it is obtained the generation of amplitude electricity and variable frequency. Later the energy happens through a transformer of reduction with relation of transformation 1: with <1, where it is the relation of returns of the transformer. Later this signal by means of a bridge of thyristors is rectified. When coming out of the bridge a rectifying stage of current is connected, whose connection is given by a coil and a resistance in series which receives the signal sends and smoothed it to the stage inverter. Later this signal is amplified by means of a transformer of elevation with relation :1 and finally is connected to the grid.

2.3. Structural stage

In figure 1 is the scheme of the structural stage. In order to understand the phenomenon of bending produced in the tower of a aerogenerator, it will be sent to figure 4. According to it, if a reference is placed X-Y in the base of the tower the bending takes place of the following way: When a wind field exists, that crosses a structure of type vertical column (tower), and to the vanes of a wind turbine takes place a force, on the gondola and this drags to the tower. Following the wind and of the structural parameters of the tower, it will be pandeará with respect to his axis (parallel axis to the tower) in a certain displacement angle. The model simplest to consider consists of a mass with means and damping, (MCK), see Figure 5.

Figure: Buckling of the tower

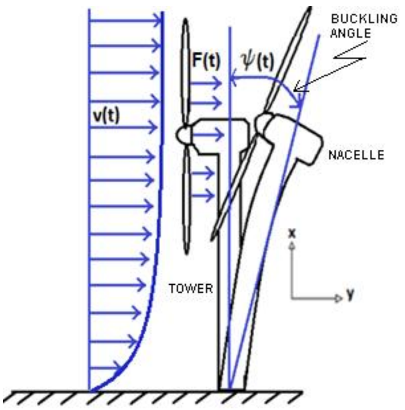
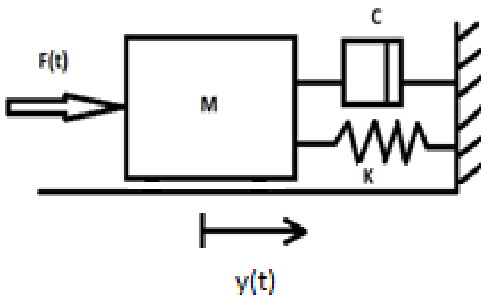


Figure: Model of the buckling of the Tower



In the light of the event of bending in the Aeolian system of conversion, it is possible to be analyzed the oscillations of the tower like a system mass-means-shock absorber, which comes from the exposition of the classic mechanics of Newton.

2.4. Nonlinear model of the WECSVV

$$\sigma_{r_i} = \frac{Bc_{r_i}}{2\pi r_i} \tag{1}$$

$$\phi_{r_i} = \tan^{-1}\left(\frac{1-a_{r_i}}{1+a'_{r_i} \quad \lambda_{r_i}}\right) \tag{2}$$

$$\alpha_{r_i} = \phi_{r_i} - \beta_{r_i} + \psi_{r_i}(t) \tag{3}$$

$$C_{n,r_i} = C_{L,r_i} \cos\phi_{r_i} + C_{D,r_i} \sin\phi_{r_i} \tag{4}$$

$$C_{t,r_i} = C_{L,r_i} \sin\phi_{r_i} - C_{D,r_i} \cos\phi_{r_i} \tag{5}$$

$$a_{r_i} = \frac{1}{\dfrac{4sen^2\phi_{r_i}}{\sigma_{r_i} C_{n,r_i}} + 1} \tag{6}$$

$$a'_{r_i} = \frac{1}{\dfrac{4\cos\phi_{r_i}\, sen\phi_{r_i}}{\sigma_{r_i} C_{t,r_i}} - 1} \tag{7}$$

$$V_{rel,r_i} = \frac{V(1-a_{r_i})}{\sin\phi_{r_i}} \tag{8}$$

$$L_{r_i} = \frac{1}{2}\rho V_{rel,r_i}^2 c_{r_i} C_{L,r_i}(\alpha_{r_i}) \tag{9}$$

$$D_{r_i} = \frac{1}{2}\rho V_{rel,r_i}^2 c_{r_i} C_{D,r_i}(\alpha_{r_i}) \tag{10}$$

