

# A NEW ROBUSTE CONTROL BASED ON SUPER TWISTING SLIDING MODE OF A DUAL STAR INDUCTION GENERATOR FOR WIND TURBINE

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**Abstract**— Traditional field oriented control using proportional integral (PI) regulator for the voltage DSIGs driven have many disadvantages such parameter tuning complication, mediocre dynamic performances and reduced robustness. Therefore, based on a  $d$ - $q$  model of the DSIG supplied by two AC-DC converters, this article proposes an advanced control scheme based on super-twisting sliding mode (STSMC). The usual sliding mode control (SMC) has large chattering on the DC voltage result on the exit of the two rectifiers. With the purpose to solve this problem, the super twisting sliding mode control is used. The simulation results show the advantage of the proposed method in the efficiency and robustness against parameters variation of the DSIG.

**Keywords**—Dual star induction generator (DSIG), super twisting sliding mode control(STSMC), field oriented control, PWM rectifier.

## 1. Introduction

In the last years, wind energy as the most widely utilized renewable resources and has been installed all over the world [2]. The reason is that the energy it produces does not cause greenhouse gases or other pollutants. Modern wind turbines use advanced power electronics to provide efficient generator control and to ensure compatible operation with the power system [1].

There are many wind generator technologies, among which the dual star induction generator (DSIG). The DSIG has a stator winding more than the ordinary induction generator; they are spatially shifted by 30 electrical degrees with isolated neutral points. Thus the state equations become more complicated as well as the coupling among the state variables. This paper concentrates on the mathematical model of DSIG whose stator windings are tight coupled. A simplified DSIG model is given as well.

In the past years the control strategy of a variable-structure using the sliding mode control (SMC) has been the subject of many studies and researches for machine control, The sliding mode control system advantage is that the controller is switched between two various control structures[19].

Though, this kind of control has an essential flaw, which is the chattering phenomenon produced by the discontinuous control action. To fix these difficulties, several Amendments to the original SMC law have been suggested, the most important being the boundary layer approach [20].

One manner to enhance SMC performance is to use a super twisting sliding mode controller (STSMC).

This paper is structured as follows. Modeling of the dual star induction and the vector control strategy (Fields and voltages equations is given and electromagnetic torque the expression) are shown in Section 2. The field oriented control (FOC) of a DSIG is presented in Section 3. The super twisting sliding mode control is developed in Section 4. The scheme presented in Fig. 2 and 4 are used for numerical simulation and the associated results are presented. Finally, the conclusions of this work are drawn.

## 2. Mathematecal model of the DSIG

The representation of the DSIG in the graduation Park is given in the following equivalent schemes.

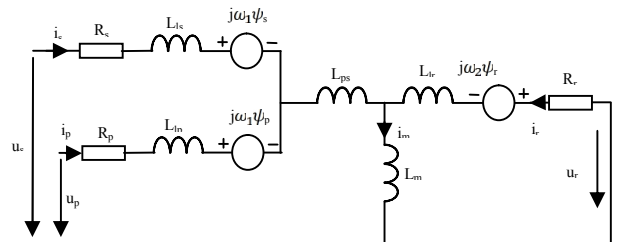


Fig.1. The d-q equivalent circuit of the DSIG

### A. The voltages equations

The expressions of the stator and rotor voltage are defined by the following equation system:

$$\begin{cases} v_d = -R_s i_d + \frac{d}{dt} \phi_d - \omega_s \phi_q \\ v_q = -R_s i_q + \frac{d}{dt} \phi_q + \omega_s \phi_d \\ v_d = -R_s i_d + \frac{d}{dt} \phi_d - \omega_s \phi_q \\ v_q = -R_s i_q + \frac{d}{dt} \phi_q + \omega_s \phi_d \\ 0 = R_r i_d + \frac{d}{dt} \phi_d - (\omega_s - \omega_r) \phi_q \\ 0 = R_r i_q + \frac{d}{dt} \phi_q + (\omega_s - \omega_r) \phi_d \end{cases} \quad (1)$$

### B. The flux equations

The expressions of the stator and rotor flux are defined by the following equation system:

$$\begin{cases} \phi_d = -l_{s1} i_{d1} - l_m (i_{d1} + i_{d2}) + L_m (-i_{d1} - i_{d2} + i_d) - L_d i_{q2} \\ \phi_q = -l_{s1} i_{q1} - l_m (i_{q1} + i_{q2}) + L_m (-i_{q1} - i_{q2} + i_q) + L_d i_{d2} \\ \phi_d = -l_{s2} i_{d2} - l_m (i_{d1} + i_{d2}) + L_m (-i_{d1} - i_{d2} + i_d) + L_d i_{q1} \\ \phi_q = -l_{s2} i_{q2} - l_m (i_{q1} + i_{q2}) + L_m (-i_{q1} - i_{q2} + i_q) - L_d i_{d1} \\ \phi_d = l_r i_d + L_m (-i_{d1} - i_{d2} + i_d) \\ \phi_q = l_r i_q + L_m (-i_{q1} - i_{q2} + i_q) \end{cases} \quad (2)$$

