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FUZZY BASED MPPT CONTROLLER OF WIND ENERGY CONVERSION SYSTEM USING PMSG

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ABSTRACT

The wind energy is one of the most developed renewable energy resources. The paper describesstator side & grid side converter using a fuzzy logic controller. The system includes a wind turbine, permanent magnet synchronous generator (PMSG) & Converters. The MPPT technique applied rotor/stator side converter control& Grid side converter control. The stator/rotor side converter control in using the fuzzy logic controller to extract the maximum power and the grid side converter control in usinga fuzzy logic controller to ensure a smooth DC link voltage between two converters.

KEYWORDS:*Fuzzy Logic Controller (FLC), Maximum Power Point Tracking (MPPT), Wind Energy Conversion System (WECS), Permanent Magnet Synchronous Generator (PMSG)*

Article History

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INTRODUCTION TO WECS's

The wind energy has become competitive form of the green and energies and economic energies. Wind power system production developing is very fast. The wind turbine system work on the different wind speed. The range of wind speed is cut in, cut out and rated speed of the wind turbine. The outside of the limit wind turbine is stopped and protect the generator.

Wind energy conversion system includes the wind turbine system, power electronics, and control system. For the wind turbines, based on the orientation of the rotation axis of the wind turbine, there are horizontal-axis wind turbines and vertical-axis wind turbines and In the horizontal-axis wind turbines, the rotation axis of the wind turbine is parallel to the ground, while in the vertical-axis wind turbines, the rotation axis is perpendicular to the ground [12]. Compared to the vertical-axis wind turbines, horizontal-axis wind turbines have higher wind energy conversion efficiency, which is widely applied in the wind energy industry [12].

The wind turbines classify as,

- Fixed-speed and wind turbines
- Variable-speed wind turbines

The fixed-speed wind turbines advantages of they are simple, robust, and require the lower construction and maintenance cost and the operation speed is fixed and cannot be controlled with the variation of the wind speed, which results in lower energy conversion efficiency compared to the variable-speed wind turbines.

Wind Energy Characteristics

The kinetic energy flows in the air. It is converted into electrical energy through wind energy conversion system. The power in the air flow can be calculated is by:

$$p_{air} = \frac{1}{2pAv^3}$$

Where,

p= Air density(approx.1.225kgm-3)

A= Area Swept by the rotor

v=Upwind free mean wind speed

The wind power is transferred to the wind turbine rotor and it is reduced by the factor called the power coefficient and power coefficient is given by the formulae given below in the equation,

Power Coefficient, Cp:

$$Cp = \frac{P(mechanicalpower)}{P_{air}}$$

The max. value of the Cp is called Betzlimit. In wind turbine case maximum efficiency was derived by Lanchester in 1915 and Betz in 1920 known asthe Lanchester Betz Law.

Then

P*mechanical power* = $CpP_{air} = \frac{1}{2pAv^3}$

Tip speed ratio in the formation of wind turbine design and it is defined as the ratio of tangential speed at the blade tip to the actual wind speed.

$$\lambda = \frac{(l+r)\omega}{v}$$

Where,

l is the length of the blade

r is the radius of the hub

µ=*is the angular speed of the blades*

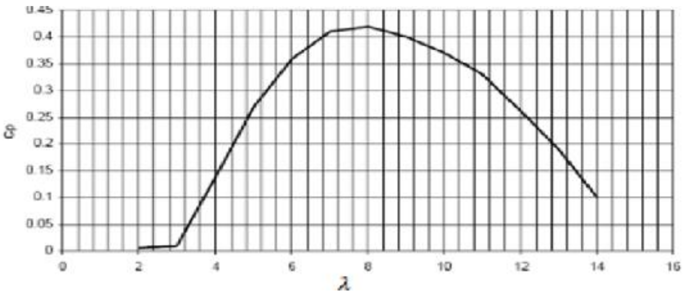

Figure 1:Power Coefficient Curve

To illustrate the performance of any size of wind turbine rotor there are two factors which are responsible are tip-speed ratio and the power coefficient Cp because they are dimensionless.

As shown in the Figure. That the maximum power coefficient can only be achieved at a single tip-speed ratio and for a fixed rotational speed of the wind turbine this only occurs at a single wind speed.

