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Modeling and Simulation of an Isolated Site Conversion Chain Driven by a Permanent Magnet Generator

Aicha Wahabi,Abdelhadi El Moudden,Fatima Ezzahra Bounifli, Kaoutar Senhaji Rhazi

***Abstract*—The objective of this work is to study the conversion of wind energy in its entirety in order to optimize the output power and improve the quality of the energy supplied. For this, we are interested in the modeling and simulation of a turbine associated with a speed multiplier, we study the modeling and control of a permanent magnet synchronous generator feeding a three-phase load which corresponds to a chain of Conversion of small-scale wind power into an isolated site. The technique adopted is developed in Matlab / Simulink / SimPowerSystems. The results of the simulation are presented and analyzed at the end of this work.**

Index Terms — **Wind generator - Permanent magnet synchronous generator -Modelization-Matlab Simulink -SimPowerSystems.**

I. Introduction

Wind turbines based on generators, either asynchronous or with a wound rotor, have the disadvantage of requiring a system of rings and brushes for thedoubly fed induction generator (DFIG) and a multiplier for the DFIG and asynchronous squirrel cage machine, resulting in significant maintenance costs, in particular for offshore projects located in saline medium[2],[5],[6]. In order to limit these disadvantages, some manufacturers have developed wind turbines based on synchronous machines with a large number of pole pairs and coupled directly to the turbine, thus avoiding the multiplier. If the generator is equipped with permanent magnets, the system of rings and brushes is eliminated.

The development of magnetic materials allowed the construction of synchronous machines with permanent magnets with costs that become competitive. Machines of this type have a large number of poles and allow the development of considerable mechanical torques [7].

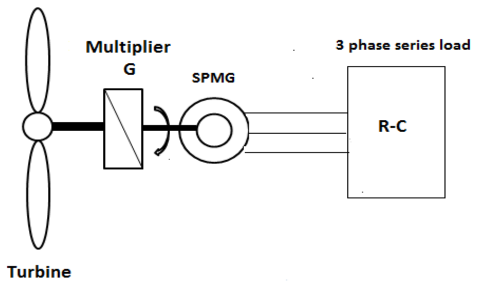
In this article, we study the modeling and control of a permanent magnet synchronous generator driving a small power wind farm for an isolated site. The results of the various simulations of the conversion, carried out in the MATLAB / Simulink environment, made it possible to evaluate the performance of the proposed system.

Aïcha WAHABI, ENSEM Casablanca / University Hassan II, Morocco,
Abdelhadi EL MOUDDEN, ENSEM Casablanca/ University Hassan II, Morocco.
Fatima-Ezzahra BOUNIFLI, ENSEM Casablanca/University Hassan II, Morocco.
Kaoutar SENHAJI RHAZI,ENSEM Casablanca / University Hassan II, Morocco

The coupling of these machines with the power electronics is becoming more and more economically attractive, making it a serious competitor of thedoubly fed induction generator.

II. Description of the Wind Energy Conversion Chain Driven by a Synchronous Permanent Magnet Generator "SPMG"

The kinetic energy of the wind is received by the blades of the turbine, transformed into mechanical energy on the turbine shaft, in the form of "slow speed and high torque", it is received by the multiplier which increases the rotational speed and decreases torque. The electric generator, which is here a permanent magnet synchronous generator, transforms the mechanical energy into electrical energy that will feed the load, because we recall that here we are studying a wind energy conversion chain for an isolated site.
The modeling and simulation of the various constituents of the chain will be examined below.



Kinetics Energy → Mechanical Energy → Electric energy

Fig. 1:Simplified scheme of the chain studied

III. Modelling of the Turbine

The wind turbine is a device that transforms the kinetic energy of the wind into mechanical energy. The kinetic energy is materialized by the movement of the particles of the mass of air passing through the section of the active surface S of the wing of the turbine.