$$p_{T,r_i} = L_{r_i} \sin\phi_{r_i} - D_{r_i} \cos\phi_{r_i} \tag{11}$$

$$p_{N,r_i} = L_{r_i} \cos\phi_{r_i} + D_{r_i} \sin\phi_{r_i} \tag{12}$$

$$A_i = \frac{p_{T,r_{i+1}} - p_{T,r_i}}{r_{i+1} - r_i} \tag{13}$$

$$B_i = \frac{p_{T,r_i} r_{i+1} - p_{T,r_{i+1}} r_i}{r_{i+1} - r_i} \tag{14}$$

$$T_{t_{i,i+1}} = \frac{1}{3} A_i \;\; r_{i+1}^3 - r_i^3 \;\; + \frac{1}{2} B_i \;\; r_{i+1}^2 - r_i^2 \tag{15}$$

$$T_{t-total} = B \sum_{i=1}^{N-1} T_{t_{r_i,r_{i+1}}} \tag{16}$$

$$C_{r_i} = \frac{p_{N,r_{i+1}} - p_{N,r_i}}{r_{i+1} - r_i} \tag{17}$$

$$D_i = \frac{p_{N,r_i}\; r_{i+1} - p_{N,r_i+1}\; r_i}{r_{i+1} - r_i} \tag{18}$$

$$F_{x_{r_i,r_{i+1}}} = \frac{1}{2} C_{r_i} \;\; r_{i+1}^2 - r_i^2 \;\; + \frac{1}{2} D_{r_i} \;\; r_{i+1} - r_i \tag{19}$$

$$F_{x-total} = B \sum_{i=1}^{N-1} F_{x_{r_i,r_{i+1}}} \tag{20}$$

$$C_p(\lambda_{r_i},\beta_{r_i})=\frac{8}{\lambda^2}\int_{\lambda_{hub}}^{\lambda}Q_{r_i}\lambda_{r_i}^3a_{r_i}^{'}(1-a_{r_i})\left[1-\frac{C_{D,r_i}}{C_{L,r_i}}\tan\beta_{r_i}\right]d\lambda_r \tag{21}$$

$$p^2y_t(t)=-\frac{k}{M}py_t(t)-\frac{c}{M}y_t(t)+\frac{1}{M}F_{x-total} \tag{22}$$

$$M=M_{GONDOLA}+M_{TORRE} \tag{23}$$

$$M_{TORRE}=\rho_{acero}\pi\left(\left(\frac{D_e}{2}\right)^2-\left(\frac{D_i}{2}\right)^2\right)L \tag{24}$$

$$k=\frac{3EI}{L^3} \tag{25}$$

$$\psi(t)=\tan^{-1}\left(\frac{y(t)}{L}\right) \tag{26}$$

$$p\omega_g=\frac{1}{J_g}\left[-f_m\omega_g+PT_{t-total}+T_e\right] \tag{27}$$

$$T_e=\frac{3}{2}P^2L_m(i_{qs}i_{dr}-i_{ds}i_{qr}) \tag{28}$$

$$pv_{ds}=\frac{1}{C_0}\left[i_{ds}-\frac{2\sqrt{3}nI_{dc}\cos\alpha_r}{\pi}\right] \tag{29}$$

$$pI_{dc}=\frac{1}{L_{dc}}\left[-R_{dc}I_{dc}+\frac{3\sqrt{3}nv_{ds}\cos\alpha_r}{\pi}+\frac{3\sqrt{3}v_{inv}\cos\alpha_I}{\pi}-\frac{3x_{ci}I_{dc}}{\pi}\right] \tag{30}$$

$$pi_{qs}=-R_sA_1i_{qs}-\left(\frac{1}{C_0v_{ds}}\left[i_{qs}+\frac{2\sqrt{3}nI_{dc}\sin\alpha_r}{\pi}\right]+A_2\omega_gL_m\right)i_{ds}+R_rA_2i_{qr}-A_1\omega_gL_mi_{dr} \tag{31}$$

$$pi_{ds}=\left(\frac{1}{C_0v_{ds}}\left[i_{qs}+\frac{2\sqrt{3}nI_{dc}\sin\alpha_r}{\pi}\right]+A_2\omega_gL_m\right)i_{qs}-R_rA_1i_{ds}+R_rA_2i_{dr}+A_1\omega_gL_mi_{qr}-A_1v_{ds} \tag{32}$$