MODELING OF WECS

In a wind energy conversion system in the kinetic energy of the moving air particles can be expressed according to the expression:

$$E = \frac{1}{2} m v_w^2 \tag{1}$$

Where,

E= air particles for kinetic energy

m=total mass of air particles

V_w =moving of the air particles

t= time

$$m = pAV_w t = p\pi r^2 V_w t \tag{2}$$

where, *p*, is the air density, and A is the swept area of the wind turbine rotor. Here, r, is the radius of the wind turbine rotor. Substituting an expression (1) into (2), the kinetic energy of the air particles can be expressed as follows:

$$E = \frac{1}{2} p\pi r^2 V_w^3 t \tag{3}$$

From theexpression (3), the actual wind power at any instant of time can be represented as:

$$P_{wind} = \frac{E}{t} = \frac{1}{2} p\pi r^2 V_w^3 \tag{4}$$

From the expression (4), theyobserved that the wind power is proportional to the cube of the wind speed, which means that the smallest increase of the wind speed will result in a largest increase of the wind power. Moreover, the power can also be increased by enlarging the wind turbine rotor radius since the power is proportional to the square of this rotor radius. This is the reason that more and more large-scale wind turbine systems (up to 10MW) are being investigated and contemplated nowadays.

From the expression (4) can only stand for the maximum potential power which is available when the wind with velocity passes through the swept area of the wind turbine with radius. The wind turbine and potential power in wind expressed following equation,

$$C_p = \frac{powerofwindturbine}{powerofwind} \tag{5}$$

Themechanical powerand is the power coefficient of the wind turbine can be expressed by thefollowing equation:

$$C_p = C_1 \left(C_2 \frac{1}{\alpha} - C_3\beta - C_4\beta - C_5 \right) e^{-c_6} \left(\frac{1}{\alpha} \right) \tag{6}$$

where,

$$\frac{1}{\alpha} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta^3} And, \lambda = \frac{\omega_m r}{V_n}$$

where,β, is the blade angle, show the below figure 2.

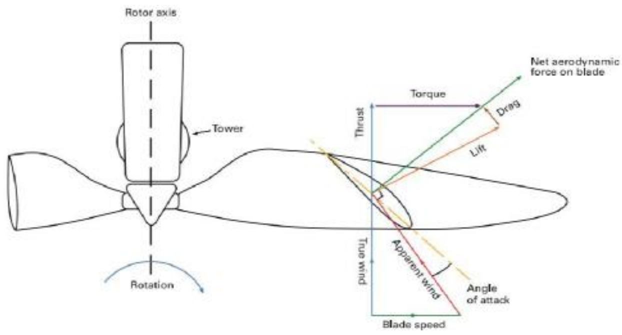

Figure 2: Blade Angle Schematic Diagram

In this Figure, the blade angle indicates, how does the wind velocity impact the wind turbine blades. The blade angle is the angle between the orientation of the blade and the wind velocity vector. When the blade is fully impacted by the wind velocity and the wind turbine will capture the maximum power in the wind. The blade is 0^0 when the wind speed is lower than the rated wind speed of the system and the high efficiency of energy capture. When the wind speed greater than the rated value, the power captured by the system will exceed the rated power if the blade angle stays unchanged at 0^0. It will make the generator and the power devices work under higher than rated output, which is harmful to the system if sustained for any length of time.

$$P_{turbine} = \frac{1}{2} p\pi r^2 C_p(\lambda, \beta) V_w^3 \tag{7}$$

Tip speed ratio is defined as the ratio of tangential speed at the blade tip to the actual wind speed.

$$\lambda = \frac{(l+r)\omega}{v}$$

Where,

l is the length of the blade

r is the radius of the hub

µ=*is the angular speed of blades*

MODELING OF PMSG

The electrical and mechanical system of PMSG machine is developed by utilizing the state space model. For obtaining the sinusoidal electromotive force firstly stator flux which is generated by the permanent magnets must be in the sinusoidal form Due to the presence of a large air gap generally found in PMSG, it is assumed that the machine has a linear magnetic circuit and the core of either stator orrotor does not saturate. The equations of the electrical and mechanical system are given below. An arbitrary dq-frame is used as the reference for stator and rotor quantities.

For developing the mathematical model for a PMSG, there are some assumptions followinggiven.

- Saturation is neglected.
- Induced electromotive force (EMF) is sinusoidal.
- Eddy currents and hysteresis losses are negligible.
- Conductivity of the permanent magnet is zero.

