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MPPT CONTROL AND GRID CONNECTED FOR VARIABLE SPEED WECS BASED ON THE PMSG

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Abstract—**nowadays research focus is towards the Variable speed power generation in instead fixed speed power generation in wind energy conversion system. With variable speed, there will be 20-30% increase in the energy capture compared to the fixed-speed operation. The output power of a wind energy conversion system (WECS) is maximized if the wind rotor is driven at an optimal rotational speed for a particular wind speed, This paper provides the brief idea about the better and faster MPPT control techniques for wind energy conversion system (WECS) using permanent magnet synchronous generators (PMSG). The available MPPT algorithms can be classified as either with or without sensors, A comparison has been made between the performance of different MPPT algorithms on the basis of various speed responses and ability to achieve the maximum energy yield.**

Keywords*—*Variable speed,, wind turbine, MPPT, WECS, fixed-speed,

I. Introduction

Wind energy systems have gained tremendous attention over the past decade as one of the most promising renewable energy sources due to the probable depletion, high costs, and negative environmental impacts of conventional energy sources. Wind energy is a pollution-free and inexhaustible source. Therefore, a wind energy generation system could be one of the potential sources of alternative energy for the future [1, 2].

This has become possible due to the rapid advances in the size of wind generators as well as the developments in power electronics and their application in optimum wind energy extraction In recent years, variable speed WECSs have become the industry standard because of their advantages over fixed speed ones such as improved energy capture, better power quality, reduced mechanical stress and aerodynamic noise [3].

Further, variable speed WECSs can be controlled over a wide range of wind speeds, to enable them operate at their maximum power coefficients, thus, allowing them to obtain larger energy capture from the wind [4, 5].

Wind turbines are controlled to operate only in a specified range of wind speeds bounded by cut-in (V cut-in) and cut-out (V cut-out) speeds. Beyond these limits, the turbine should be stopped to protect both the generator and turbine. Fig. 1 and Fig.1shows the typical power curve of a wind turbine [8, 9]. From the figure, it can be observed that there are three

Different operational regions. The first is the low-speed region, where the turbine should be stopped and dis-connected from the grid to prevent it from being driven by the generator [10]. The second is the moderate-speed region that is bounded by the cut-in speed at which the turbine starts working, and the rated speed (V rated), at which the turbine produces its rated power. The turbine produces maximum power in this region, as it is controlled to extract the available power from the wind. In the high speed region (i.e., between V rated and V cut-out), the turbine power is limited so that the turbine and generator are not over- loaded and dynamic loads do not result in mechanical failure [10,11]. It is noteworthy that to protect the turbine from structural over-load, it should be shut down above the cut-out speed. This paper focuses on the moderate-speed region, where the maximum power point tracking (MPPT) algorithm is needed.

Although the speed of the wind turbine could be fixed or variable, maximization of the extracted energy is achievable with variable speed wind turbines only. Since these turbines can change their rotational speed to follow instantaneous changes in wind speed, they are able to maintain a constant rotational speed to wind speed ratio [12]. It can be noted that there is a specific ratio called the optimum tip speed ratio (TSR) for each wind turbine for which the extracted power is maximized [1]. As the wind speed is instantaneously changing, it is necessary for the rotational speed to be variable to maintain the optimal TSR at all times. To operate in variable-speed conditions, a wind energy system needs a power electronic converter to convert the variable voltage variablefrequency of the generator into a fixed voltage fixedfrequency that is suitablefor the grid [1314]. In addition to increasing the energy capture, variablespeed turbines can be controlled to reduce the load on the drive-train and tower structure, leading to potentially longer installation life [11]. Researchers [13, 15, 16] have discussed the different possible configurations of power converters and electrical generators for variable-speed wind turbine systems.

In WECS, several types of electric generators are used such as Doubly Fed Induction Generator (DFIG), Squired Cage Induction Generator (SCIG) and Permanent Magnet Synchronous Generator (PMSG) with power electronic converter systems [6-7].