$$pi_{qr}=R_sA_2i_{qs}+A_2\omega_gL_si_{ds}-A_3i_{qr}+\left(\frac{1}{C_0v_{ds}}\left[i_{qs}+\frac{2\sqrt{3}nI_{dc}\sin\alpha_r}{\pi}\right]+A_1\omega_gL_m\right)i_{dr} \tag{33}$$

$$pi_{dr}=-A_2\omega_gL_si_{qs}+R_sA_2i_{ds}-A_3i_{dr}+A_2v_{ds}+\left(\frac{1}{C_0v_{ds}}\left[i_{qs}+\frac{2\sqrt{3}nI_{dc}\sin\alpha_r}{\pi}\right]-A_1\omega_gL_s\right)i_{qr} \tag{34}$$

$$A_1=\frac{L_r}{L_sL_r-L_m^2} \tag{35}$$

$$A_2=\frac{L_m}{L_sL_r-L_m^2} \tag{36}$$

$$A_3=\frac{R_r(1+A_2L_m)}{L_r} \tag{37}$$

$i=1,2,3\ldots17$

In Table 1 the considered variables are defined; in Table 2 the parameters and in the Table 3 are indicated the inputs and outputs.

Table 1. Variables of the WECSVV

Símbolo	Variable
$T_{t_{r_i,r_{i+1}}}$	Torque, produced for the r_i segment the blade
$T_{t-total}$	Total torque, sum of the contributions of the r_i segment the blade
$F_{y_{r_i,r_{i+1}}}$	Normal force, produced for the r_i segment the blade
$F_{y-total}$	Total normal force, produced for the sum r_i segment the blade
$C_p(\lambda_{r_i}, \beta_{r_i})$	Power coeficient of the blades
p_{T,r_i}	Tangential force produced for the r_i segment of blade
p_{N,r_i}	Normal force produced for the r_i segment of blade
L_{r_i}	Lift force produced for the r_i segment of blade
D_{r_i}	Drag force produced for the r_i segment of blade
λ_{r_i}	Rate velocity produced for the r_i segment of blade
λ	Rate tip velocity the blade
β_{r_i}	Pitch angle produced for the r_i segment of blade
β	Pitch angle in the tip blade
α_{r_i}	Attack angle in r_i segment of blade
α	Attack angle in the tip blade
ϕ_{r_i}	Flow angle the wind for the r_i segment of blade
ϕ	Flow angle the wind in the tip blade
a_{r_i}	Axial induction factor produced for the r_i segment of blade
a'_{r_i}	Tangential induction factor produced for the r_i segment of blade
V_{rel,r_i}	Relative velocity wind view for the r_i segment of blade
$y_t(t)$	Tower position
$\psi(t)$	Buckling angle of the tower
ω_g	Generator velocity
i_{ds}, i_{qs}	Stator currents d-q axis
i_{dr}, i_{qr}	Rotor currents d-q axis
v_{ds}	Stator voltage d-axis
I_{dc}	DC current link
α_r, α_i	Fires angles, inverter and rectifier correspondly
v_{inv}	Output voltaje inverter
T_e	Electric torque
P_0	Electric power generated
p	Derivate operator

Table 2. Parameters of the WECSVV

Símbolo	Parámetro
r_i	r_i distance for the segment of blade
R	Large of blade
c_{r_i}	Chord for the r_i segment of blade
σ_{r_r}	Solidity angle for the r_i segment of blade
ρ	Density wind
N	Number segments of blade
B	Number of blades
h	Tower high
Q_{r_r}	Glauer correction for the r_i segment of blade
C_{D,r_i}	Drag coefficient for the r_i segment of blade
C_{L,r_i}	Lift coefficien for the r_i segment of blade
M	Tower Mass
k	Coefficient of rigid of spring
c	Coefficient of viscous damping
E	Young´s module
I	Moment of inertia of tower
η	Gear box transformation relation
n	Transformer amplifier o reduction relation
J_g	Inertia of High velocity axis
P	Poles pairs numbers
R_s, R_r	Stator and Rotor resistances
L_s, L_r, L_m	Stator, Rotor, Magnetization induction
C_0	Self-excited capacitance for phase
f	Coefficient friction
x_{ci}	Inverter switching reactance
L_{dc}	Link dc inductance
R_{dc}	Link dc Resistance

