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Modeling and control of a switched reluctance machine for wind generation

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Abstract- The rotational speed of a wind turbine is very low compared to that of classical generators, a speed multiplier is then necessary. To eliminate this last, research was directed towards the design of new structures of generators called direct drive (without a speed multiplier). The synchronous and especially asynchronous machines still dominate the market of the wind applications. However, the Switched Reluctance Generator or SRG is regarded as a serious alternative to the traditional generators thanks to its multiple assets (robustness, simplicity of construction, low cost, high torque...). In this work, it is intended to model and simulate a switched reluctance generator 6/4 (SRG) (6 poles with the stator and 4 poles with the rotor) of a power of 30 kW. The design is carried out by finite element method (Software Mag.Net). The modeling and the simulation of this system are carried out under Matlab /Simulink environment

Keywords— Switched-Reluctance Generators , Command, Power Converter, Wind Turbine, Direct attack.

I. INTRODUCTION

The aero-generator, whatever the technology used, collects its energy of the wind by the intermediary of an aerodynamic structure of the blades and converts it into mechanical power. The integration of a speed multiplier and/or static inverters strongly depends on the technology of conversion used.[1,3]

Among the major problems of maintenance in the wind parks until now, it is the maintenance of the speed multiplier, which is complicated and expensive. This problem is solved with the family of the machines with direct attack, where one finds the synchronous generators with great number of poles, the synchronous permanent magnet generators (where only one stage of speed multiplier is used) and finally the generators with variable reluctance which makes the subject of this work. The SRG is a synchronous generator which is compatible with variable-speed operation of advanced wind turbines.

See [2,5] for operational characteristics of the variable reluctance motor (VRM). These characteristics carry over to the SRG.

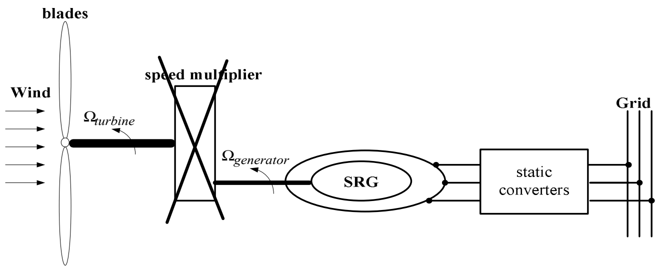

Figure1. Switched reluctance generator coupled indirectly to the grid

The torque developed by the generator is independent of the current sign of the winding supply. Consequently, the converter which supplies the machine can be thus one-way while running. This allows a simplification of its structure (asymmetrical half-bridge) and possibly a reduction of the number of semiconductors. The figure1 shows an assembly of supply of one phase of the SRG.

The converter topology chosen for this study is shown in figure 2. Its structure is made of H asymmetric half-bridge voltage inverter.

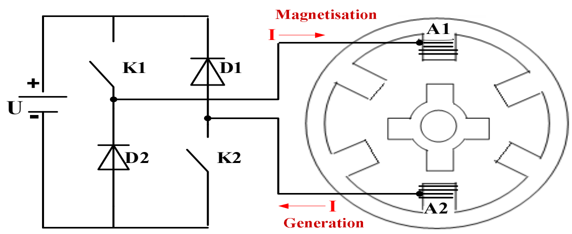

Figure2. Simplified structure of one phase supply of the SRG 6/4. [1]

The rotor of the generator is a variable reluctance motor driven by a primary. The rotor position can be obtained by a position sensor. The controller will generate the control signals based on information on the rotor position. The control signals of the switches (IGBT) of the power converter will control the phases of magnetization and the electrical generation.[4.6].

The Figure 2 shows that there are two switches K1 and K2, and two diodes D1 and D2 in each phase.

- When the two switches K1 and K2 are closed, the stator winding is energized; the system has absorbed the energy of the excitation source: magnetization phase.

- When K1 and K2 are open, winding releases energy through the diodes D1 and D2; the system provides power to external loads: the generation phase.

