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Wind Conversion Chain Model Simulation with Closed Loop PI Controler

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***Abstract*—The presented paper deals with simulation of a detailed model of wind conversion chain based on permanent synchronous machine. In this paper, wind energy is transformed to a mechanical energy by blade and turbine and turbine, which is transmitted to the shaft of the PMSM, that's was modeled then simuled with MATLAB. Also the out put voltage of this wind conversion chain is controlled by a PI regulator integred in a voltage regulation loop answer the quality of the produced electric power.**

***Index Terms*— Modeling, PI controller, PMSM, Power, Simulation, Wind.**

I. Introduction

Energy is a hot topic in the universe, known for a long time or the basic principle of power generation based on the conversion of mechanical energy into electrical one, in most cases, a fluid drive a turbine [1].

We focus our study on the modeling of a conversion chain oriented to numerical simulation after a detailed mathematical description.

II. Description Of The Conversion Chain

Fig.1 and Fig.2 present an overall scheme which describe the various essential parts dedicated to the conversion of the wind power into electrical energy based on permanent magnet synchronous machine mechanically coupled with a wind turbine via a reduction gear box, the latter is driven by a wind profile that will be modeled.

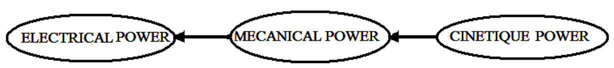

Fig. 1. Wind conversion Principle.

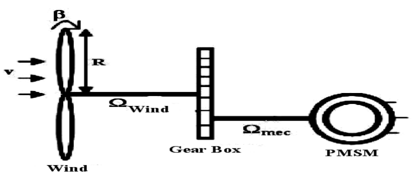

Fig. 2. Wind conversion Principle.

III. Modeling Of The Wind Conversion Chain

A. Wind Profile Modeling

From the distribution point of view wind is necessary in wind project, through it we can estimate the rate of electrical energy production and profitability of the system operated so knowledge of dynamic properties of the wind are crucial to the study of the entire chain as the power conversion wind under optimal conditions is the cube of the Wind speed [2] [3].

Wind speed can be modeled as a fractional scalar evolves over time [1].

$$v_v = f(t) \tag{1}$$

Wind speed can be represented as a function of harmonics as in (2).

$$v_v(t) = A + \sum^{i} a_n \sin\,(b_n w_v t) \tag{2}$$

$$v_v = 9 + 0{,}2\sin(0{,}10477t) + 2\sin(0{,}2665t) + \sin(1{,}2930t) + 0{,}2\sin(3{,}6645t) \tag{3}$$

This equation represent an uncertain wind profile evolve around a known medial value

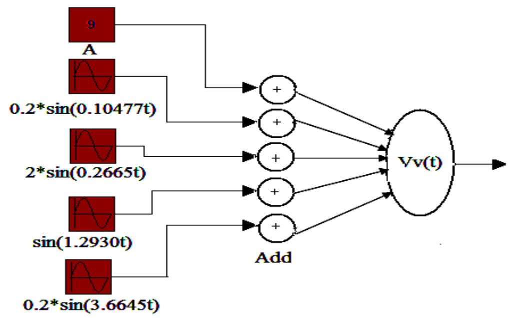

Fig. 3. Simulation bloc of uncertain wind profil.

B. Wind turbine modeling

The wind turbine is a three-dimensional, with complex shapes in motion, immersed in a flow air; it converts the wind's kinetic energy and delivers mechanical power characterized by a rotating speed and mechanical torque and rotation [1].

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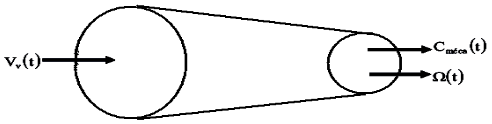

Fig. 4. Input and output model of wing.