The rotation of wind turbine causes the rotor of the PMSG to rotate and it is represented in theform of d-q coordinate system, which is given as follows:

$$Vqs = -RsIqs + Lqs\left(\frac{d}{dt}\right)Iqs - wrLdsIds + wr(\frac{dy}{dx})\Psi ds$$

$$Vds = -RsIds + Lds\left(\frac{d}{dt}\right)Ids + wrLqsIqs$$

Where,

Vqs Quadrature-axis (q-axis) stator voltage

Vds Direct-axis (d-axis) stator voltage

Ids D-axis stator current

Iqs Q-axis stator current

ωr Angular velocity of generator rotor

Rs Resistance of the stator winding

Lds Stator inductance in d-axis

Lqs Stator inductance in q-axis

(d/dt)Ψds Amplitude of the flux linkages

$$Te = \frac{3P}{4}[idsiqs(Lds - Lqs)iqs(\frac{d}{dt})\Psi ds$$

Where,

Te Electromagnetic torque

P Pole number of generator stator

FUZZY SYSTEM

Fuzzy system is the process of the mapping from a given input to an output using fuzzy logic. The mapping,then provides a basis from which decisions can be made, or patterns discerned.The process of fuzzy inference involvesMembership Functions, Logical Operations, and If-Then Rules.

The two types of classifying fuzzy system,

- Mamdani-type and
- Sugeno-type

These two types of inference systems vary somewhat in the way outputs are determined. See the Bibliography for references to descriptions of these two types of fuzzy inference systems.

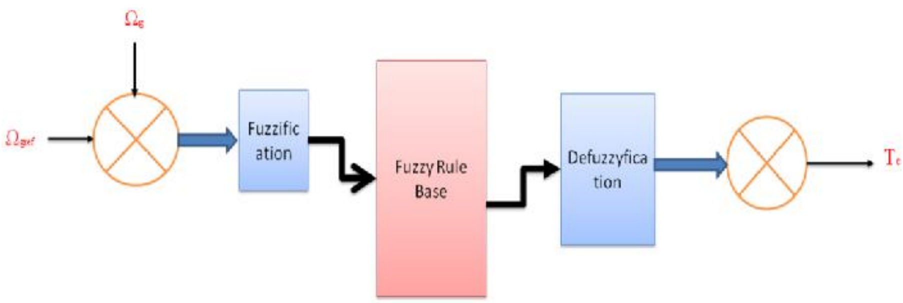

Figure 3: Block Diagram of Fuzzy System

Fuzzy Inferencing

The process of fuzzy reasoning is incorporated into what is called a Fuzzy Inferencing System. It is comprised of three steps that process the system inputs to the appropriate system outputs. These steps are 1) Fuzzification, 2) Rule Evaluation, and 3) Defuzzification. The system is illustrated in the following figure.

Each step of fuzzy inferencing is described in the following sections.

Fuzzification

Fuzzificationis the first step in the fuzzy inferencing process. This involves a domain transformation where crisp inputs are transformed into fuzzy inputs. Crisp inputs are exact inputs measured by sensors and passed into the control system for processing, such as temperature, pressure, rpm's, etc.. Each crisp input that is to be processed by the FIU has its own group of membership functions or sets to which they are transformed. This group of membership functions exists within a universe of discourse that holds all relevant values that the crisp input can possess. The following shows the structure of membership functions within a universe of discourse for a crisp input.

Where,

Degree of Membership: Degree to which a crisp value is compatible with a membership function, value from 0 to 1, also known as truth value or fuzzy input.

Membership Function: MF: defines a fuzzy set of mapping crisp values from its domain to the sets associated degree of membership.

Defuzzification

Defuzzification involves the process of transposing the fuzzy outputs to crisp outputs. A method of averaging is utilized here and is known as the Center of Gravity method or COG, it is a method of calculating centroids of sets. The output membership functions to which the fuzzy outputs are transposed are restricted to being singletons. This is so to limit the degree of calculation intensity in the microcontroller. The fuzzy outputs are transposed to their membership functions similarly as in fuzzification. With COG the singleton values of outputs are calculated using a weighted average, illustrated in the next figure. The crisp output is the result and is passed out of the fuzzy inferencing system for processing elsewhere.

CONTROL STRATEGY

Stator Side Converter Control

A linear relationship between the q-axis current and electromagnetic torque, the d-axis stator current is regulated to be equal to zero.

$$i_{sqref} = \frac{2}{3p\varphi_s} T_{eref}$$

And the reference generator speed following equation,

$$\Omega_{gref} = \delta \frac{\lambda_{opt}}{R} v$$

As shown figure, a reference current was derived by using an FLC, in order to regulate generator speed to optimal value and MPPT strategy.