By applying the theory of momentum and the Bernoulli theorem we can determine the incident power (theoretical power) of the wind [1], [3].

$$P_{incident} = \frac{1}{2}\rho.S.v^3 \quad (1)$$

S:The surface swept by the blades of the turbine [m²];

ρ: The density of air (ρ = 1225 kg / m3 at atmospheric pressure);

v: Wind speed [m /s].

In a turbine, the power extracted from provided on the rotor of the turbine is lower than the incident power.

$P_{ext} = \frac{1}{2}\rho.S.C_p(\lambda,\beta).v^3$ (2)

$C_p(\lambda,\beta)$**:** is the power coefficient which expresses the efficiency of the turbine, it depends on the ratio λ, this ratio represents the ratio of the turbine speed at the end of the blades and the wind speed, and the orientation angle β.

$\lambda = \frac{R.\Omega_t}{v}$(3)

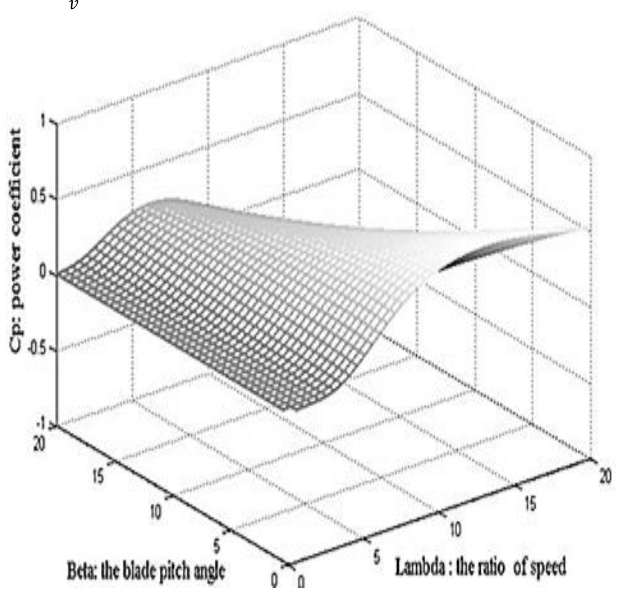


Fig. 2. **:** Power coefficient $C_p(\lambda,\beta)$

The maximum power coefficient C_p was determined by Albert Betz (1920) as follows**:**

$C_p^{max}(\lambda,\beta) = \frac{16}{27} \approx 0{,}593$ (4)

This coefficient depends on the constitution of the turbine, for a wind medium power we have:

$C_p(\lambda,\beta) = c_1.\left(c_2.\frac{1}{A} - c_3.\beta - c_4\right).e^{-c_5\frac{1}{A}} + c_6.\lambda$(5)

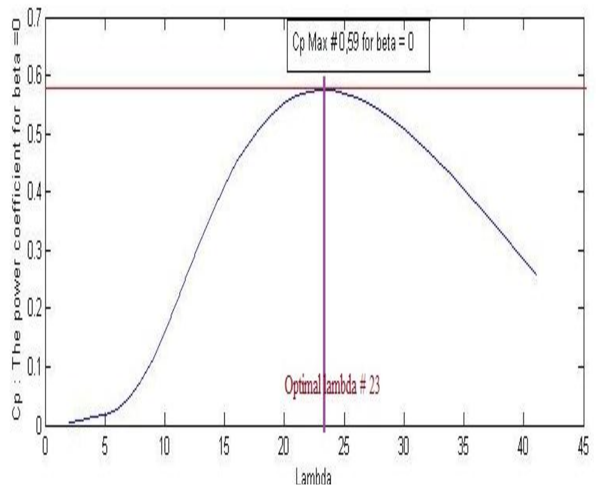


Fig. 3: C_p Power coefficient for β = 0

Also, we can say that this turbine will present its maximum efficiency for a speed ratio λ [1] [2],of the order of 23 since in general, C_p is maximal for β = 0 °