Nowadays, the use of the PMSG configuration is becoming more and more common for several reasons such as: the elimination of the external excitation current, lower operational noise is achieved, very high torque can be achieved and it can reduce again weight, costs, losses and maintenance requirements [17] and permanent magnet material at reasonable price, and possibility of smaller turbine diameter.

This paper provides the brief idea about the two MPPT control techniques (P&O) and TSR for wind energy conversion system (WECS) using permanent magnet synchronous generators (PMSG).

The proposed global model can easily be simulated with the help a software like Matlab- SIMULINK. Simulations are carried out by considering a 7kW wind generator.

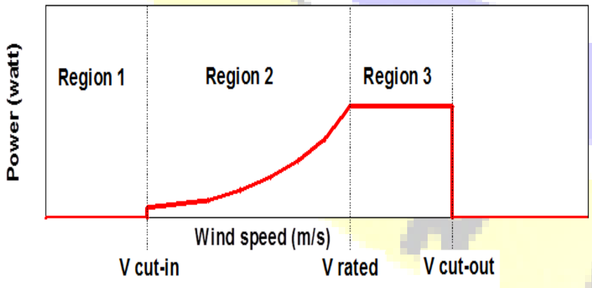


Fig. 1 Ideal power curve of wind turbine.

II. WECS SYSTEM MODELING.

Wind energy conversion system (WECS) converts kinetic energy of wind to mechanical energy by means of wind turbine rotor blades; then the generator converts the mechanical power to electrical power. The resulting electrical power is being fed to the electrical network through power electronic converters. The WECS under study consists of a gearless wind turbine coupled to PMSG generator with a generator side converter linked through a DC-link to electrical network side converter as shown in Fig.3.

A. Wind turbine modeling

Modeling of the turbine is inspired by [18]. The power available from the wind through a A_v surface is defined by:

$$P_v = \frac{1}{2} A_v v^3 \quad (1)$$

The aerodynamic power at the rotor of the turbine is given by the following equation:

$$P_t = \frac{1}{2}\rho\pi R_t^2 v^3 C_p(\lambda,\beta) \quad (2)$$

The Power coefficient is expressed as follows:

$$C_p = \frac{P_a}{P_v} \quad (3)$$

The speed ratio λ is given by [19]:

$$\lambda = \frac{R_t\Omega_t}{v} \quad (4)$$

The mechanical torque produced by the turbine is expressed as follows:

$$T_t = \frac{1}{2}\rho\,\pi\, R_t^3 v^2 C_m(\lambda,\beta) \quad (5)$$

The torque coefficient is given by:

$$C_m(\lambda,\beta) = \frac{C_p(\lambda,\beta)}{\lambda} \quad (6)$$

The target optimum power from a wind turbine can be written as:

$$P_{t.max} = K_{t.opt}\Omega_{opt}^3 \quad (7)$$

$$K_{t.opt} = \frac{1}{2}\rho\,\pi\, R_t^5 C_{p.max}/\lambda_{opt}^3 \quad (8)$$

$$\Omega_{opt} = \frac{\lambda_{opt}\, v}{R_t} \quad (9)$$

For different values of β,the$C_p(\lambda,\beta)$curves are shown inFig.2.

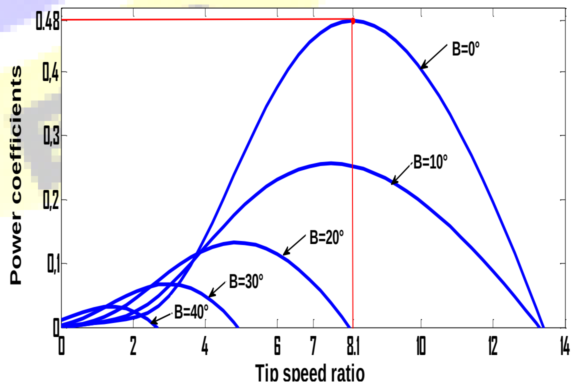


Fig.2C_p- λ the curves for different values of the pitch angle β.

