Influence of the Parameters Variations on the Power Injected to the Network by Wind Turbine Using PMS

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ABSTRACT: This paper describes the operation and control of a variable-speed wind generator using the permanent magnet synchronous generator (PMSG). The wind profile is realized by using Dspace to impose the corresponding speed on the DC motor. The PMSG is connected to the grid by a converter controlled by pulse width modulation (PWM). The main objectives are, control the power delivered to the grid and discovering the Influence of the parameters variations on this injected power in order to improve it; for that we applied the strategies of maximum power point tracking (MPPT) with speed controller; and we affected variations in resistor, DC voltage link and field. This paper shows the performance of the complete system by its simulation using Matlab Simulink.

Keywords: Permanent-magnet synchronous generator (PMSG), Maximum power point tracking (MPPT) control, Pulse wave modulation (PWM), modeling.

1. INTRODUCTION

Nowadays, various technologies are developed for wind energy conversion systems by using of the Permanent magnet synchronous generators (PMSGs) due to their good characteristics, Furthermore, thanks’ to its operation in low rotational speed, the gearbox influences the efficiency can be omitted [1]–[2]. The used technology has two main objectives, control the power delivered to the grid and discovering the Influence of the parameters variations on this injected power in order to feed it by a high power and quality of electrical energy. We chose one of the best topology operates on variable-speed [3], which enables operation of the turbine at its maximum power coefficient over a wide range of wind speeds. The PMSG is connected to grid via two converters as it is shown in “Fig. 1”.

2. WIND TURBINE MODEL

The wind profile can be modeled by a sum of several harmonics, in accordance with [04]-[05]-[06]:

\[ V(t) = 10 + 0.2\sin(0.1047t) + 2\sin(0.2665t) + \sin(1.2930t) + 0.2\sin(3.6645t) \]  

(1)

Where,

\( V \) : wind speed [m/s]
\( t \) : time [s]

The simulation of the wind profile corresponding to used turbine is shown in “Fig. 2”:

Fig. 2. Wind Profile.

The wind profile is realized by using Dspace to impose the corresponding speed on the DC motor which is controlled by a controlled rectifier as it is shown on “Fig.3”:

Fig. 3. Wind profile and the speed of DC motor.

The power captured by the wind turbine may be written as [7]:

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\[ P_m = \frac{1}{2} C_p(\lambda) \rho AV_1^3 \]  
(2)

The tip-speed ratio is defined as:
\[ \lambda = \frac{\Omega R_t}{V_1} \]  
(3)

Where,
- \( A \): blade swept area \([m^2]\)
- \( \rho \): specific density of air \([kg/m^3]\)
- \( V_1 \): wind speed \([m/s]\)
- \( R_t \): radius of the turbine blade \([m]\)
- \( \Omega_t \): rotating speed \([rpm]\)
- \( C_p \): coefficient of power conversion

If the blade swept area and the air density are constant, the value of \( C_p \) is a function of \( \lambda \) and it reaches the maximum at the particular \( \lambda \) named \( \lambda_{opt} \), “Fig.4”. Then, from “(2)” becomes:
\[ P_{max} = \frac{1}{2} C_{pMax}(\lambda_{opt}) \rho AV_1^3 \]  
(4)

The optimal rotor speed of the turbine determined from “(3)” is given by:
\[ \Omega_{ref} = \frac{\lambda_{opt} \cdot V_1}{R_t} \]  
(5)

3. MPPT CONTROL

The goal of the (MPPT) strategy is to pick up the maximum power from the wind; it involves following the power curve shown in “Fig.5”, given by:
\[ P_{opt} = P_{max} = \frac{1}{2} C_{p^{opt}}(\lambda_{opt}) \rho AV_1^3 \]  
(6)

\[ T_{em} = T_{em-ref} \]  
(7)

The reference electromagnetic torque \( T_{em-ref} \) allows obtaining a mechanical speed of the generator equals to the reference speed \( \Omega_{ref} \) by the relation below, [3]:
\[ T_{em-ref} = C_{aux}(\Omega_{ref} - \Omega_{mech}) \]  
(8)

Where:
- \( C_{aux} \): speed controller.

