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OPTIMAL TRACKING AND ROBUST POWER CONTROL OF THE DFIG WIND TURBINE

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ABSTRACT

In the present paper, an optimal operation of a grid-connected variable speed wind turbine equipped with a Doubly Fed Induction Generator (DFIG) is presented. The proposed cascaded nonlinear controller is designed to perform two main objectives. In the outer loop, a maximum power point tracking (MPPT) algorithm based on fuzzy logic theory is designed to permanently extract the optimal aerodynamic energy, whereas in the inner loop, a second order sliding mode control (2-SM) is applied to achieve smooth regulation of both stator active and reactive powers quantities. The obtained simulation results show a permanent track of the MPP point regardless of the turbine power-speed slope moreover the proposed sliding mode control strategy presents attractive features such as chattering-free, compared to the conventional first order sliding technique (1-SM)

Keywords (: Doubly fed Induction Generator, Fuzzy MPPT Algorithm, Power Control, Sliding Mode Control, Wind Turbine.

I. INTRODUCTION

These wind turbines are all based on variable speed operation using a Doubly Fed Induction Generator (DFIG) or a direct driven synchronous generator (without gearbox). The doubly fed induction generator is used in several wind energy conversion systems. This machine has proven its efficiency due to qualities such as robustness, cost and simplicity. It offers several advantages including variable speed operation (33% around the synchronous speed), and four-quadrant active and reactive power capabilities Such system also results in lower converter cost and lower power losses compared to a system based on a fully fed synchronous generator with full-rated converter. Moreover, the generator is robust and requires little maintenance.

During the last decades, especially after the oil crisis in the 1970s, global interest for clean and renewable energy sources has been growing intensively. Wind energy in particular, has received a strong impulse, reflected in great technology advances regarding reliability, cost-efficiency and integration to the grid of the wind energy conversion systems (WECSs). Wind turbines generate about 1.5% of the word electricity consumption, with an installed capacity of 121 GW by the end of 2008 comprising more than 70 countries.

The control law of the converter can be applied in order to extract maximum power of the wind turbine for different wind many papers have been presented with different control schemes of DFIG. These control schemes are generally based on vector control concept (with stator flux or voltage orientation) associated with classical controllers. With the improvements technologies in materials, power electronics and blade design, classical controllers for WECS can be updated by the development of more efficient strategies based on modern control techniques such as: fuzzy logic control, robust control [adaptive control and sliding-mode control. Among these control strategies, sliding mode (SM) control emerges as an especially suitable option to deal with variable speed operating WECS. This control technique has proven to be very robust with respect to system parameter variations and external disturbances.

In this paper, an optimal operation of a grid-connected variable speed wind turbine, based on a doubly fed induction generator is presented. The proposed control algorithms focus two main goals: a permanent track of the available maximum wind power, and a smooth regulation of the stator active and reactive powers exchanges between the machine and the grid. In Section 2, explicit models of the different sub-systems are described. In Section 3, the proposed control algorithms are detailed precisely, while in Section 4 simulation results are presented and discussed.

II. SYSTEM DESCRIPTION

a) DOUBLY FED INDUCTION GENERATOR

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly (see brushless doubly-fed electric machines), but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine.

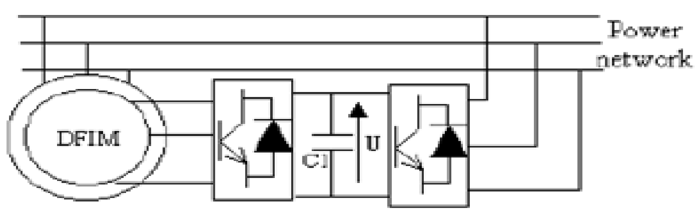

Fig 1. Block diagram of conventional wind generator with a DFIG.

The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency (50 or 60 Hz). By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed.

The control of the rotor voltages and currents enables the induction machine to remain synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine utilizes the available wind resource more efficiently than a fixed speed wind turbine, especially during light wind conditions. Third, the cost of the converter is low when compared with other variable speed solutions because only a fraction of the mechanical power, typically 25-30 %, is fed to the grid through the converter, the rest being fed to grid directly from the stator. The efficiency of the DFIG is very good for the same reason.

b) WIND ENERGY: Wind power is the conversion of wind energy into a suitable form of energy, such as using wind turbines to generate electricity, windmills for mechanical power, wind pumps for water pumping, or sails to propel ships