### C. Electromagnetic torque

The expression of electromagnetic torque of the DSIG is written:

$$C_e = \left(\frac{3}{2}\right) \left(\frac{p}{2}\right) \left(\frac{L_m}{L_d}\right) [(i_{q1} + i_{q2})] \phi_d - (i_{d1} + i_{d2}) \phi_q \quad (3)$$

## 3. Control strategy of the system

### A. The control rotor field orientation

In this control strategy, the field vector coincides with  $d$ - $q$  axis. Then the component  $\phi_{qr}$  is zero and  $\phi_{dr}$  is constant. The advantage of this presentation is to have a constant size in permanent regime.

$$\begin{cases} d = r \\ q = 0 \\ p_r = 0 \end{cases} \quad (4)$$

The application of the rotor field orientation on the model of the DSIG given by the voltages equations:

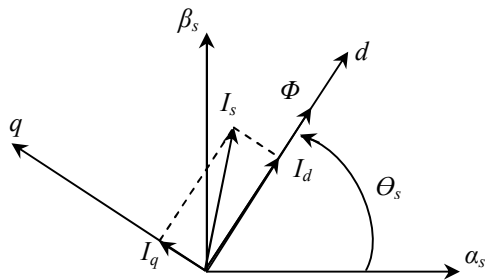


Fig.2. Fundament of Rotor Field Orientation.

We obtain:

$$\begin{cases} i_d = 0 \\ i_q = -\frac{(\omega_s - \omega_r) r}{R_r} \end{cases} \quad (5)$$

The final torque expression is written:

$$C_e = p \frac{L_m}{L_m + L_r} (i_{q1} + i_{q2}) r \quad (6)$$

### B. The Control algorithm

The objective of our control is to maintain constant the voltage at the output of the two rectifiers.

The expression of the reference power is written:

$$V_d i_d = P = P_e = C_e \Omega \quad (7)$$

The torque expression is:

$$C_e = \frac{P}{\Omega} \quad (8)$$

The torque is controlled by the quadrature of current  $i_{qs1}$  and  $i_{qs2}$  of the two stars:

$$i_{q1} + i_{q2} = \frac{(L_m + L_r) C_e}{p L_m r} \quad (9)$$

The flux  $\phi_r^*$  is estimated from the currents  $i_{sd1}$  and  $i_{sd2}$  of the two stars:

$$r = \frac{R_r L_m}{(L_r + L_m) P + R_r} (i_{d1} + i_{d2}) \quad (10)$$

### C. Sliding mode controller (SMC)

To avoid chattering some approaches were proposed. The main idea was to change the dynamics in small vicinity of the discontinuity surface in order to avoid real discontinuity and at the same time to preserve the main properties of the whole system.

$$\dot{x} = f(x, t) + B(x, t) V(x, t), x \in \mathbb{R}^n, V \in \mathbb{R}^m, r_1 \quad (B(x, t)) = m \quad (11)$$