II. PRINCIPLE OF OPERATION

Given that the electromagnetic torque has the following expression:

$$C_{em} = \frac{1}{2} i^2 \frac{\partial L(\theta)}{\partial \theta}$$

The power of the machine with a constant current during the phase of increasing or decreasing inductance gives the required operating system, Figure.3:

- Motor mode ($C_{em} > 0$) on the increasing phase of the inductance ($\frac{\partial L(\theta)}{\partial \theta} > 0$).

- Generator mode ($C_{em} < 0$) on the decreasing phase of the inductance ($\frac{\partial L(\theta)}{\partial \theta} < 0$).

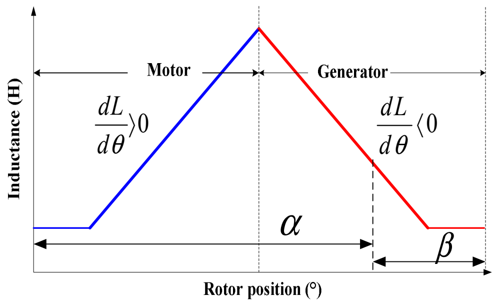

Figure 3. Variation of the inductance as a function of the rotor position. [2]

The principle of operation in generator mode is fairly simple; its complexity is in the order of the associated converter. In deed, ignition sequences (α) and extinction switches must be in perfect synchronism with the relative positions of rotor and stator teeth (need a position sensor) during the phases of excitation and generation, Figure 3, [2].

As a result, the proposed strategy to optimize the control of SRG 6/4 running at variable speed is based on finding optimal conduction angles.[7].

III. DESIGN AND SIMULATION

Functional geometric sizes are the main factors determining the machine geometry to achieve their determination and to identify the skeleton preliminary actuator designed, Figure 4.

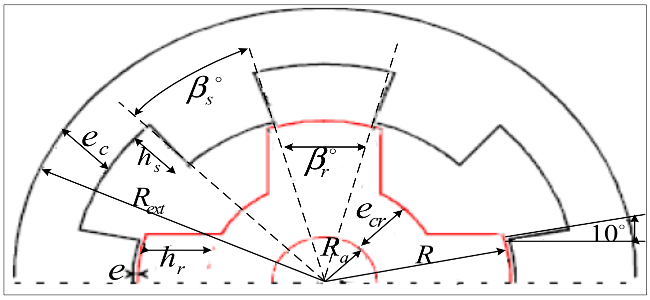

Figure4. Dimensional parameters defining the prototype

TABLE I. PRINCIPAL DIMENSIONS OF PROTOTYPE .[3]

Named	Notation	Dimensional
Active length	L	150mm
Outer radius	R_{ext}	125mm
Rotor radius	R	75mm
Height of stator teeth	h_s	25.6mm
Height of rotor teeth	h_r	28mm
Thickness airgap	e	0.8mm
Thickness of stator breech	e_{cs}	23.6mm
Thickness of rotor breech	e_{cr}	26mm
Radius of the shaft	R_a	21mm
Stator pole arc	β_s	30°
Rotor pole arc	β_r	30°

Thus, in order to perform the magnetic behavior of the actuator, the choice was set on the use of steel plates in Silicon (Arnon7) whose initial magnetization curve is given by the Figure.5. Also to take into account the effects of saturation and non-linearity introduced by the material on the magnetic behavior of the actuator, we proceeded by introducing into the database of the solver, the first magnetization curve.

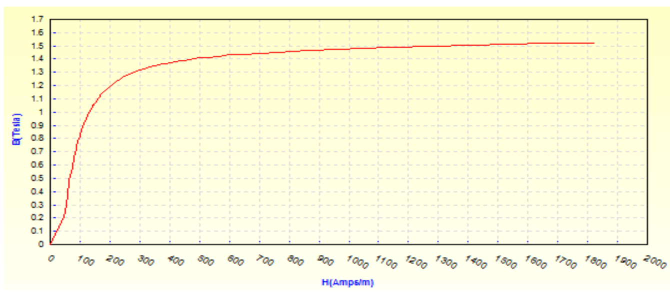

Figure5. Magnetic characteristic B (H) of the material Arnon7

IV. ELECTROMAGNETIC CHARACTERISTICS

To determine the flow of curves, inductance and torque, these actions are repeated for different angular positions of the rotor between 0 ° and 90 ° and an electrical supply of phase current from 25A DC up to 210 A . The Figures6, 7, 8 and 9 show the magnetic properties obtained with the finite element method, software Mag.Net 7.1.