The reference speed of the turbine corresponds to the optimal value, in our study the specific speed (\( \lambda_{opt} = 8.7 \)) and the maximum of power coefficient \( C_{pMax} = 0.5 \) is given by, [8]:
\[ \Omega_{mech} = \frac{\lambda_{opt} \cdot V_1}{R_t} \]  
(9)

By developing the proportional integral PI controller, the torque becomes:
\[ T_{em-ref} = \left( b_0 + b_1 S \right) \left( \Omega_{ref} - \Omega_{mech} \right) \]  
(10)

\( b_0 \) and \( b_1 \) are controller parameters to determinate, \( S \) is Laplace magnitude.

Figures “7”, “8”, “9” and “10” show the simulation results of MPPT strategies by using the wind profile of “Fig.2”.

![Fig. 4. Characteristics of power coefficient.](image)

![Fig. 5. Wind power characteristics in function of mechanical speed.](image)

![Fig. 6. Block diagram of the PI with advance phase controller.](image)

![Fig. 7. Coefficient of power conversion.](image)

![Fig. 8. Speed ratio.](image)
3.1. Results analysis

We observe that the coefficient of power and the speed ratio follow very well their references corresponding to optimal values after a small dynamic, “Fig. 7” and “Fig. 8”, which involves extracting of the maximum power “Fig. 10”. “Fig. 7” shows a good operation of PMSG on optimal rotor speed with a fast dynamic performance.

4. MODELING AND CONTROL OF PMSG

The voltage equation of the PMSG is expressed at synchronous reference frame by [9]:

\[
\begin{bmatrix}
V_{ds} \\
V_{qs}
\end{bmatrix} =
\begin{bmatrix}
R_s + SL_d & -\omega L_q \\
\omega L_d & R_s + SL_q
\end{bmatrix}
\begin{bmatrix}
i_{ds} \\
i_{qs}
\end{bmatrix} +
\begin{bmatrix}
0 \\
\omega \Phi_f
\end{bmatrix}
\]  

(11)

Where:
- \( S \): differential operator
- \( V_{ds}, V_{qs} \): d-q axis stator voltage
- \( i_{ds}, i_{qs} \): d-q axis stator current
- \( L_d, L_q \): d-q axis inductance
- \( R_s \): stator resistance
- \( \omega \): electric pulsation
- \( \Phi_f \): magnetic flux leakage

The electromagnetic torque is expressed as

\[
T_{em} = \frac{3}{2} p \left[ \left( L_q - L_d \right) i_{ds} i_{qs} + i_{qs} \Phi_f \right]
\]  

(12)

Where
- \( p \): number of poles pairs.

By using the vector control, q-axis is aligned with the magnetic flux, then

\[
T_{em} = \frac{3}{2} p L_q \Phi_f = K i_{qs}
\]  

(13)

The q-axis current component can be used for the speed control of the generator by using the reference from MPPT control, and the d-axis current is set to zero [10].

5. CONTROL OF POWER DELIVERED TO THE GRID

The control system must allow to maintain constant the tension of the bus continuous, and to obtain sinusoidal currents in PMSG, an amplitude and frequency identical to those of the network in order to generate the active power by PMSG to the grid. The DC link contains a capacitor that is charged-discharged to obtain a constant tension.

The power equations in the synchronous reference frame are given by [1]:

\[
P = \frac{3}{2} \left( V_{gs} i_{sd} + V_{qs} i_{sq} \right)
\]  

(14)

\[
Q = \frac{3}{2} \left( V_{qs} i_{sd} - V_{gs} i_{sq} \right)
\]  

(15)

Where ‘\( P \)’ and ‘\( Q \)’ respectively are active and reactive power, ‘\( V_g \)’ is grid voltage, and ‘\( i_q \)’ is the grid current. The subscripts “\( d \)” and “\( q \)” stand for direct and squaring components, respectively.