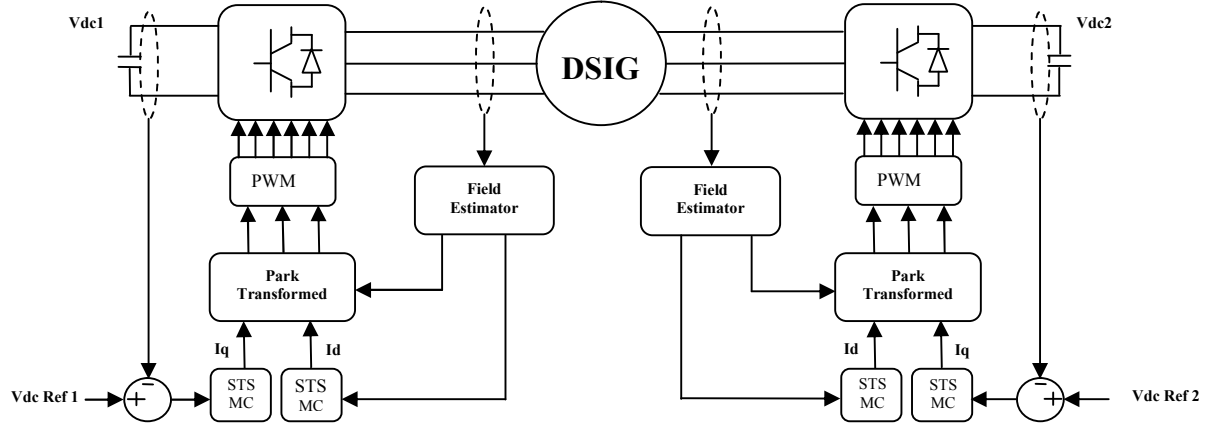


Fig.4. Block diagram of the DSIG voltage control with STSMC

#### D. Super twisting sliding mode controller (STSMC)

This method generalizes the essential sliding mode idea by acting on the higher order time derivatives of the sliding manifold, instead of influencing the first time derivative as it is the case in SMC, therefore reducing chattering and avoiding strong mechanical efforts while preserving SMC advantages.

In order to ensure the DSIG voltage convergence to their reference, a second order sliding mode control (STSMC) is used. Considering the sliding mode surface given by (21), the following expression can be written:

$$\begin{cases} S = V_d - V_a \\ \dot{S} = Y(t, x) + \Lambda(t, x)I_R \end{cases} \quad (23)$$

Where  $Y(t, x)$  and  $\Lambda(t, x)$  are uncertain functions which satisfy:

$$Y > 0, |Y| > \lambda, 0 < K_m < \Lambda < K_M \quad (24)$$

Basing on the super twisting algorithm introduced by Levant in [10], the proposed high order sliding mode controller contains two parts:

$$I_R = v_1 + v_2 \quad (25)$$

With

$$\begin{aligned} v_1 &= -k \cdot s_1 \quad (S) \\ v_2 &= -l \cdot |S|^\gamma \cdot s_1 \quad (S) \end{aligned}$$

In order to ensure the convergence of the sliding manifolds to zero in finite time, the gains can be chosen as follows [11].

$$\begin{cases} k > \frac{\lambda}{K_m} \\ l^2 > \frac{4\lambda}{K_m^2} \frac{K_M(k+\lambda)}{K_m(k-\lambda)} \\ 0 < \gamma < 0.5 \end{cases} \quad (26)$$

#### 4. Simulation results and discussions

The simulation is realized by a generator 158V/50Hz whose characteristic is given in Table 1. The scheme proposed for the simulation of the DSIG as shown in Fig 3, the assembly has two rectifiers connected to the two stars of the DSIG. The goal is to make a comparison between the two control methods; with PI controller and higher order sliding mode controller, two tests have been realized: pursuit test, and robustness against machine parameter variations.

##### A. Pursuit test

In this test the two reference voltages is defined  $V_{dc1}$  and  $V_{dc2}$  desired in the output of the two rectifiers, in this study the torque is equal to zero. The voltages and currents across the two stars of the DSIG are presented in Fig 5 and 6. The results for this test show that the voltages at the exit of the two rectifiers perfectly follow their references as shown in Fig 7. It is clear that the STSMC controller reacts faster than the PI controller; the static error is almost zero for two regulators. From these results we can say that the STSMC controller is more efficient than a PI controller.

## B. Robustness test

In order to test the behavior of the machine during the saturation, initially we will modify the parameters of the DSIG as following; we decreased the stator and rotor inductances by 5%, increase resistance by 10%. The results presented in Fig 8 show that the parametric variation presents an effect on the  $V_{dc}$  voltage response time of the two controllers. Comparing the performance of each controller as shown in the Fig 9 we deduced that STSMC controller is faster and more stable than a PI controller, so we can conclude that STSMC regulator is more efficient than a PI regulator against this parameter variation.

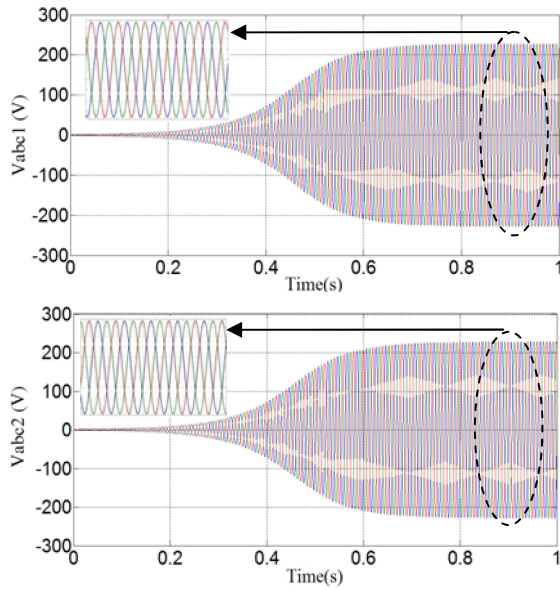


Fig.5. Voltage of stator 1 and 2 respectively.