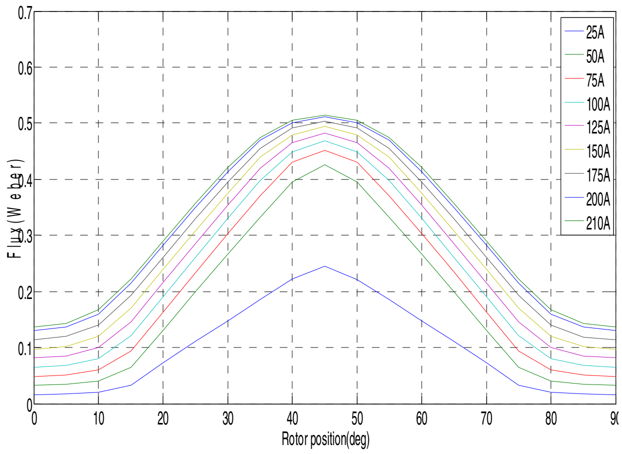

Figure6.Characteristicsof flux versus position

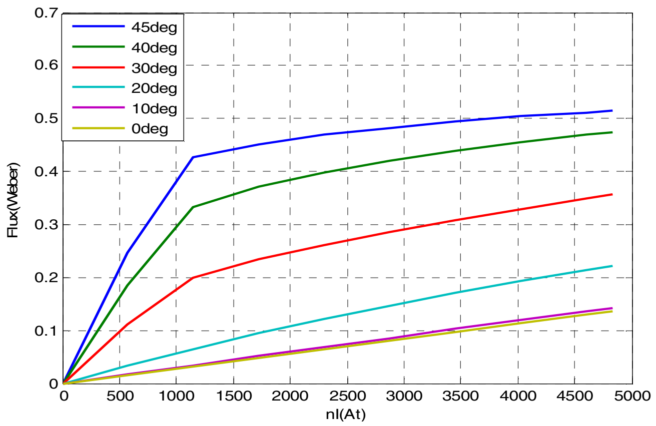

Figure7.Caracteristics for Flux-ni

From these magnetic characteristics, we deduced the inductance curves, Figure 7, and torque, Figure 9, depending on the position of the rotor for different excitations.

During generation, the stator windings of the SRG produce a negative torque (resistant), which tends to oppose the rotation of the blades subjected to the wind. If the phase stator is energized while the rotor poles are coming into position of conjunction, the rotor receives the stress of the opposite rotational torque of generation.