Table 3. Inputs and outputs of the WECSVV

Inputs	Outputs
Pitch Angle	Tower Position
Fire angle rectifier	Generator Velocity
Fire angle inverter	Generated Electric Power
Velocity wind	Stator current q-axis
Voltage inverter	Stator current d-axis
	Rotor current q-axis
	Rotor current d-axis
	Eléctric Torque
	DC link current

The following assumptions are realised in each one of the stages of the WECSVV:

1°. In the Aerodynamic stage it is considered: (i) The used blade is a presented model in (Hansen 2008) pages 57-62; (II) The correction factor of glauert, is equal to 1; (III) The values of the factor of axial induction “a” are between 0 and the 0,5 and factor of tangential induction “ a’ “is between 0 and -10. With those values the theory of the blade element moment can be applied; and (IV) the drag coefficient, between the wind field that hits to the blades, is null in each the blades.

2°. In the Electromechanical stage it is considered: (i) There are no losses by rubbing in the gears; and (II) there are losses by switching in the rectification thyristors and investment of no signal.

3°. In the Structural stage it is considered: (i) The tower only moves in two dimensions, parallel to the wind flow that hits to the blades; (II) The material of the tower, is assumed like steel; (III) The base of the tower is totally compact and rigid. It does not have dynamic in the base; and (IV) the material of the tower, owns a sufficiently rigid composition to evaluate the effects of buckling of the tower.

In Figures 6 and 7 one is to the interaction between the stages and the configuration of inputs-outputs of the WECSVV.

Figure 6. Relation between the inputs variables and outputs of the WECSVV

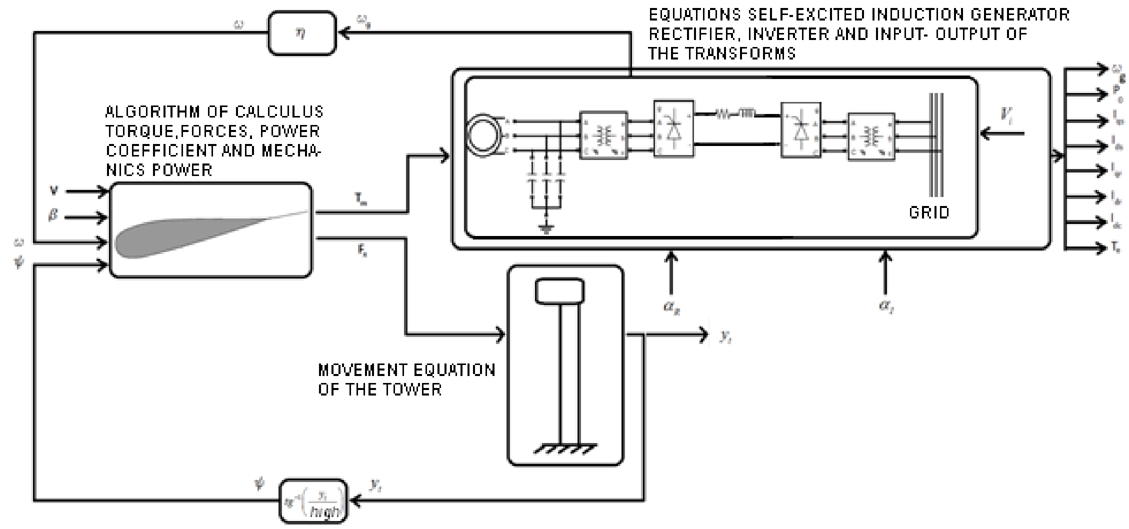
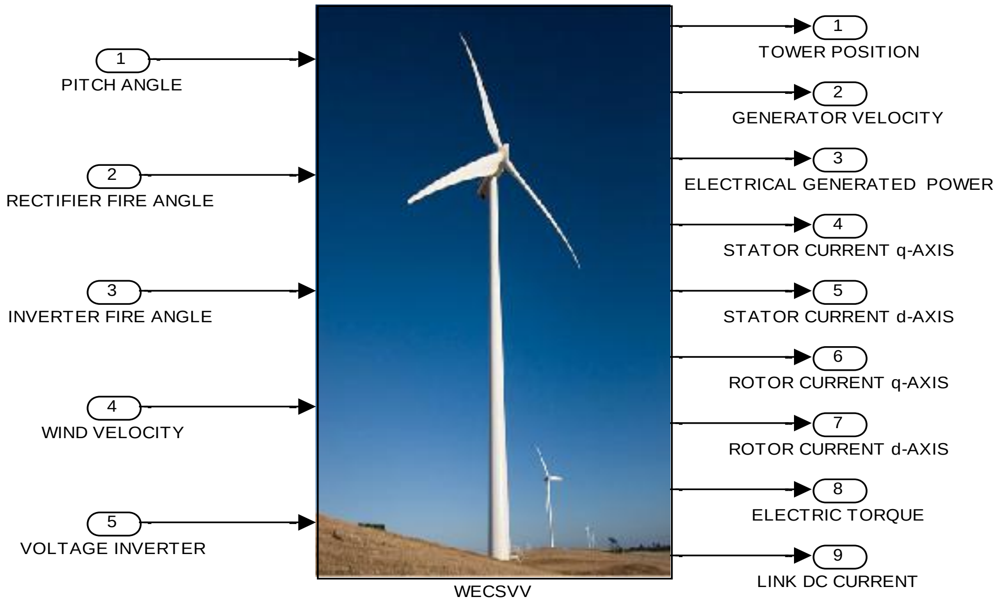