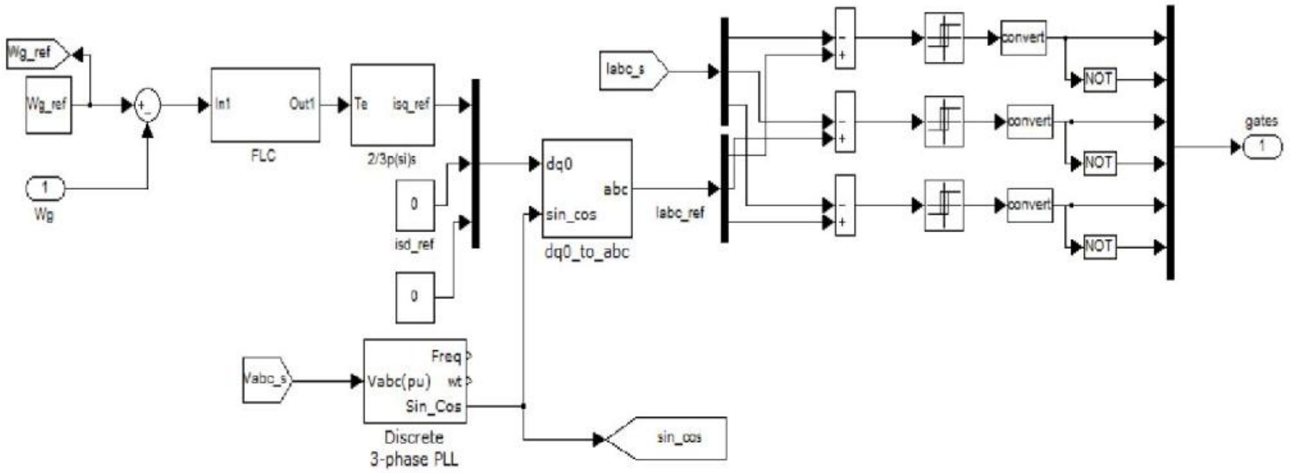

Figure4: Stator Side Converter Control

The input of the fuzzy controller is speed error (e) and its variation (Δe).

$e = \Omega gref - \Omega g$

$\Delta e = (1-z^{-1})e$

The fuzzy rules are shown in the table. The rules are described in the following:

NB- Negative Big

NS- Negative Small

EZ- Equal Zero

PS- Positive Small

PB- Positive Big

K2Δe \ K1e	NB	NS	EZ	PS	PB
NB	NB	NB	NS	NS	EZ
NS	NB	NS	NS	EZ	PS
EZ	NB	NS	NS	EZ	PS
PS	NS	EZ	PS	PS	PB
PB	EZ	PS	PS	PB	PB

The Defuzzification used based on the center of gravity method and 25 rules calculated following equation:

$$\Delta Tem = K3\left(\sum_{i=1}^{25} \frac{u_{ci} X_{Gi} S_i}{\sum_{i=1}^{25} u_{ci} S_i}\right)$$

Then, the reference electromagnetic torque is expressed by:

$$T_{em}(k) = T_{em}(k-1) + \Delta T_{em}$$

Grid Side Converter Control

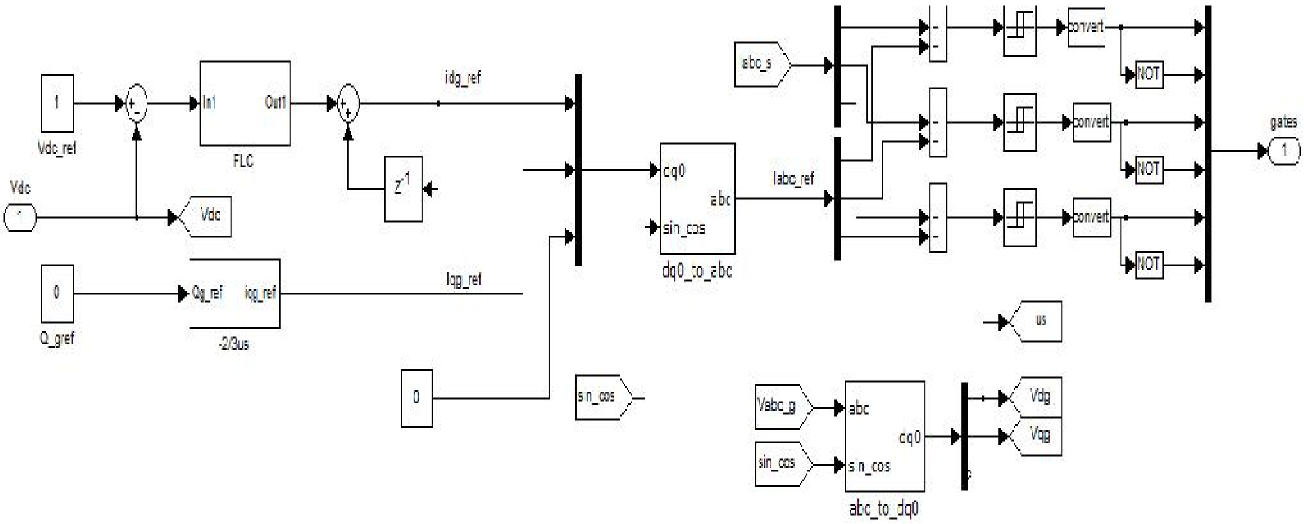

Figure5: Grid Side Converter Control

The control of the GSC is smooth DC voltage between the two converters. The use of FLC 2 shown in figure. The error e_{dc} and Δe_{dc} are expressed following equation:

$$e_{dc} = V_{dc_{ref}} - V_{dc}$$

$$\Delta e_{dc} = (1 - z^{-1}) e_{dc}$$

The Grid Phase voltage can be expressed as following equation:

$$V_{ainv} = R_g i_{ag} + L_g \frac{di_{ag}}{dt} + V_{ag}$$

$$V_{binv} = R_g i_{bg} + L_g \frac{di_{bg}}{dt} + V_{bg}$$

$$V_{cinv} = R_g i_{cg} + L_g \frac{di_{cg}}{dt} + V_{cg}$$

Where,

Vabc_inv are converter voltage

Iabc_g are grid current

Vabc_g are grid voltage

Rg and Lg are Resistance and inductance

DC capacitor voltage is controlled by the current component (idg) in the voltage vector oriented reference frame. Also, to achieve a unity power factor at grid side, the reactive current equal to zero. After a dq-abc transformation of these reference current implemented to control the grid side converter.

SIMULATION RESULTS

Simulation is performed on the model system using MATLAB Software. The FLC Control system implemented SSC side & GSC Side. Wind Energy Conversion System is controlled to Track maximum power operating point with a unity power factor at the grid side. (see Figure 6 to Figure 11). Show simulation results for a filtered wind speed in presented in Figure 6. The power Coefficient and Tip speed ratio are their optimum values of 0.4993 and 6.4 respectively (Figure 7 &Figure 8). The mechanical power and electrical torque presented Figure 9 &Figure 10. The d axisstator current (isd) of the PMSG is kept around zero, according to the control strategy(Figure11). The q axis stator current is regulated to its reference value (see Figure 12). The active power (Pg), injected into the grid, is varied according to the MPPT Strategy. And a unity power factor is ensured at the grid side. And the reactive power (Qg) injected into the grid is equal to zero (see Figure13). The grid voltage (Vag) and its current (iag) shows that the wind energy conversion system produces only active power to the grid with a unity power factor (see Figure14).

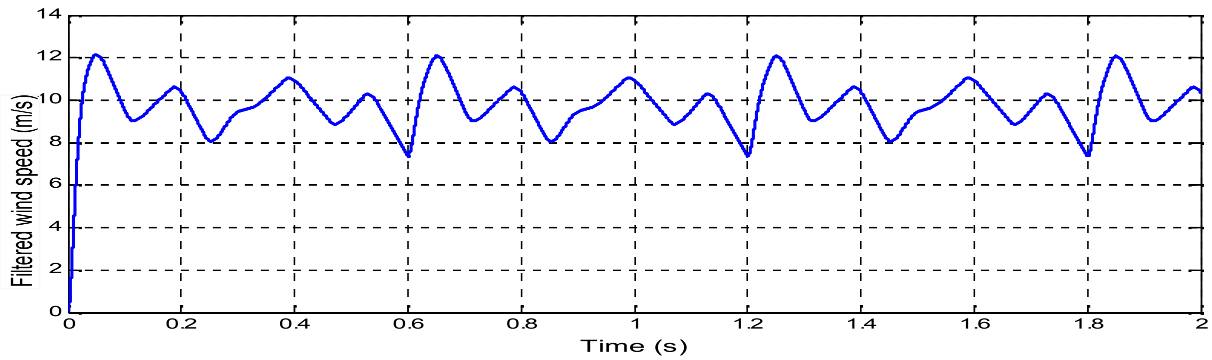

Figure 6: Filtered wind Speed(m/s)