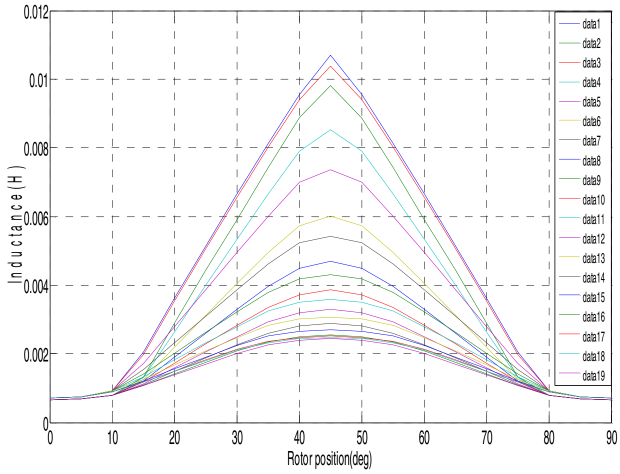

Figure8. Curves of the inductance for different currents

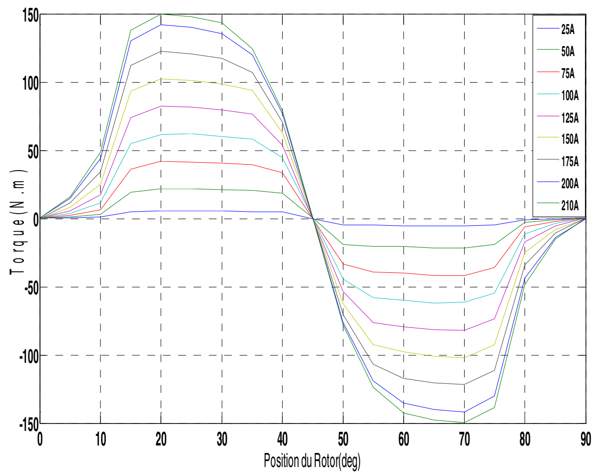

Figure9. Evolution of the torque versus of position for different currents

In the Figure 9, we distinguish the presence of oscillations at some of these features. These oscillations can be the cause of nature (non-linearity) of the chosen ferromagnetic material (Silicon Steel Arnon7) or mesh density applied to the modeling of the structure.

To characterize the magnetic behavior of the whole field of use of the generator in question, a computer program has been developed around interpolation techniques. This program has allowed us to obtain database illustrated in Figures10, 11 and

12. These bases, presented in the form of three-dimensional graphs, implement the response surface flux, inductance and torque.

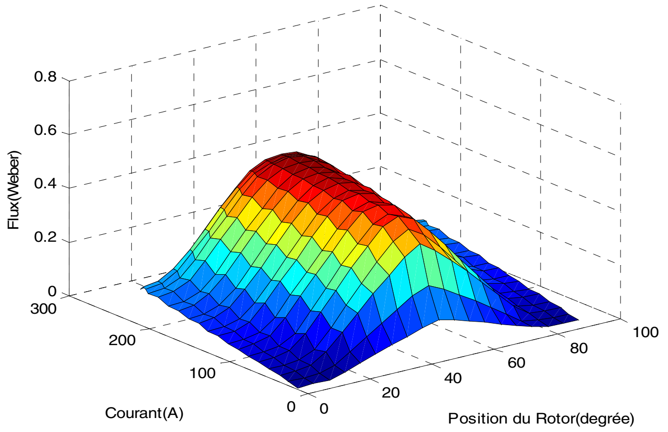

Figure.10. Response surface of the flow as a function of the current and position

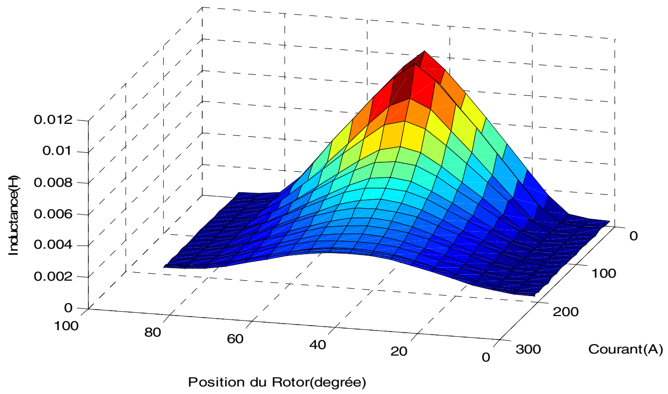

Figure.11. Response surface of the inductance as a function of the current and position