Figure 7. Representation inputs-outputs of the WECSVV



2.5. Characterization of the not linear model for a model of Hammerstein

Provided that: (i) The aerodynamic stage is not linear and static in the time; (ii) The Electromechanical stage is not linear and invariant in the time; and (iii) The structural stage is linear and an invariant in the time; the model of the WECSVV can be represented under a structure of the type Hammerstein, where the principal components are a function of not linear static entry and a linear dynamic model (Sáez, 2000).

Where, schematically it is had: $u(t) \rightarrow \boxed{\boxed{f(u(t))} \rightarrow x(t) \rightarrow \boxed{\dfrac{B(z^{-1})}{A(z^{-1})}}} \rightarrow y(t)$

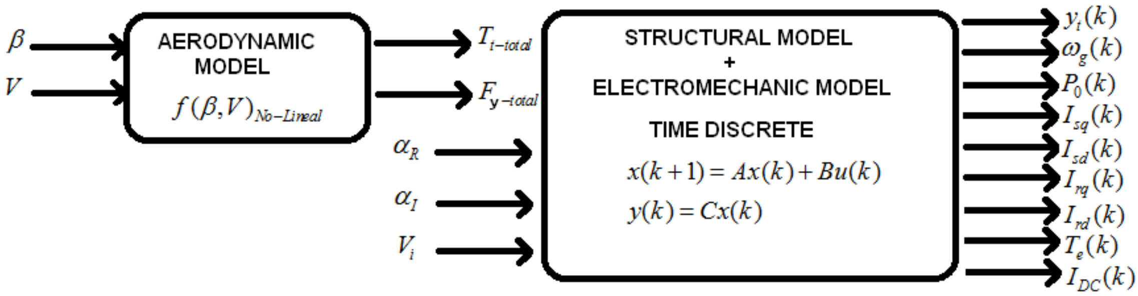
In this case: $y(t) = \dfrac{B(q^{-1})}{A(q^{-1})} x(t)$ $\qquad x(t) = f(u(t))$

with $A(q^{-1}) = 1 + a_1 q^{-1} + \ldots + a_{n_y} q^{-n_y}$ $\qquad B(q^{-1}) = b_1 q^{-1} + \ldots + b_{n_u} q^{-n_u}$

where it is an internal not measurable variable and is a static not linear function, which can be brought near by the following polynomial of finite order with , degree of the polynomial which gives the accuracy of the aproximation, and , a coefficients, as follows: $x(t) = \sum_{i=0}^{N} \gamma_i u^i(t)$

Therefore the model of the wind system of conversion can remain expressed as the Figure 8, which possesses a structure of the type Hammerstein.