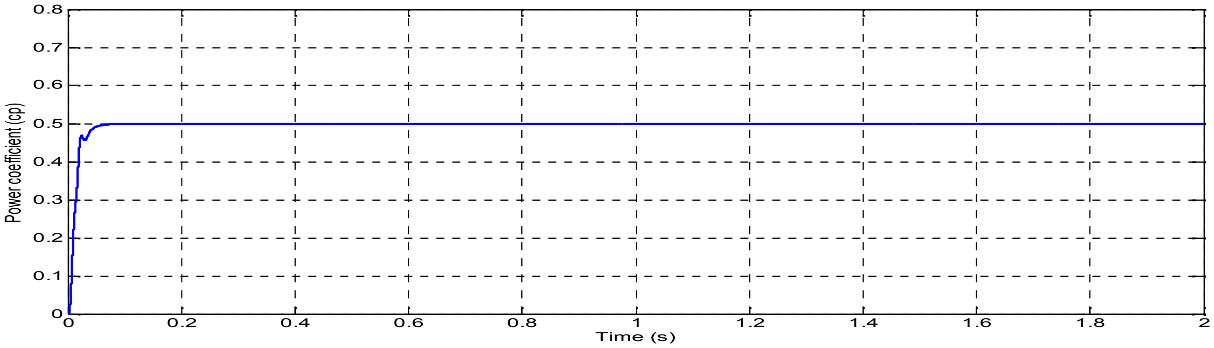

Figure 7: Power Coefficient (Cp)

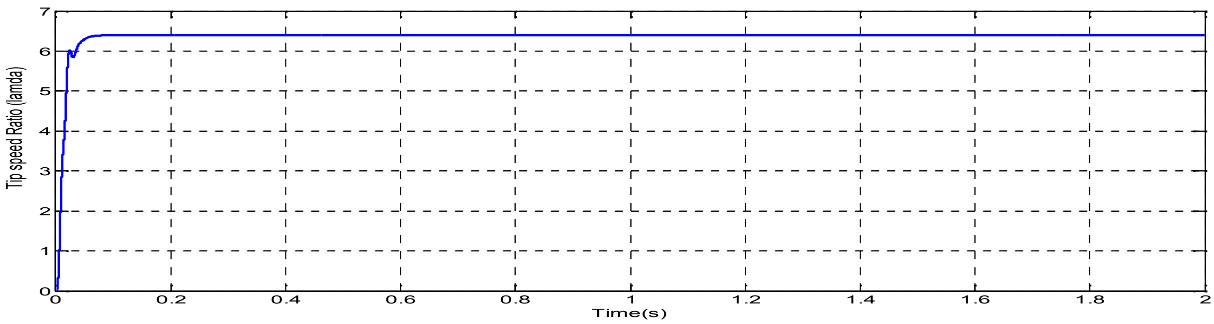

Figure 8: Tip Speed Ratio (Lamda)

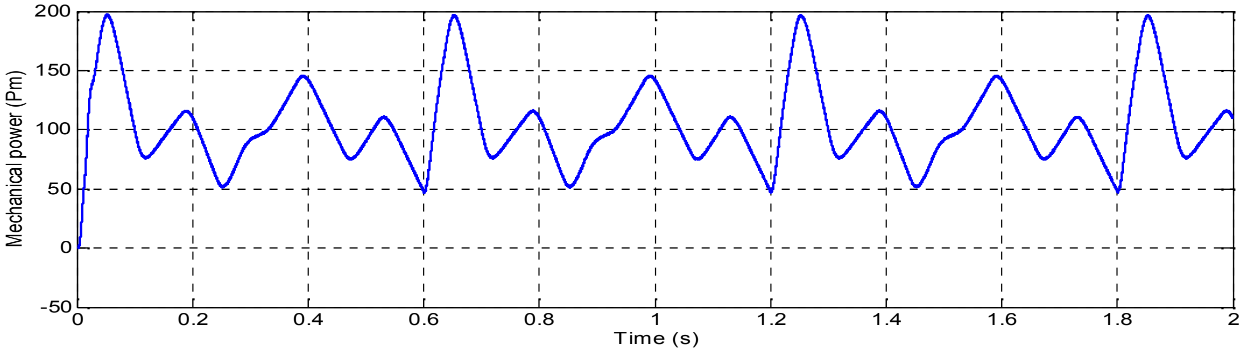

Figure 9: Mechanical Power (Pm)