We note the existence of the maximal value of power coefficient C_p corresponding to the optimal value of the speed ratio λ_{opti} for each value of pitch angle β .The maximum value of C_p that is $C_{p\,max} = 0.48$, is achieved for $\beta = 0^{\circ}$ and for $\lambda_{opti} = 8.1$, this particular value λ_{opti} results in the point of optimal efficiency where the maximum power is captured from wind by the wind turbine.

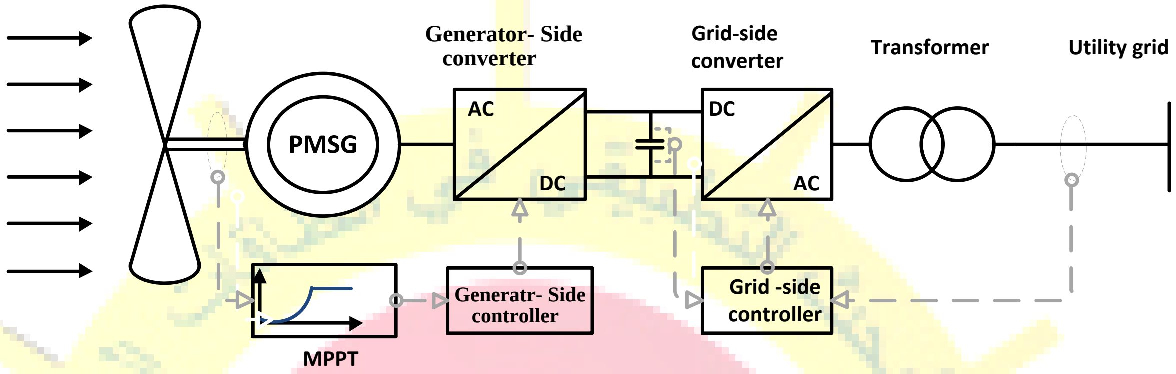


Fig.3 Schematic diagram of the overall system.

B. PMGS Modeling:

The voltage equations of a permanent magnet synchronous generator in the d-q reference frame are given by: [20]

$$V_{sd} = R_s I_{sd} + L_d \frac{dI_{sd}}{dt} - \omega_e L_q I_{sq} \quad (10)$$

$$V_{sq} = R_s I_{sq} + L_q \frac{dI_{sq}}{dt} + \omega_e L_d I_{sd} + \omega_e \psi_{fl} \quad (11)$$

If the PMSG is a wound rotor machine, which is good for surface mounted applications, the electrical torque of the generator can be expressed as:

$$T_e = \frac{3}{2} n_p \left(\psi_{fl} I_{sq} + (L_d - I_q) I_{sd} I_{sq}\right) \quad (12)$$

For surface mounted PMSG, we can consider an approximation $L_d = L_q$, then torque will be:

$$T_e = \frac{3}{2} n_p \psi_{fl} I_{sq} \quad (13)$$

III. CONTROL OF PMGS.

A. Control of the generator side converter

The generator-side converter controls the rotational speed of the PMSG to achieve variable speed operation with the MPPT control. Vector control scheme is used in the control methodology as shown in Fig. 4. The speed loop will generate the q-axis current component to control the generator torque and speed at different wind speed via estimating the

references value of I_α, I_β as shown in Fig. 4. The torque control can be achieved through the control of the I_{sq} current as shown in Eq. (13) shows the stator and rotor current space phasors and the excitation flux of the PMSG. The quadrature stator current I_{sq} can be controlled through the rotor reference frame (α ,β axis) [21].