If the velocity ratio λ is maintained at its optimum value λ_{opt}, the coefficient of power is at its maximum value $C_{pMAX}=C_p(\lambda_{opt})$, the maximum of power of the wind turbine [4]is:

$P_{opt} = \frac{1}{2}\rho.S.C_{pMAX}.v^3$;with $v=\frac{R}{\lambda_{opt}}.\Omega_t$(6)So $P_{opt} = \frac{1}{2}\rho.S.C_{pMAX}.(\frac{R}{\lambda_{opt}}.\Omega_t)^3$(7)

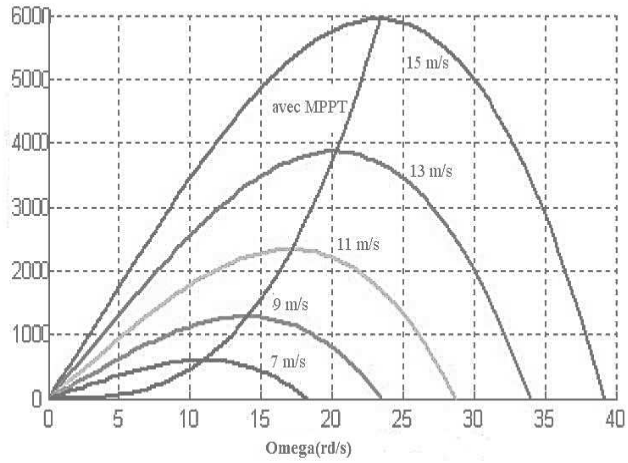


Fig. 4: Wind Power (W) for several wind speed and β = 0

We note that the wind power is very affected by the variation of v: the wind speed, because the coefficient Cp depends on lambda therefore of v, and from the relation

$P_{ext} = \frac{1}{2}\rho.S.C_p(\lambda,\beta).v^3$, we sees that the power is proportional to the cube of the wind speed. Moreover, it is noted that the maximum power extracted varies as a function of the wind speed, hence the advantage of using for a large plant a generator which adapts to the wind speed the "DFIG" (Doubly Fed Induction Generator) which is the most Able to extract at each moment the maximum power [ ].

C_t is the torque on the slow axis at the turbine:

$C_t = \frac{P_{ext}}{\Omega_t} = \frac{1}{2}\rho.S.C_p(\lambda,\beta).v^3.\frac{1}{\Omega_t}$(8)

The total inertia j consists of the inertia of the turbine jt reduced the fast axis and the inertia of the generator j_g :

$j = \frac{j_t}{G^2} + j_g$(9)

The fundamental equation of dynamics can be written:

$j\frac{d\Omega_{Mec}}{dt} = C_M = C_t - C_{em} - f\Omega_{Mec}$ (10)

IV. Modelling of Synchronous Permanent Magnet Generator "SPMG"

Thanks to the advantages it offers compared with other types of electrical machines (not requiring magnetization, performance, robustness, etc.), the permanent magnet synchronous machine is advantageous for a generator application coupled to an isolated wind turbine.

To model and control a permanent magnet synchronous generator, the model of the most appropriate machine and for the implementation of the control laws is inspired by the work [1],[3],[4].

For the 3-phase stator, this writing is summarized by the following condensed matrix:

$[V_{sabc}] = [R_s] * [i_{sabs}] + \frac{d}{dt}[\emptyset_{sabc}]$ (11)

With $[V_{sabc}]$: three-phase stator voltage of the synchronous machine. [Rs] : Resistance of stator phase. $[i_{sabs}]$: Three-phase stator current of the synchronous machine. $[\emptyset_{sabc}]$: Feed-phase stator of the synchronous machine.