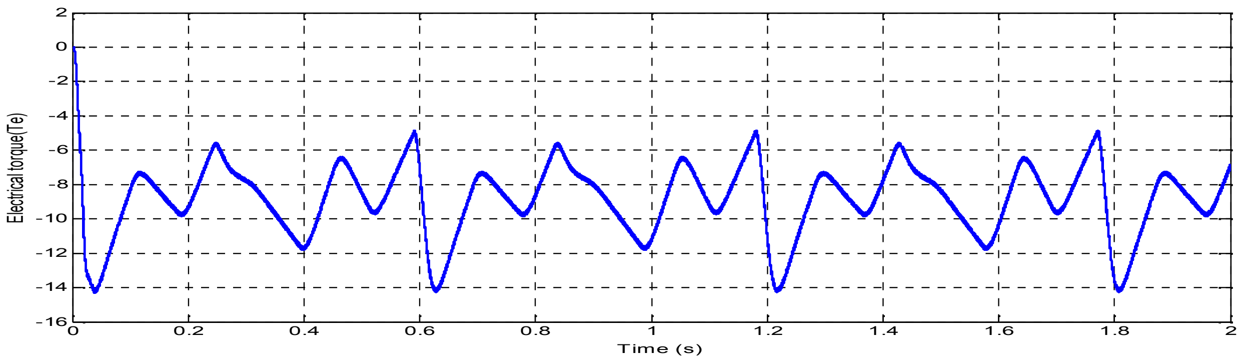

Figure 10: Electrical Torque(Te)