Figure 8. Shape WECSVV as a Hammmerstein's Model



3. Results

Basically of the results found in the answers of the SCEVV, it is clear that there exists a dependence of the oscillations of the tower due to the aerodynamic variables of entry and the parameters of inflexibility that possesses the tower. The oscillatory phenomena in the speed of the generator, produce an oscillatory torque that it spoils to the mechanical system and happen in a relatively long time. The previous thing owes principally to the aerodynamic variables since there is a strong dependence of the mechanical torque with the axes of discharge and of low speed. Also the forces generated by the arms are principally axial depending on the angle of pitch that have the arms. Then when the angle of pitch is minimal, that is to say 0, then there is generated an axial maximum force, and this implies that the tower bending more than when the angle of pitch moves away from the maximum, which generates a straightening of the tower, or rather a reduction of buckling angle .

The consequences on the generation of electrical power can visualize from the Figure 9. Though it is true, which is waited always is that the tower of the SCEVV is kept in a vertical fixed position to achieve a transfer of power that depends only on actions of the angle of pitch and / or on Yaw in other occasions, what we see in the Figure 9 is unusual, since as the tower has an angle of minor bulge or it straightens up, the production of electrical power diminishes, whereas if the tower had not moved, then the electrical power does not change due to the fact that the speed and the torque, mechanical and electrical have not changed.

The values of nominal operation of the WECS are indicated in the Table 4 and 5.

Table 4. Characteristics of Nominal Operation for the income

Inputs	Range	Operation Point (O.P.)	Step respect O.P.
Pitch Angle [°]	≥ -10 , ≤ 10	0	15 [%]
Fire Angle Rectifier [°]	≥ 0 , ≤ 90	0	15 [%]
Fire Angle Inverter [°]	≥ 90 , ≤ 180	90	20 [%]
Wind Velocity m/s	≥ 3 , ≤ 20	16	20 [%]
Voltage Inverter [V]	anything	200	20 [%]

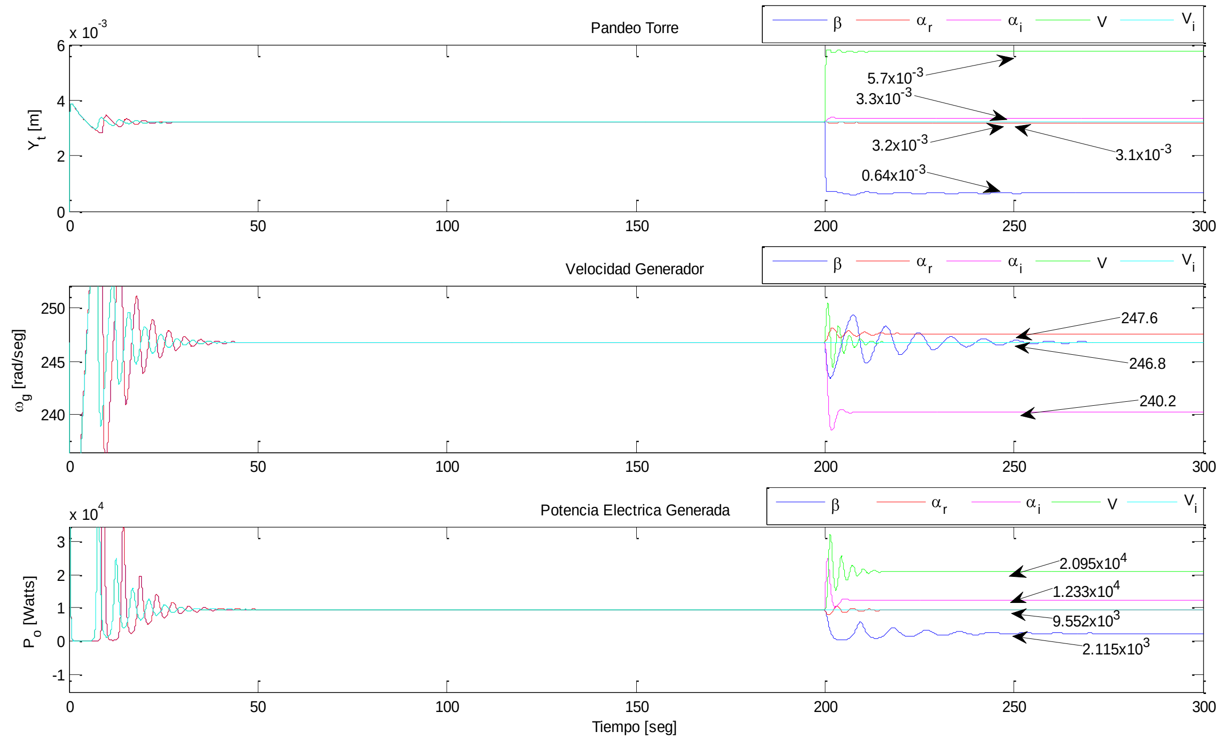
Table 5. Characteristics of nominal operation for the outputs