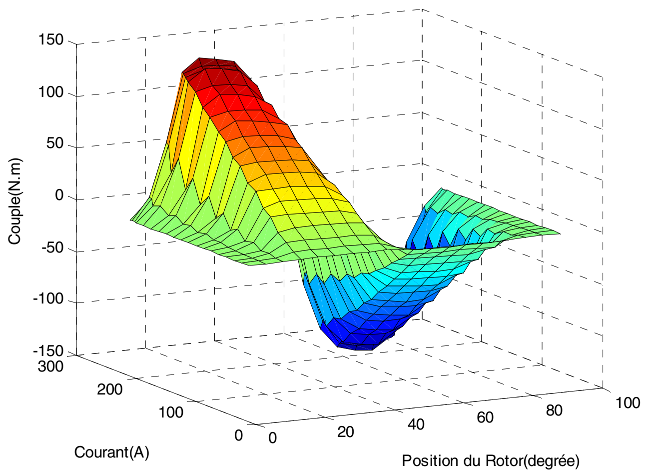

Figure.12. Response surface of the torque as a function of the current and position

V. INFLUENCE OF THE ELECTRICAL AND THE MECHANICAL PARAMETERS ON THE PERFERMANCES OF THE GENERATOR

The Figure13 shows the Simulink model of the SRG. This model consists of the blocks mentioned above (block GRVDS, power converter, power and position sensor block and current hysteresis controller). The scope is used to view the variation of main parameters.

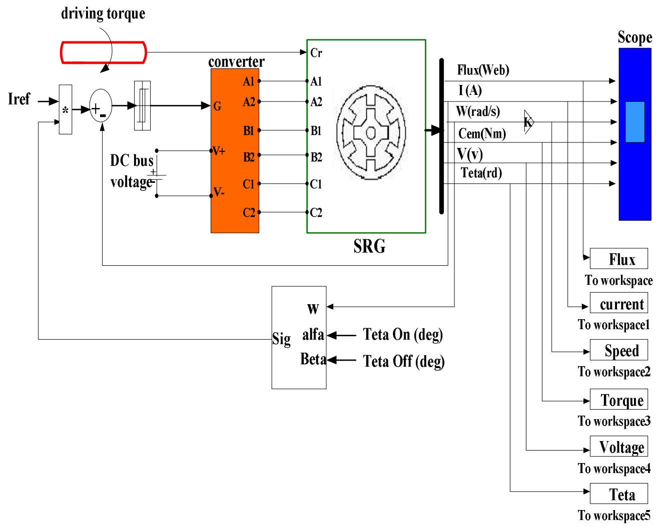

Figure.13.Bloc SRG 6/4

Generally, if we refer to the mechanical equation, to reduce the speed we must increase the torque. We can also decrease more if we increase the current phase according to the following equation:

$$(e = \frac{dL(\theta, i)}{d\theta} \Omega i).$$

Thus, the reference current can be increase too.

We have increased the driving torque to the value of (-135Nm), the reference current to the value of (200A), and only the ignition angle was conserved (74 degree). The value of the extinction angle is increased to (35 degree), and finally we have decreased the voltage to 110V DC bus.

The following figures show the results of the corresponding simulation.

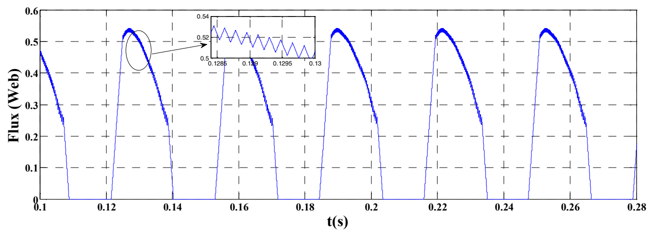

Figure.14. Shape of the flux for phase A for α = 74 ° and β = 35 °

The Figure14 illustrates the flux of the phase A. It is oscillating in the decreasing part, due to the elevation of the ripples and currents of the torque. The flux value is increased to 0.54Web which leads to the phase current to increase.

The flux of the other phases B and C are shifted of $\left(\theta_{dec}=\frac{2\pi\Delta t}{T}\right)$.