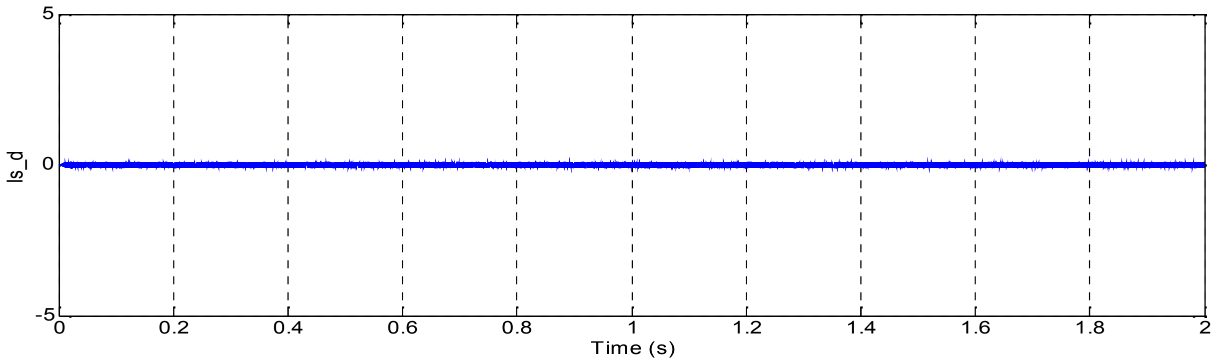

Figure 11: Stator d-axis Current

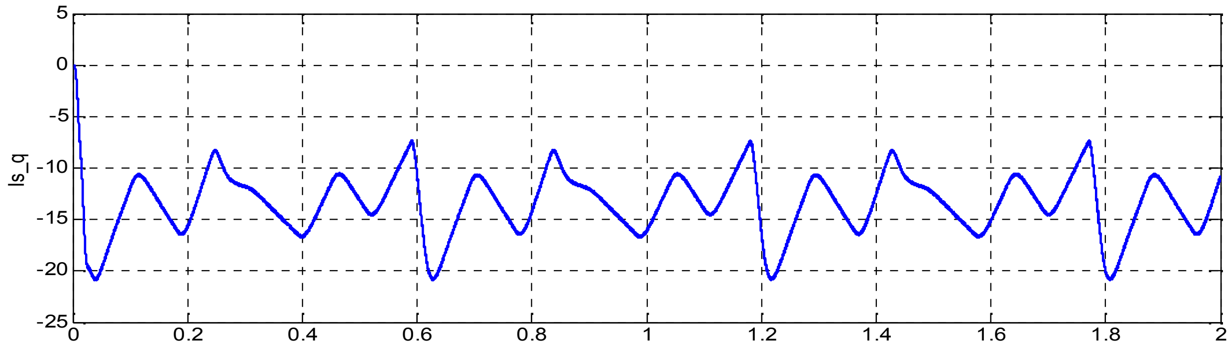

Figure 12: Stator q-axis Current

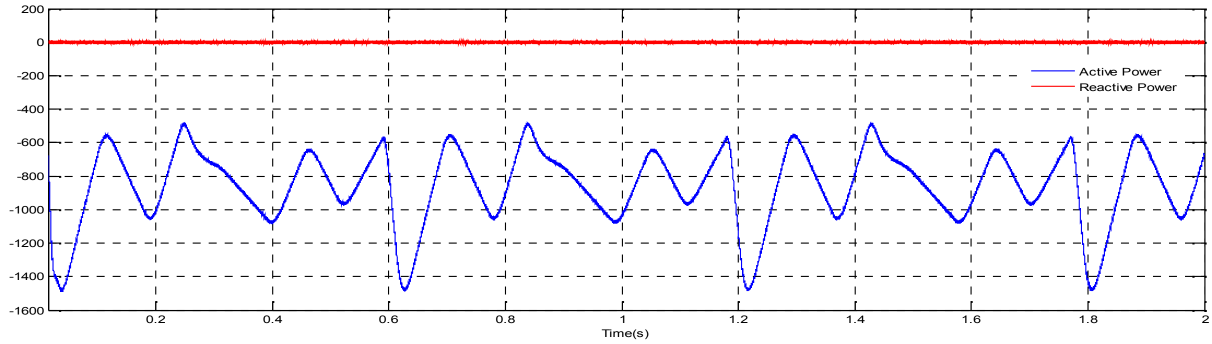

Figure 13: Active & Reactive Power

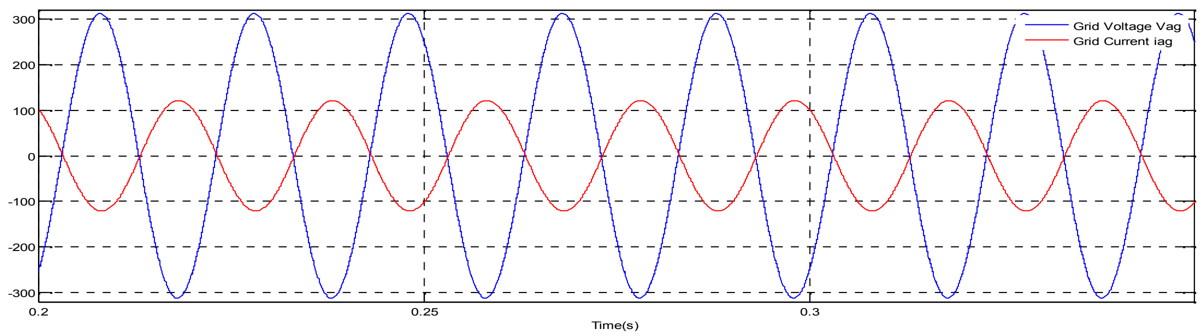

Figure 14: Grid Voltage & Grid Current

CONCLUSIONS

This paper presents the control of a Wind energy conversion system based on a PMSG for MPPT power Generation. The SSC has been controlled, using a speed fuzzy logic controller, in such a way to permit to the wind system to track its maximum power operating point for a wind range of wind speed and ensure the MPPT strategy. The GSC has controlled also by using another fuzzy logic controller to ensure a smooth DC voltage between two Converter (Stator side & Grid side converter). The Wind energy conversion system can be also controlled to operate in standalone mode.

APPENDIX

The parameters of wind turbine and generator used for simulation are shown in Tables I & II, respectively.

Table 1: Parameters of Wind Turbine for Simulation

Nominal Mechanical Output Power	$8.5x10^3$[W]
Base wind Speed	12[m/s]
Cut in Speed	5[m/s]
Cut out speed	25[m/s]
Maximum power Coefficient	0.4993
Tip speed Ratio	6.4
Pitch Angle	0^0

Table 2: Parameter of PMSG for Simulation

Base Power of Electrical Generator	9.44[VA]
No. of Phases	3
Back EMF Waveform	Sinusoidal
Rotor Type	Salient Pole
Mechanical Input	Torque Tm
Stator Phase resistance	0.985Ω
Inductance Ld, Lq	0.01[H],0.01[H]
Flux Linkage	0.55133
Voltage Constant	300.0006[V]
Torque Constant	2.481[N.m/A Peak]

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