Wewill use the Park model of this machine. The equations of the machine in the referentialtwo-phase of Park are the following [ ]

$$V_{sd} = R_s * i_{sd} + L_s * \frac{di_{sd}}{dt} - L_s * i_{sq} * \omega \quad (12)$$

$$V_{sq} = R_s * i_{sq} + L_s * \frac{di_{sq}}{dt} + (L_s * i_{sd} + K_A) * \omega \quad (13)$$

$$C_{em} = p * K_A * i_{sq} \text{ And } \omega = p * \Omega \quad (14)$$

V_{sd} ,V_{sq} and i_{sd}, i_{sq} : are the stator voltage and stator current in the two-phase reference.

C_{em}, p : Are the electromechanical couple and the numberof pairs of pole, *Ls*: cyclical inductance of a stator phase.

V. SIMULATION OF THE CHAIN STUDIED

We have placing the different constituents of the chain and we connected them and simulated them. After some adjustments, the system work correctly. The results of the simulation will be presented and interpreted in the following paragraph.

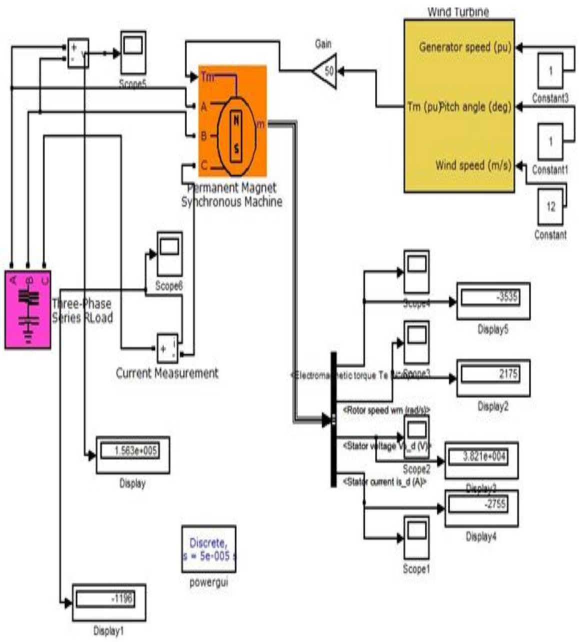


Fig. 6:Block diagram of the wind chain driven by apermanent magnet generator.

A. Simulation results

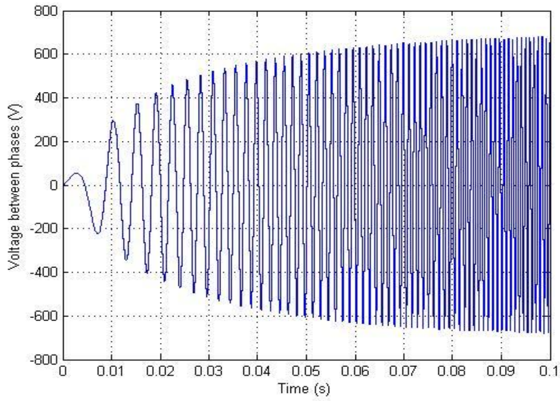


Fig.7 : Variation of stator voltage between phase as a function of time

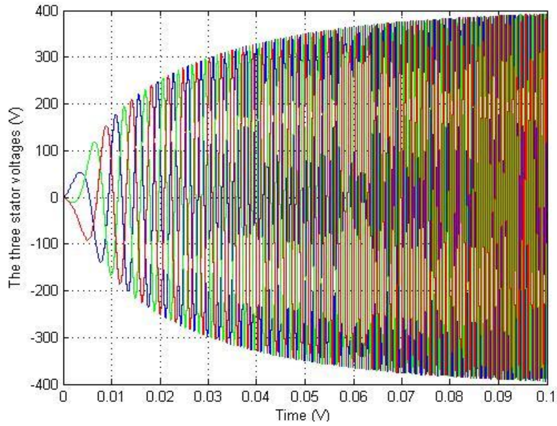


fig. 8 : Variation of the three stator votagesas a function of time.