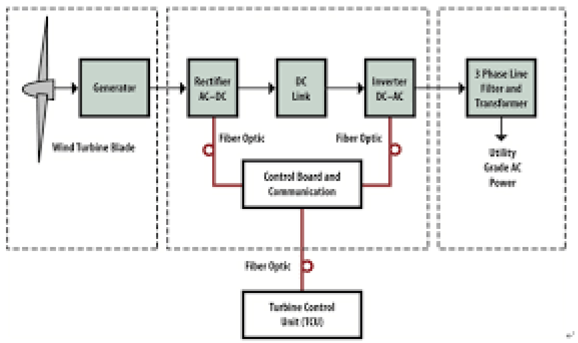

Fig 2. Block diagram for WECS

The total amount of economically extractable power available from the wind is considerably more than present human power use from all sources. Wind power, as an alternative to fossil fuels, is abundant, renewable, widely spread, clean, and produces no greenhouse gas emissions during operation. Wind power is the world‘s rapid growing source of energy.

$$E=\frac{1}{2}mv^2 \quad (1)$$

$$P_a=\frac{1}{2}\rho A v^3 \quad (2)$$

Where:

ρ – Air density

A – Area swept by the rotating blades

v – Wind speed

It easy to see that mechanical power have a cubic relation with wind speed. It is considerable advantage in situation when the wind is blowing with constant speed but this condition is happens rarely in real. Therefore that cubic relation is significant disadvantages of wind turbine making them very floating resource.

III. MODELLING OF WIND TURBINE

The aerodynamic power captured by the aero turbine rotor is given by,

$$P_a = 0.5\rho\pi R^2 v^3 C_p(\lambda,\beta) \quad (3)$$

CP is the power coefficient which is a nonlinear function of the tip speed ratio (TSR) λ, it is given by,

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$$C_p(\lambda) = a_0 + a_1\lambda + a_2\lambda^2 + a_3\lambda^3 + a_4\lambda^4 + a_5\lambda^5 \quad (4)$$

The TSR is defined as the ratio between the linear blade tip speed and the wind speed, expressed as:

$$\lambda = \frac{R\Omega_t}{v} \quad (5)$$

Then the aerodynamic torque is given by,

$$T_a = \frac{P_a}{\Omega_t} = 0.5\rho\pi R^3 v^2 C_T(\lambda,\beta) \quad (6)$$

Where,

$$C_T(\lambda,\beta) = \frac{C_P(\lambda,\beta)}{\lambda} \quad (7)$$

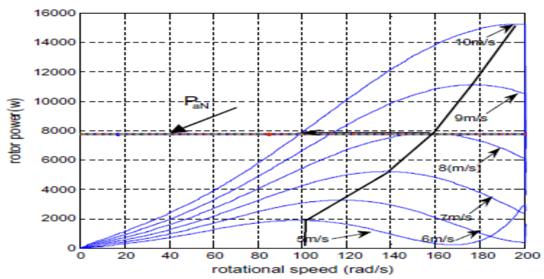

Fig.3.Rotor power versus rotational speed of generator.

IV. CONTROLLING TECHNIQUES

a) The fuzzy MPPT controller:

In order to tracking an optimal rotor speed reference, without measuring the wind speed and without the knowledge of the turbine characteristics because the use of wind speed sensor to measure the wind speed adds to a system a cost and presents some difficulties in practical implementation.

The control rules are indicated in Table 1: with (ΔPa) and (ΔΩm) as inputs, while (ΔΩmref) represent the output. These inputs and output variables are expressed in terms of linguistic variables (such as BN (big negative), MN (means negative), SN (small negative), Z (zero), SP (small positive), MP (means positive), BP (bigpositive)).

Table 1
Fuzzy rule table.

$\Delta\Omega_m$	Δ Pa						
	BN	MN	SN	Z	SP	MP	BP
BN	BP	BP	MP	Z	MN	BN	BN
MN	BP	MP	SP	Z	SN	MN	BN
SP	MP	SP	SP	Z	SN	SN	MN
Z	BN	MN	SN	Z	SP	MP	BP
SP	MN	SN	SN	Z	SP	SP	MP
MP	BN	MN	SN	Z	SP	MP	BP
BP	BN	BN	MN	Z	MP	BP	BP

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b) High order sliding mode controller:

The sliding mode control has a unique place in control theories. First, the exact mathematical treatment represents numerous interesting challenges for the mathematicians. Secondly, in many cases it can be relatively easy to apply without a deeper understanding of its strong mathematical background and is therefore widely used in engineering practice. This article is intended to constitute a bridge between the exact mathematical description and the engineering applications. After a short overview of the sliding mode control the article presents its mathematical foundations, namely the theory of differential equations with discontinuous right-hand sides. The power electronic circuits, which always have some kind of switching elements, can be typically described by such differential equation. Such equations don’t fulfill the regular theorem of existence and uniqueness, but under certain conditions remain valid, if we interpret the solution of the differential equation according to the definition proposed by Filippov.