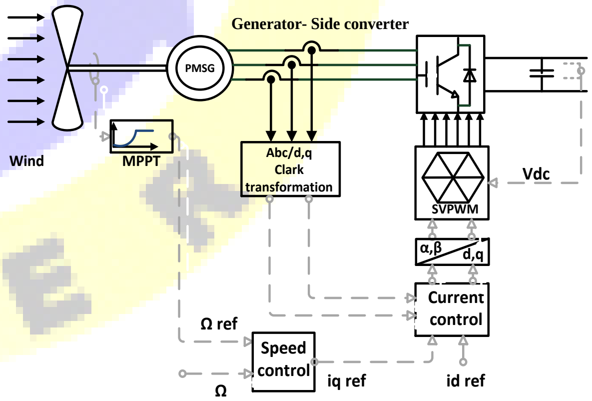


Fig.4 Control block diagram of generator side converter

B. . Control of the grid side converter

The power flow of the grid-side converter is controlled in order to maintain the dc-link voltage at reference value, 700 v.

Since increasing the output power rather than the input power to dc-link capacitor causes a decrease of the dc-link voltage and vice versa Fig. 5. The output power will be regulated to keep dc-link voltage approximately constant. The dc-link voltage has been maintained and the reactive power flowing into the grid has been controlled at zero value. This has been done via controlling the grid side converter currents using the d–q vector control approach. The active and reactive power can be defined as the following [22]:

$$P_N = \frac{3}{2}(V_{Nd}I_{Nd} + V_{Nq}I_{Nq}) \quad (16)$$

$$Q_N = \frac{3}{2}(V_{Nq}I_{Nd} - V_{Nd}I_{Nq}) \quad (17)$$

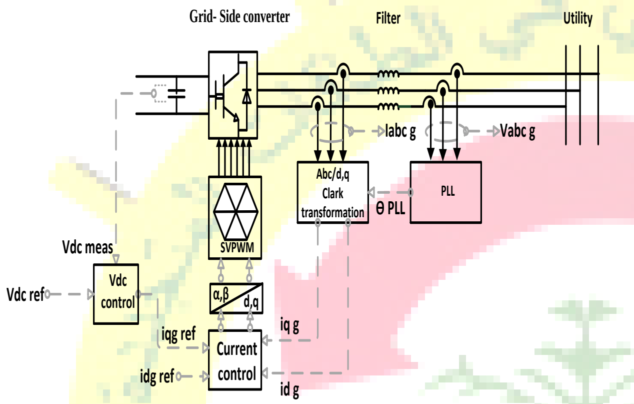


Fig.5 Control block diagram of grid side converter.

IV. MPPT TECHNIQUES.

A. *MPPT method' tip speed ratio (TSR) control.*

The TSR control method regulates the rotational speed of the generator in order to maintain the TSR to an optimum value at which power extracted is maximum. This method requires both the wind speed and the turbine speed to be measured or estimated in addition to requiring the knowledge of optimum TSR of the turbine in order for the system to be able extract maximum possible power fig.7. a precise measurement for wind speed is impossible in reality and increases the cost of the system. Fig.6. shows the block diagram of a WECS with TSR control [23].

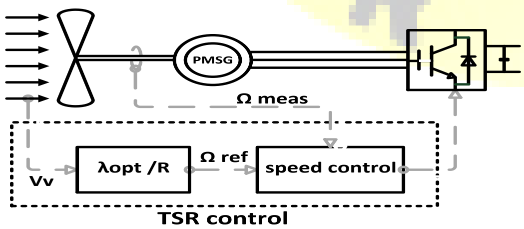


Fig.6the block diagram of the tip speed ratio control MPPT.

A. *.The P&O control*

The perturbation and observation (P&O), or hill-climb searching (HCS) method, is a mathematical optimization technique used to search for the local optimum point of a given function. It is widely used in wind energy systems to determine the optimal operating point that will maximize the extracted energy. This method is based on perturbing a control variable in small step-size and observing the resulting changes in the target function until the slope becomes zero Fig 8.

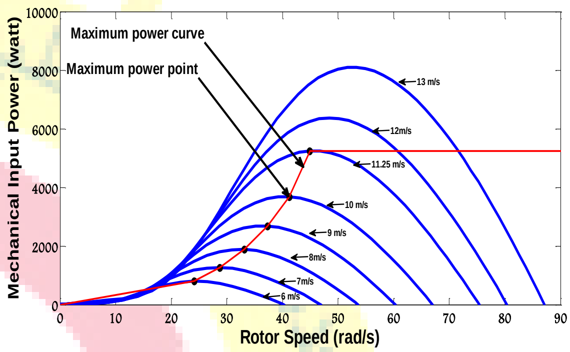


Fig. 7 the power characteristic of the wind turbine used in this study.