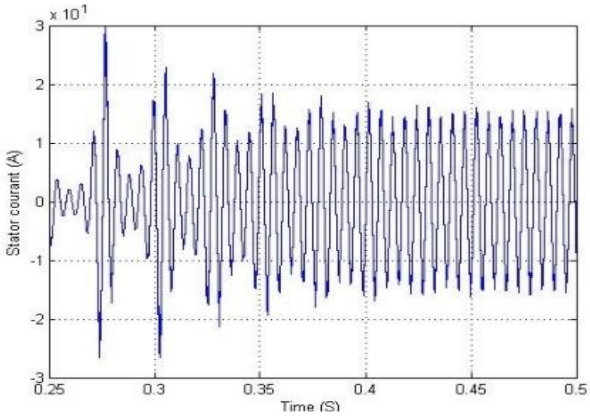


Fig. 9a. Stator current in transient mode

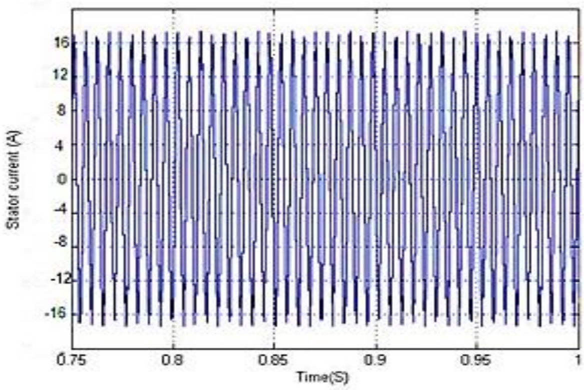


Fig. 9b. Stator currentduringsteady state

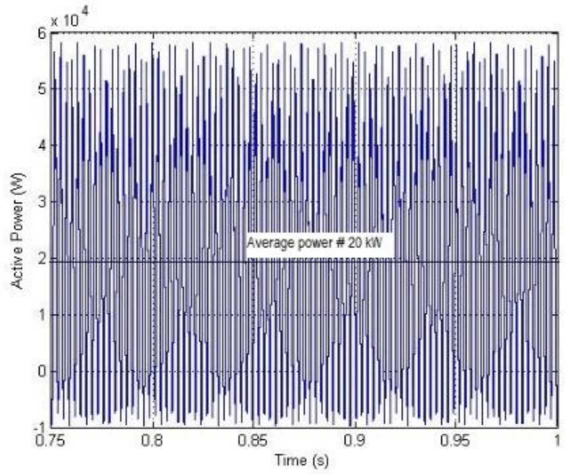


Fig. 10. Total active power producedby the chain

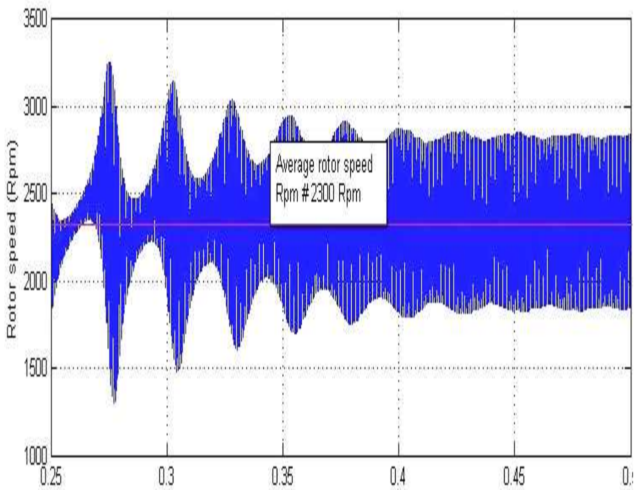


Fig. 11. Rotor speed in Rpm

B. *Comments and Discussions*

The results presented above show that the chain was correctly modeled and simulated, indeed the flow of energy received by the turbine was actually sent to the electric generator to supply the load with electrical energy.