The kinetic energy of a mass of air that moves with a velocity V is: [2]

$$E_c = \frac{1}{2}\, mV^2 \tag{4}$$

(5) Give the instantaneous power given by the turbine

$$P_v = \frac{1}{2}\rho S V^2 \tag{5}$$

So we obtain the power coefficient, which it is the ratio between the extracted power and the available power Pe

$$C_p = \frac{P_e}{P_v} \tag{6}$$

(7) give the get back wind power

$$P_e = 0{,}5\rho S C_p V^3 \tag{7}$$

C_p : power coefficient
ρ: density of air (1.25 Kg/m3)
S : area swept by the turbine
V : wind speed

The wind turbine is characterized by its curve $C_p=f(\lambda)$ With λ is the ratio between the tip peripheral speed of blades and the wind speed

$$\lambda = \frac{R\Omega}{v} \tag{8}$$

Ω : angular speed
R : turbine rayon

According to the characteristic of the wing; $C_p=f(\lambda)$ is represented by 6 order polynomial as:

$$C_p = C_c . \lambda \tag{9}$$

$$C_c = a_0 + a_1\lambda + a_2\lambda^2 + a_3\lambda^3 + a_4\lambda^4 + a_5\lambda^5 + a_6\lambda^6 \tag{10}$$

C. PMSM Modeling

For modeling it is necessary to go from the abc axes system to dq axes.

$$V_a = R_s I_s + L\frac{di}{dt} \tag{11}$$

$$V_b = R_s I_s + L\frac{di}{dt} \tag{12}$$

$$V_c = R_s I_s + L\frac{di}{dt} \tag{13}$$

By the using of the Parck transformation we can describe that equation in to dq frame (14)

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{14}$$

Where: V_a, V_b, V_c are the instantaneous tree phases values, (V_q, V_d) are the instantaneous biphasic values, and (V_0) is the zero components.

Where the inverse matrice of Parck let we return to abc system (15)

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & -\sin(\theta) & \frac{1}{\sqrt{2}} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \tag{15}$$

(16) And (17) represent the electromagnetic Torque and the mechanical equations

$$C_{em} = \frac{3}{2}P\left[(L_d - L_q)I_d I_q + I_q\sqrt{\frac{3}{2}}K_1\right] \tag{16}$$

$$J\frac{d\Omega}{dt} + f\Omega = C_{em} - C_{eol} \tag{17}$$

After mathematical development the PMSM model in the Parck referential will be given by (18) and (19)

$$V_d = R_s i_d + L_d\frac{d}{dt}i_d + \omega_r L_q i_q \tag{18}$$

$$V_q = R_s i_q + L_q\frac{d}{dt}i_q + \omega_r\left(L_d i_d + \phi_f\right) \tag{19}$$

(20) And (21) give the coupling electromagnetic equations

$$\phi_d = L_d i_d + \phi_f \tag{20}$$

$$\phi_q = L_q i_q \tag{21}$$

IV. RESULTS AND INTERPRETATION

The mathematical model obtained from the conversion chain energy is implanted under Matlab Fig.5 show the simulation bloc diagram with specifications of each case the shape of the wind profile chousen :

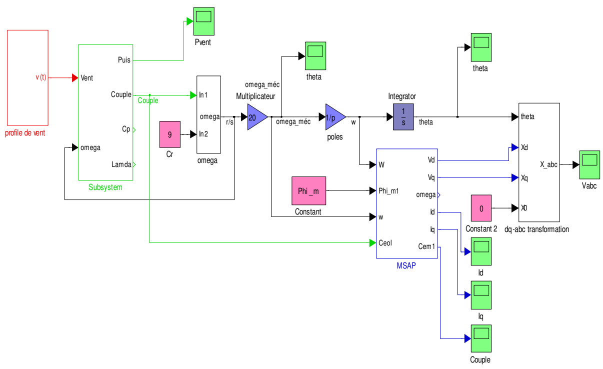

Fig. 5. Simulation Bloc of wind conversion chain Model.