In electrical power measurement, the mechanical sensors are not required, and thus they are more reliable and low-cost. Therefore the the(P&O) method does not require prior knowledge of the wind turbine's characteristic curve, it is independent, simple, and flexible. However, it fails to reach the maximum power points under rapid wind variations if used for large and medium inertia wind turbines.

Additionally, choosing an appropriate step size is not an easy task: though larger step-size means a faster response and more oscillations around the peak point, and hence, less efficiency, a smaller step-size improves efficiency but reduces the convergence speed [24 25, 26], as shown in Fig. 9.

-if$\Delta\Omega$ is large compared to that optimal: MPPT algorithm is fast, but characterized by a fairly large ripple speed power point maximum oscillate around ($\Omega_{ref} + \Delta\Omega$) and($\Omega_{ref} - \Delta\Omega$).

-if$\Delta\Omega$ is small compared to that optimal: MPPT algorithm will be very long and the final reference speed is reached after a very important time minimum operating power for a long time.

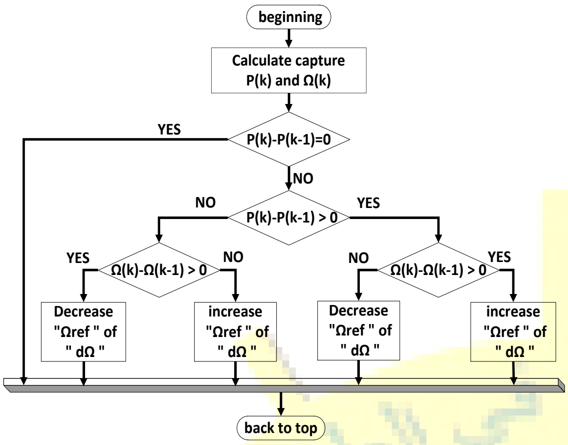


Fig.8 MPPT (P&O) process algorithm.

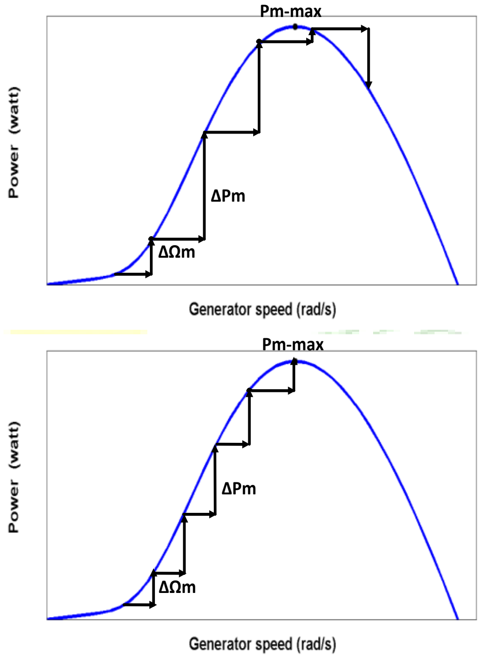


Fig.9. the P&O control larger perturbation and smaller perturbation.

V. SIMULATION

Two different cases have been studied to simulate the model according to wind variation. The parameters of the systemunder study are given in table (1, 2). MATLAB/SIMULINKsoftware is used to perform the simulation using powersystem block sets with a simulation time of 5 seconds.

Case (1):

The wind power is optimized with MPPT strategy and keeps at his nominal value when the turbine speed exceeds the nominal value. This first section, we present the simulation results relating to the two strategies MPPT applied to the WECS (TSR and P&O method).

WECS has been subjected to both TSR and P&O control MPPT. The MPPT method TSR requires both the wind speed and the turbine speed to be measured or estimated in addition to requiring the knowledge of optimum TSR of the turbine , but the method P&O does not require prior knowledge of the wind turbine's characteristic curve, it is independent.