Fig 7 and 8 show the stator voltages supplied by the generator. These are sinusoidal voltages of period T = 0.02s which correspond to a frequency of 50 Hz of maximum values Vmax ≈ 400V for the phase-to-neutral voltage (680V for the compound voltage) this is an acceptable voltage because the chain studied corresponds to an installation in an isolated site of average power and it is the voltage that is generally adopted.

Fig. 9a and 9b show the line current supplied by the generator in transient and permanent condition. It is a sinusoidal current of period T = 0.02s also which correspond to a frequency of 50 Hz. The maximum value is Imax ≈ 16A.

Fig.10 shows the variation of the total active power supplied by the wind system. We note that the power delivered is considerable and that it is subjected to fluctuations. It can also be said that the average power delivered is of an average value of 20 kw.

The last figure gives us an idea of the speed of rotation of the generator which is almost equal to 2300ppm (we added a multiplier to have the unit ppm) one notices that the rotation speed also undergoes fluctuations.

VI. Conclusion

In this article, we recalled the mathematical models of the components of the wind energy conversion system (turbine models, permanent magnet synchronous machine).

The results of the simulation carried out for the different models allowed to validate the proposed mathematical models of the wind system.

We will improve this work in order to have a constant value of the active power produced and the speed of rotation by inserting filters to minimize the fluctuations of these two curves.

We also plan to study a chain driven by the same generator but avoiding the multiplier since there are machines with a very high number of poles.

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Pr. WahabiAicha: I am an assistant professor at the School of Technology (EST) in Casablanca, Morocco since 1991. Between 2012 and 2015, I was part of the Computer Systems Laboratory and renewable energy (Liser) I am preparing my doctoral thesis in the field of renewable energy including wind power at the National School of Electricity and Mechanics (ENSEM). I obtained the graduate degree in 2000 at the National School of Electricity and Mechanics (ENSEM) Casablanca, Morocco. I am an electromechanical engineer from the National School of Mineral Industry (ENIM) in Rabat, Morocco (1990). I have published articles in Morocco, and in international scientific journals of wind energy in the years 2013, 2014, 2015 and 2016.

Pr. Dr. El MouddenAbdelhadi: Doctor of Science from The National Polytechnic Institute of Toulouse (INPT) in 1993 - FRANCE.

He is now a professor in the National School of Electricity and Mechanics (ENSEM), University Hassan II Aïn Chock, Casablanca, Morocco.

Between 2006 and 2015, he has been a member of Laboratory Computing, Systems and Renewable Energies (LISER) - Team Analysis and Command of Electrical Energy Systems (ACSEE).

His research interests include Dynamic Simulations of Electric Machinery, Simulation and Optimization of Renewable Energy Systems. He has presented and published many articles in scientific journals and conferences.

Mrs Bounifli Fatima-Ezzahra: I am electrical engineer at OCP Group, Morocco (since 2014). I am also a doctoral student preparing a doctoral thesis in the National School of Electricity and Mechanics (ENSEM), University Hassan II Aïn Chock, Casablanca. Team Analysis and Command of Electrical Energy Systems (ACSEE) - Laboratory of Computing, Systems

and Renewable Energy (LISER). On June 2013, I got an engineering diploma specialized in electrical energy in ENSEM. My doctoral thesis is about direct and fuzzy-logic control systems of the double-feed induction generator wind turbine. I've submitted three papers in Morocco on wind energy during the years 2014 and 2015.

Pr. SenhajiRhaziKaoutarI am a professor in Electrical engineering at the superior school of technology (EST) in Casablanca, Morocco**.** I wish to inform you that I'm preparing my habilitation. I completed the national thesis in July 2006. I got the research preparation certificate (CPR) from EMI (Mohammadia School of Engineers Rabat Morocco December 97). I am an engineer of the State owned (EMI) in Rabat, Morocco (in 1991)