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where fig.6 present the model of PMSM

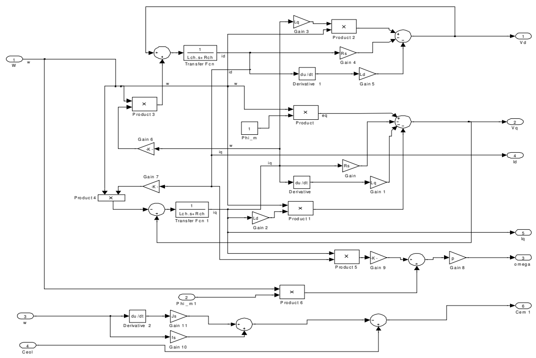

Fig. 6. PMSM simulation Bloc.

A. Output voltage for a constant wind value

As a first essay we will attack our system by a constant value of wind v=9 m/s.

Fig.7 shows the change of the output voltage of the machine according to the time.

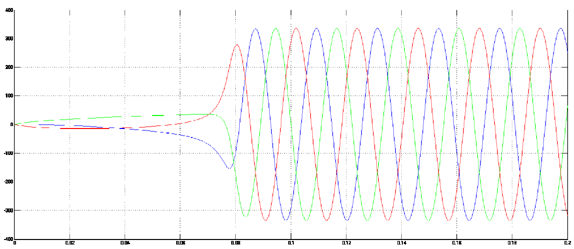

Fig. 7. Voltages Evolution for a constant wind.

After a 0.8s transit regime, the output voltages attaint the permanent regime at the values $V_a=V_b=V_c=320$v.

B. Output voltage for a sinusoidal variation in wind profile

In this section we will make a simulation of the conversion chain and it is assumed that the sheep of the wind has a sinusoidal variation

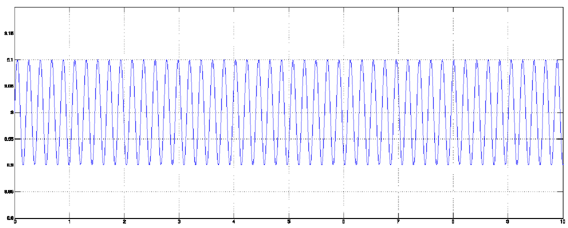

Fig. 8. Wind form with sinusoidal variation.

From the form of the output voltage fig.8 we see that the produced wind to drive the wind turbine has affect the quality of the energy produced by the generator fig.9.

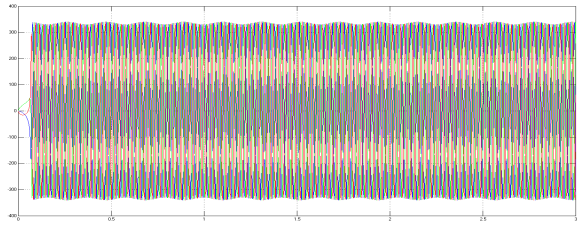

Fig. 9. PMSM output voltage when wind has a sinusoidal variation.

C. Output voltage for uncertainly Wind profile

By the fig.3 we have make a simulation of the wind profile. Fig.10 show the variation of the wind speed according to the time variation (t=100s) between to values v=6 m/s and v=12 m/s uncertainly. This gives a reflection of a real wind profile.

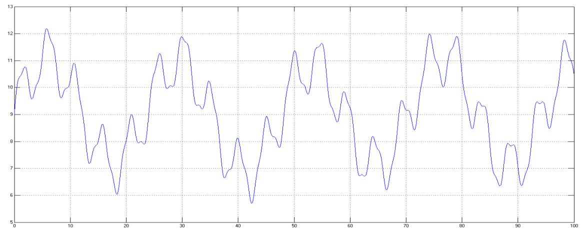

Fig. 10. Wind profile.

The PMSM output voltage change according to the wind profile variation Fig.11.

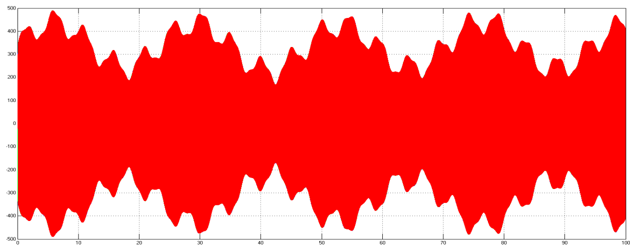

Fig. 11. PMSM Output voltages with uncertaintly wind profile.