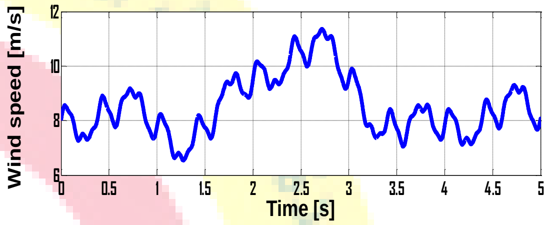


Fig.10Wind speed variation in (m/s).

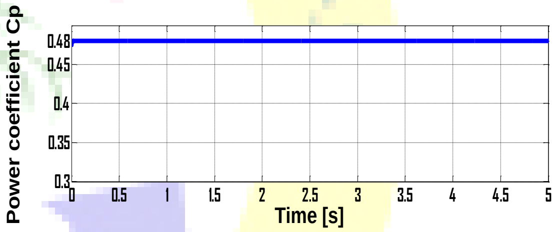


Fig.11Power coefficientC_p. (TSR)

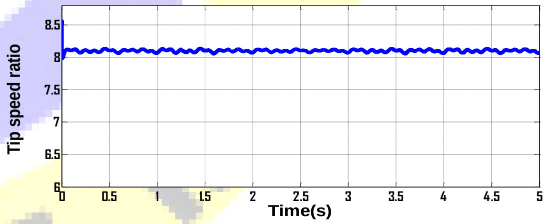


Fig.12.Tip speed ratioλ (TSR)

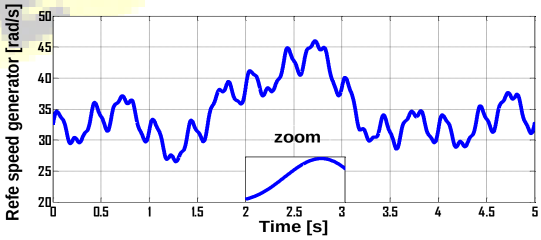


Fig.13.reference speed of PMSG in rad/s.(TSR)

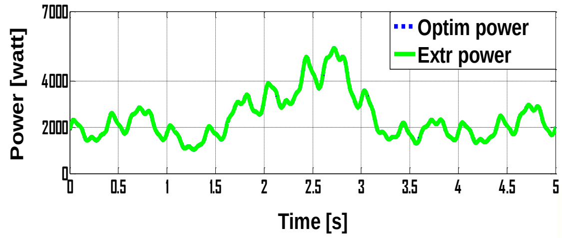


Fig.14. Optimal and extracted mechanical power (TSR)

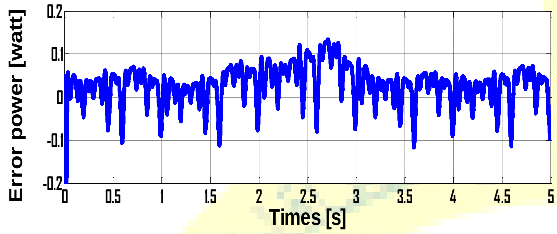


Fig.15. Error power (TSR)

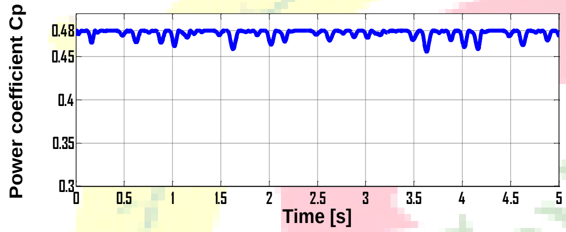
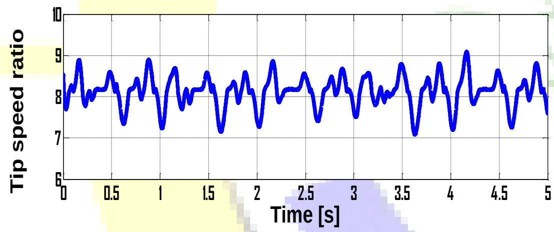