After orienting the reference frame along the grid voltage, \( v_d \) equals to zero. Then, active and reactive power may be expressed as [1], [2]:

\[
P = \frac{3}{2} V_{gs} i_d
\]  

(16)

\[
Q = \frac{3}{2} V_{gs} i_q
\]  

(17)

According to “(16)”, “(17)”, we used two control paths. In the first, reactive power control, the d-axis current reference should be set to zero to obtain unit power factor. In the second path, DC-link voltage (\( V_{dc} \) set to 700V) control loop is used to set the q-axis current reference for active power control [11]. The control of the power delivered to the grid (50Hz) can be illustrated in figure “11”.

![Diagram control of the delivered power to the grid.](image-url)
The DC-link voltage must remain constant [12], the error of measured at the DC side is used to determine the generator power set-point via a PI-controller. The DC current is then regulated at the reference value by the PI-controller of the inverter. The parameters of the PI-controller are chosen to achieve a fast and well-damped response of the DC-link voltage and generator power [1]-[3].

6. SIMULATION OF WIND TURBINE SYSTEM

In this part we are going to simulate the normal case of the parameters, then we affect parameters variations and changing as it is given in the table below [13]:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimal Value</th>
<th>Nominal Value (reference)</th>
<th>Maximal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_s [\Omega]$</td>
<td>0.815 (-10%)</td>
<td>1.63</td>
<td>2.445 (+10%)</td>
</tr>
<tr>
<td>$V_{dc} [\text{V}]$</td>
<td>770 (-10%)</td>
<td>700</td>
<td>630 (+10%)</td>
</tr>
<tr>
<td>$\phi [\text{Wb}]$</td>
<td>0.45 (-20%)</td>
<td>0.9</td>
<td>1.35 (+20%)</td>
</tr>
</tbody>
</table>

“Fig. 12” shows the wind profile applied, “Fig. 13” and “Fig. 14” show the capacitor voltage and the injected currents to grid in the nominal case, which is considered as a reference to the other cases.

6.1. Results analysis of the nominal case

We observe that the tension of DC link follows its reference and the injected currents are sinusoidal with a unit factor (reactive power is null), this means that all the active power is delivered to the grid with a good quality of current which appears in “Fig. 15”.

6.2. Results analysis of parameters variations

In all studied cases we observe that the DC link follows its reference and the injected currents are sinusoidal with a unit factor, this means that the control is robust. The influence on the injected power is noted in resistor variation, it is inversely proportional to the resistor value because of loses, “Fig. 16”, “Fig. 17”, the resistor variation has also an influence on the regulation dynamic due to the variation of correctors ` PI' parameters.

Fig. 12. Wind profile.

Fig. 13. Nominal case DC link tension.

Fig. 14. Nominal case injected currents.
Fig. 17. Injected currents to grid.

Fig. 18. DC link tension.

Fig. 19. Injected currents to grid.

Fig. 20. DC link tension.
The power injected to the grid in form of current increases in the case of high value of DC voltage because the flow of power increases. “Fig. 18”, “Fig. 19”. The same for the case of high value of the field of permanent magnet, “Fig. 20”, “Fig. 21” this makes the choice of the permanent magnet quality is very important.

7. CONCLUSION

In this paper, a wind turbine based on PMSG was proposed. The rectifier is controlled to deliver sinusoidal currents; and to pick up the maximum power from the wind by using the MPPT control, then, this power was controlled and injected to the network to obtain unit power factor. The wind profile is realized by using Dspace, the validity and robustness of the studied converter system has been verified by simulation results using Matlab Simulink. Furthermore, it was noted after parameters modification that the power injected to the network becomes significant for the small values of stator resistance and the high values of the continuous bus and the field of the permanent magnet, which returns the choice of the magnet quality very important.

REFERENCES


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