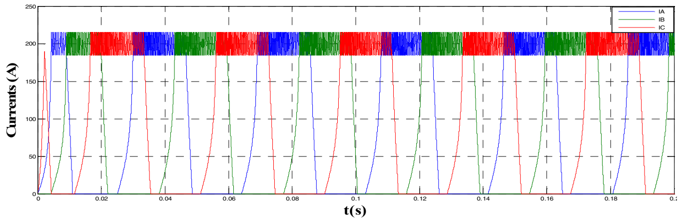

Figure15. Phase currents for $\alpha = 74^{\circ}\, et\, \beta = 35^{\circ}$

According to Figure15 and 16, the current of each phase has increased; it oscillates around the value of the reference current (200A), with a band of 30A. The currents of the other phases B and C are shifted of $\left(\theta_{dec}=\frac{2\pi\Delta t}{T}\right)$

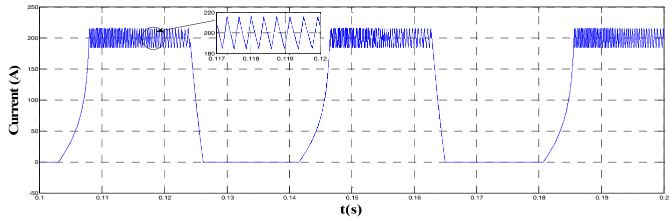

Figure16. Current of the phase A for $\alpha = 74^{\circ}\, et\, \beta = 35^{\circ}$

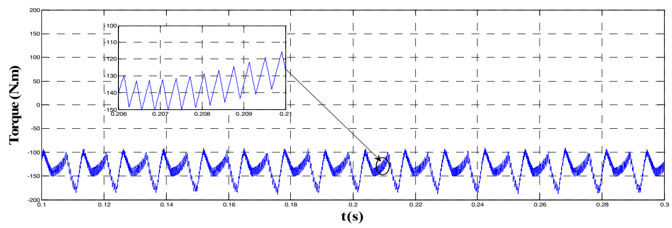

Figure17. Electromagnetic torque of the SRG for $\alpha = 74^{\circ}\, et\, \beta = 35^{\circ}$

The Figure 17 illustrates the torque ripple, it oscillates around driving torque and it is highly oscillating and pulsating which causes acoustic noise.

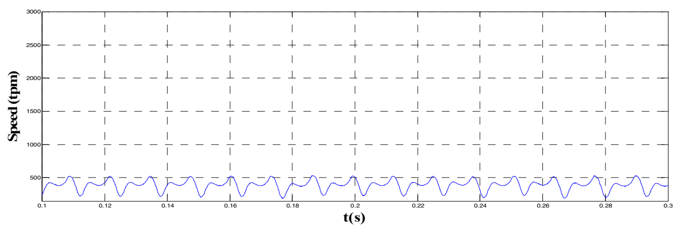

Figure18. Speed of the generator for $\alpha = 74^{\circ}\, et\, \beta = 35^{\circ}$

The speed of Figure18 oscillates around 300tr/min, and these parameters can sweet perfectly with our generator directly without speed multiplier with wind turbine.

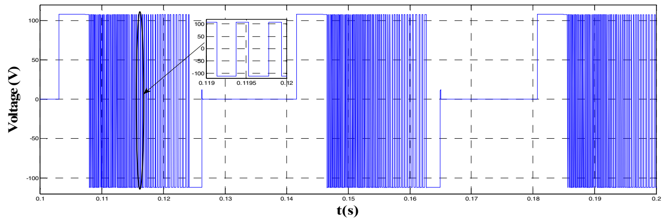

Figure19. Voltage for phase A for $\alpha = 74^{\circ}\, et\, \beta = 35^{\circ}$

Figure19 shows the voltage of phase A. The voltage is chopped due to the current-based PWM control at low speeds.

VI. Conclusion

Switched reluctance generators have been found to offer important advantages over conventional AC machines. This paper has investigated to model and simulate a switched reluctance generator 6/4 (SRG) (6 poles with the stator and 4 poles with the rotor) of a power of 30 kW. The design is carried out by finite element method (Software Mag.Net). The modeling and the simulation of this system are carried out under Matlab /Simulink environment. The control of the (SRM) is more complicated for generator operation than it is for motor. In generator mode, the turn-on and turn-off angles control the peak phase currently jointly and severally.

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