Fig.16.Power coefficientC_p (P&O)



7.Tip speed ratio λ .(P&O)

Fig.1

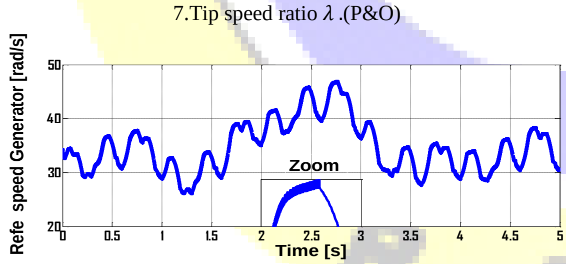


Fig.18.reference speed of PMSG in rad/s.(P&O)

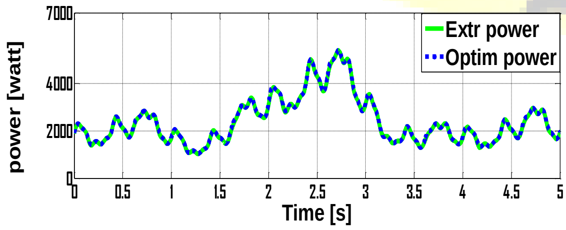


Fig.19. Optimal and extracted mechanical power(P&O)

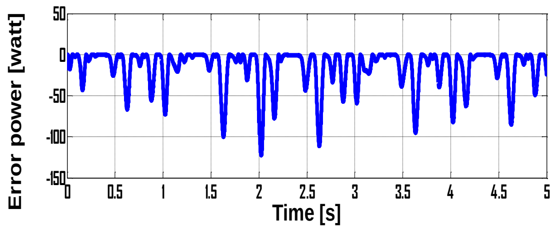


Fig.20. Error power (P&O)

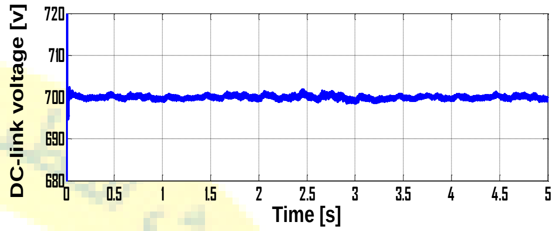


Fig.21 DC- link voltage in (v)(TSR).

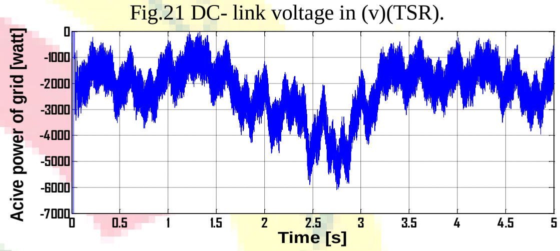


Fig.22 Grid output active power in (W)(TSR).

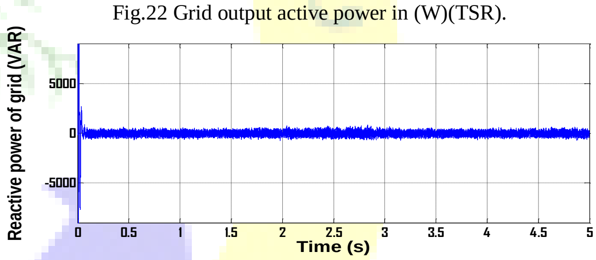


Fig.23Grid output reactive power in (VAR)(TSR).

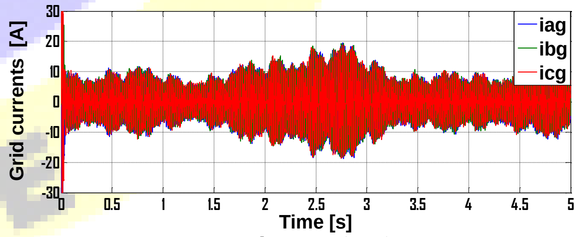


Fig.24 Grid currents(TSR).