Fig.12 present a zoom of the generator output voltage between two values t = 0 s to t = 20 s and show the influence of wind profile variation into the quality of the induced f.e.m.

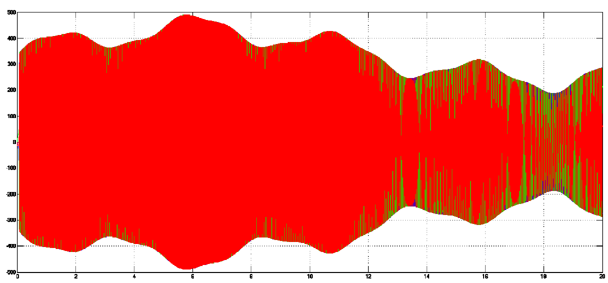

Fig. 12. output voltage of variable wind profile.

This make the use of the wind power armful to coupling with electrical net work, although that the

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obtained f.e.m form is sinusoidal and there frequency is stable as it is shown in Fig.13

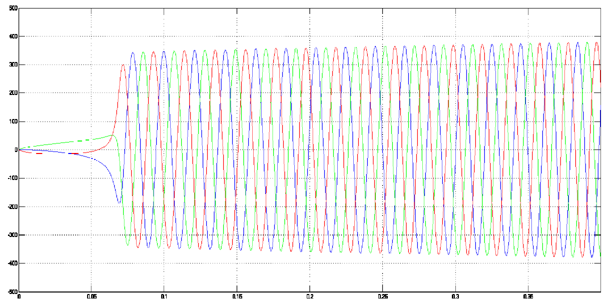

Fig. 13. Zoom of uncertain wind profile PMSM output voltage.

Because of the important variations of the amplitudes of the tree phases, this need a modification on the wind conversion chain by the introducing of a control part and correction system wish allow the stabilized voltage output.

V. Proposed Structure for Regulation

The voltage regulation of the presented conversion chain can be performed with the help of a PI regulator based on the diagram presented in Fig.14.

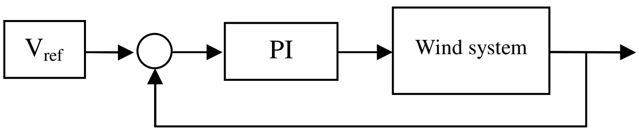

Fig. 14. PI regulator control principle.

This will be implanted in the system according to the diagrams shown by fig.15 where the regulator based on the obtained error after the Parck transformation of the output voltage V_a, V_b, V_c to the rotor refrence frame V_d,V_q.

This regulator will be integrated with our wind conversion chain as it is presented on Fig.15.

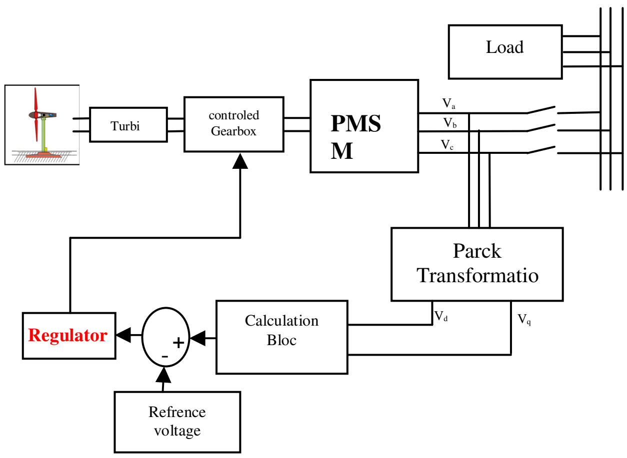

Fig. 15. wind chain voltage regulation principle.

The principle of the proposed regulation is to make a Parck transformation of the PMSM output voltages to biphasic repos which will subsequently injected into the block of calculation, we can extract current amplitude voltages supplied by the machine, to be compared with a desired reference voltage, that gives us an error.