V. PARAMETERS AND SPECIFICATIONS

A.DFIG DATA	
Rated power	7.5KW
Rated line voltage	220 V
Grid frequency	50 (Hz)
Rs	0.455 (Ω)
Rr	0.62 (Ω)
Ls	0.084 (H)
Lr (refer to stator)	0.081 (H)
Lm (refer to rotor)	0.078 (H)
Moment of inertia, J	0.3125 (kg m^2)
Friction coefficient, f	6.73.10*3 (N m s^(-2))

B.WIND TURBINE DATA

Rated power PaN	7.8 (kw)
a0	0.001
a1	6.38 * 10^(-2)
a2	-9.40 *10^(-2)
a3	9.86 *10^(-3)
a4	-17.375 * 10^(-4)
a5	7.956 * 10^(-5)
R	3.80 (m)
Rated wind speed	8 (m s¯1)
Cut-in speed	5 (m s¯1)

VI. SIMULATION AND RESULTS

DFIG connected to WECS with Fuzzy:

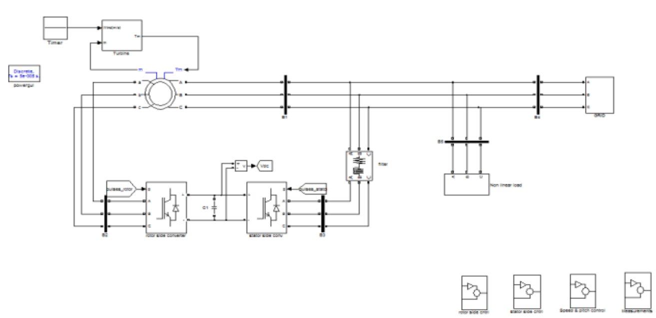

Fig.4. MATLAB/SIMULINK Diagram Of DFIG Connected To WECS With Fuzzy

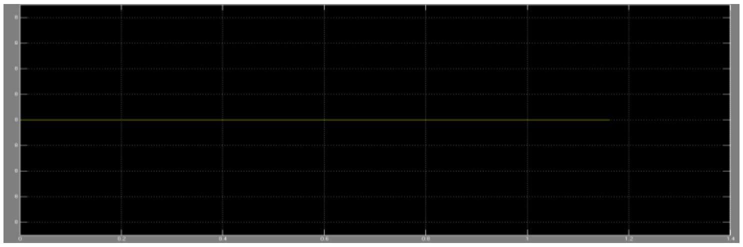

Fig.5. Wind Speed (m/s)

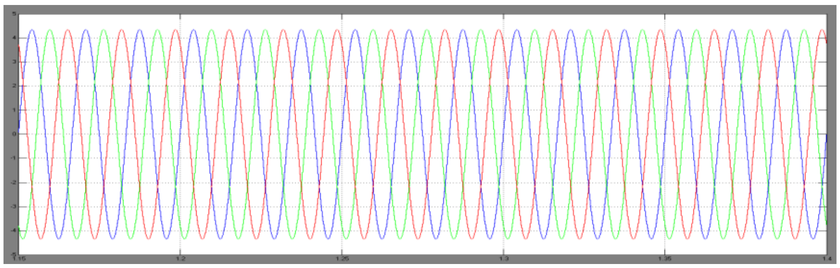

Fig.6.grid voltage(Vabc)

VII.CONCLUSION

In this paper, a complete system to produce electrical energy using DFIG is presented. The stator is directly connected to the grid and the rotor is connected to the utility by the way of two converters (machine inverter and grid rectifier). A cascaded control algorithms where properly designed to ensure the optimal operation of the whole system. In the outer loop, a fuzzy logic controller was designed to extract the maximum aerodynamic power up to the rated power, regardless of the turbine power-speed slope. If the wind power exceeds the rated value, the system switches to power regulation mode, via the power limitation circuit. In the inner loop, the described high order sliding mode controller has been designed to control the active and reactive powers exchanged between the machine and the grid, through the machine inverter. The obtained simulation results show that the system switches with flexibility between the ‘‘Tracking mode’’ and the ‘‘Power regulation mode’’ without synchronous speed overshoot. On the other hand, the stator power quantities provided by the 2-SM strategy.

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