Case (2):

this second section, show the principle of power control of PMSG based variable speed wind turbine connected to the grid, it is controlled in order to capture the maximum wind energy by the method the TSR MPPT. The output power will be regulated to keep dc-link voltage approximately constant.

For comparison, the TSR MPPT control is also carried out and the results are shown in Figure (11, 12, 13, 14 and 15) the wind speed is shown in Figure 10. In 5 s

Fig (11, 12 and 16.17) presents the evolution of power coefficient and tip speed ratio (C_p,λ) values in the same time interval of wind. It is showing the (C_p,λ) values of MPPT TSR close to the optimal one appear the most often than (P&O) MPPT method.

Fig (13.18) the reference speed of generator has fewer oscillations with the method TSR MPPT control than with the method P&O MPPT

Figures (14, 19) show the optimal power and the extracted power with the MPPT control (TSR and P&O), Figure (15, 20) shows the lose (error) in the extracted power by relative optimal power.

The DC bus voltage is represented in Fig.21 which demonstrates that this voltage is perfectly constant equal to 700 V and thus proves the effectiveness of the established regulators.

Figures (22) show the active power of grid which is substantially equal, except for the losses, to the generated power by wind source.

The reactive power reference value is maintained equal to zero (Fig.23) then we operate with unitary power factor.

The injected currents to the grid are represented in Fig 24.

VI. CONCLUSION.

In this work, we have presented a complete wind energy conversion system made with a PMGS. This system is constituted of a PMGS with the stator connected directly to the grid through AC-DC-AC SVPWM converters. First, In practical wind power system, the difficulties of measuring wind speed and measurement errors affect the use of wind energy. This paper proposed two MPPT control method for a WECS.

The TSR method requires both the wind speed and the turbine speed to be measured or estimated in addition to requiring the knowledge of optimum TSR of the turbine, a precise measurement for wind speed is impossible in reality and increases the cost of the system. but The advantages of the implemented controller are the fast response and the simplicity the implementation, Another advantage is noting that the losses in the extraction of mechanical power is low therefore can dir. the performance of this type of control is High.

In the P&O method the mechanical sensors are not required, and thus they are more reliable and low-cost. Therefore the the P&O method does not require prior knowledge of the wind turbine characteristic curve, it is independent, simple, and flexible. Additionally, choosing an appropriate step size is not an easy task: though larger step-size means a faster response and more oscillations around the peak point, and hence, less efficiency, a smaller step size improves efficiency but reduces the convergence speed and Another disadvantage is noted that the losses in the extraction of mechanical power is high so dir. can the performance of this type of control is low.

The simulations results obtained by Matlab / Simulink show that the method of TSR is more efficient than the method P & O despite the low cost and ease of implementation this last.

Second, Active and reactive powers produced to the grid can also be controlled to meet the network code through grid side converter. DC-link voltage is controlled to ensure the transmission of power from generator to the grid within the designated value. These control schemes can also be used to have a unity power factor ($Q_N \approx 0$) delivered to electrical network and consequently not alter the overall power factor of the system.

Appendix A:

TABLE I

Wind turbine Parameters

Radius of the turbine	$R_t = 2$ m
Volume density of the air	$\rho = 1.225$ kg.m^3
The pitch angle	$\beta = 0^\circ$
specific optimal speed	$\lambda_{opti} = 8.1$
Coefficient of maximum power	$C_{p\,max} = 0.48$

Appendix B:

TABLE III

Permanent magnet synchronous generator parameters

Rated power	$P = 10$ kw
Stator resistance	$R_s = 0.00829\Omega$
Direct stator inductance	$L_d = 0.174$ mH
Stator inductance quadrature	$L_q = 0.174$ mH
Field flux	$\psi_{fl} = 0.071$ wb
Number of pole pairs	$n_p = 6$ paire pole
Inertia	$J_t = 0.089$ kg.m^2
Friction	$f = 0.005$N.m

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