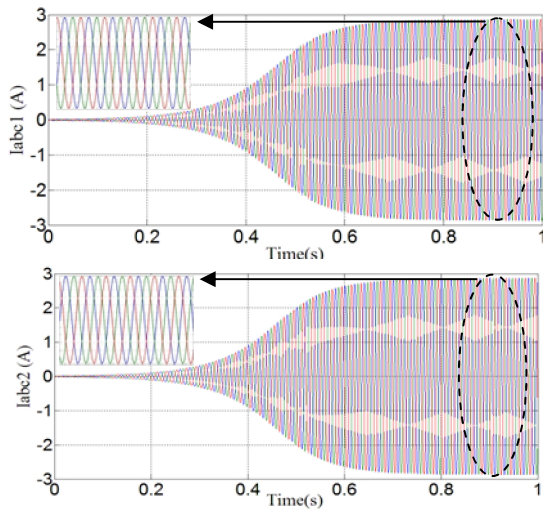


Fig.6. Current of stator 1 and 2 respectively.

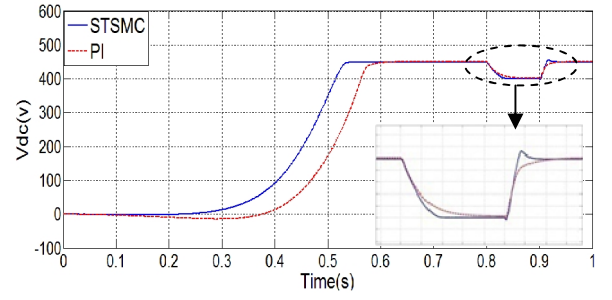


Fig.7. Pursuit test.

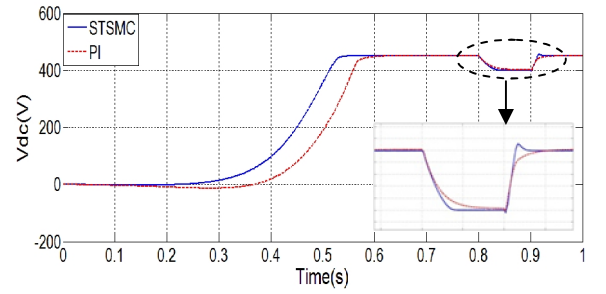


Fig8. Pursuit test with parametric variation.

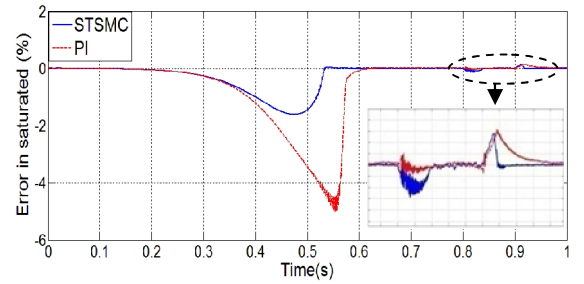


Fig9. Robustness test.

## 5. Conclusion

In this paper we present a simple scheme control of DSIG supplied by two power rectifiers. We used two control techniques; the field oriented control (FOC) and the high order sliding mode control (STSMC). The results obtained after simulation show the efficiency using a high order sliding mode control regulator compared to a simple PI regulator. According to the robustness test which shows that the STSMC regulator is more robust than the PI regulator with the parameter variations (stators and rotor resistances).

## Appendix

Table 1. Nomenclature.

Symbol	Significance
$d, q$	Direct and quadrate indices for orthogonal components,
$R_{s1}, R_{s2}, R_r$	resistances of the star 1 and 2 and the rotor,
$l_{s1}, l_{s2}, l_r$	Stator leakage inductances (star 1 and 2) and rotor respectively
$l_m$	The mutual leakage inductance to the two stars,
$L_{dq}$	Cyclic inter saturation inductance,
$\phi_{s1}, \phi_{s2}, \phi_r$	Flux of the star 1 and 2 and the rotor,
$\omega_s$	Stator current frequency (rad/s),
$\omega_r$	The rotor rotation speed
$J$	Inertia ( $J_n$ nominal value of $J$ ),
$C_{em}$	Electromagnetic torque.

Table 2. The DSIG parameters.

Parameters	Value	IS-Unit
Stator voltage	158	V
Stator/rotor frequency	50	Hz
Star 1 resistance	1.9	$\Omega$
Star 2 resistance	1.9	$\Omega$
Rotor resistance	2.1	$\Omega$
Star 1 inductance	0.0132	H
Star 2 inductance	0.0132	H
Rotor inductance	0.0132	H
Mutual inductance	0.011	H
Inertia	0.038	Kg.m <sup>2</sup>

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