A PI regulator generate a command according to the last error to controlling the drive speed of the PMSM with a controlled gearbox which provides a controllable rapport of variable transformation between the rotational speed of the turbine and the generator speed.

VI. Simulation Of The Proposed Structure

Fig.16 present a simulation bloc of the proposed structure implanted under Matlab Simulink.

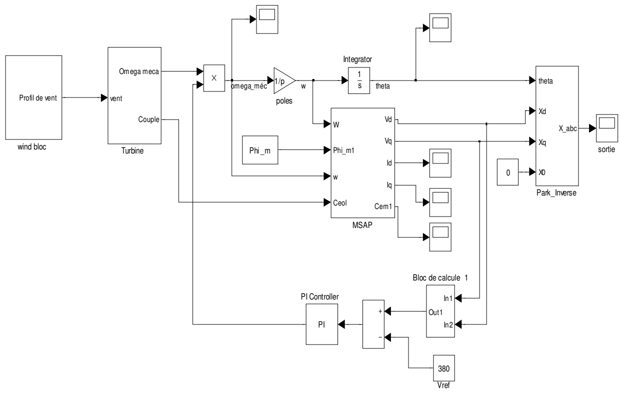

Fig. 16. simulation Bloc of wind chain controled by PI regulator.

The integration of the controller with the wind conversion chain can stabilize the output voltage around the desired reference (Vref = 380 v), fig.17 and fig.18, whatever the variation of the wind and ensures the possibility of operating a quality energy can be injected to the electric network.

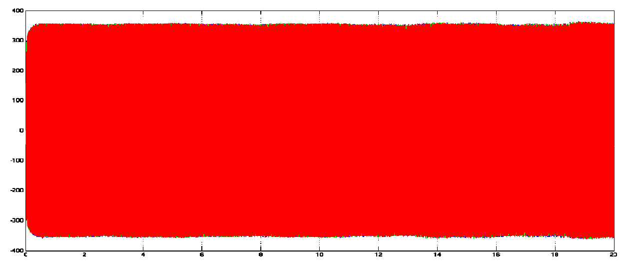

Fig. 17. PMSM output voltage with PI regulation.

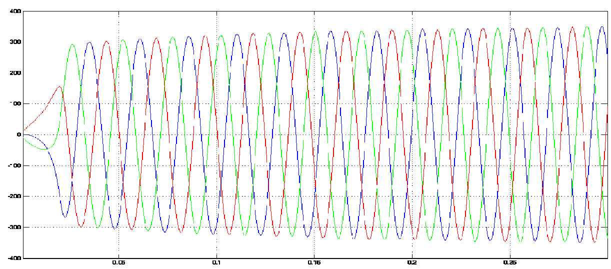

Fig. 18. Zoom of the PMSM output voltage with PI regulation.

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A. Regulation effectivety:

Fig.19 shows the robust of the PI controller in the pursuit of reference with a short response time and an acceptable depassement (near to zero).

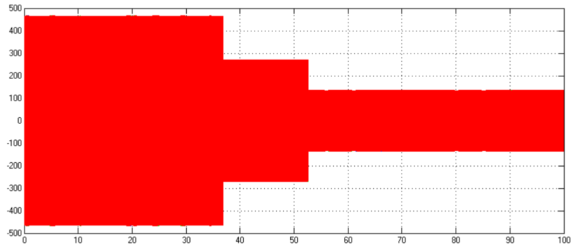

Fig. 19. PMSM Output voltage with a variable refrence controled by PI

VII. CONCLUSION

The work that has been presented allows us about simulate the dynamic behavior of the chain conversion wind using a random wind profile similar to a profile of the true wind, the waveform of the voltage output obtained helped us to give the look of a technique to make it comply with regulations production of energy required (constant amplitude), carrying use a PI controller, the heart of the proposed control loop.This after that a mathematical modeling of the wind conversion chain done, this leat we clearly see the influence of each parameter of each part of the system on the quality of the electrical energy produced by the PMSM generator also the pursues of various signals in each step through the simulation offered the development and software simulation.

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