Outputs	Operation Point (O.P.)
Tower position $[m]$	0.0032
Generator velocity $[rad/seg]$	249.27
Electrical generated power $[KW]$	9.55
Stator current q-axis $[A]$	114.60
Stator current d-axis $[A]$	2.41
Rotor current q-axis $[A]$	62.36
Rotor current d-axis $[A]$	-5.06
Eléctric torque $[Nm]$	-1017
DC Link current $[A]$	43.73

4. Conclusions

Of the exposed previous thing it is possible to conclude that the proposed model allows evaluating the systems of wind generation easily, of way of using this model as a benchmark in the study of strategies of control. The incident of the dynamics and structural parameters of the tower on the production of electric power, it is strong and not trivial, in spite of the fact that this phenomenon is not common according to Amirat (2009) and Arifujjaman (2009). Though it is true, the bulge is very small in comparison at a height of the tower, the variation that takes place in the electrical power is valuable. The results throw that the electrical oscillations due to the structural oscillations happen first for the aerodynamic stage by means of the speed of the axis of high and low speed. This fact, it allows to presume of that the aerodynamic stage is not even a species of filter in a case and not in another case it is an amplifier, since the structural oscillations have correlation great with the electrical oscillations, in spite of the fact that direct connection does not exist between the structural stage and the aerodynamic stage, as appreciates in the Figure 6. Finally it is necessary to add that studies realized in literature do not exist for contractar, to evaluate or to validate the obtained results. Since future work proposes as method of validation of the model, to use a model of royal wind generator and with different aerodynamic, mechanical and electrical model, to compare the results of measurements of variables with the proposed theory, of this form it is possible to have information more occurred, respect of the functioning of this theory.

Figures 9. Response to step of the position, speed and electrical generated power



5. References

Amirat, Y. et, al., 2009. Of a Brief Status on Condition Monitoring and Fault Diagnosis in Wind Energy Conversion systems. Renewable and Sustainable Energy Reviews.

Arifujjaman, Md., 2009. Reliability analysis of grid connected small wind turbine power electronics. Applied Energy 86, 1617–1623.

Baker, C.J., 2007. Wind Engineering-Past, Present and Future. Wind Engineering and Industrial Aerodynamics 95, 843–870.

Burton, T., Sharpe, D., Jenkins, N., Bossanyi, E., 2001. Handbook. Wind Energy. 1a Ed., John Wiley and Sons Ltd., Chichester.

Hansen, M.O.L, 2008. Aerodynamics of Wind Turbines, 2da Ed., Earthscan, London – England and United States.

Meirovich, L., 2001. Fundamentals of Vibrations. Mechanical Engineering Series. International Edition, McGraw Hill. New York, USA.

Munduate, X., 2007. A CFD Investigation of the Near-Blade 3D Flow for a Complete Wind Turbine Configuration. Centro de Energia Renovable de España, CENER.

Sáez, D., 2000. Predictive Control of Non-Linear Systems and its Application to the Control of a Thermal Power Plant Boiler. Tesis Doctoral, Pontificia Universidad Católica de Chile, Chile.

Steinbuch, M., 1989. Dynamic Modelling and Robust Control of a Wind Energy Conversion System. Doctoral Thesis, Delft University, Holland.

Timoshenko, S., Gere, J., 1963. Theory of Elastic Stability. Student Ed., 2da Ed., McGraw Hill, Auckland, Australia.

Contact details (For further information, please contact)

Pablo Sánchez, Nelson Aros

Universidad de La Frontera, Departamento de Ingeniería Eléctrica

Av. Francisco Salazar 01145 (4811230), Temuco - Chile

E-mail: naros@ufro.cl