International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
Index Copernicus Value (2015): 62.86 | Impact Factor (2015): 3.791

Parallel Connection of a Hybrid Energy Conversion System

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Abstract: ***This paper treats the parallel connection by modeling and simulation of a hybrid wind-photovoltaic energy conversion system.) In first, mathematical modeling of each elements of the conversion system is presented. The different parts of the conversion's chain are then connected together to build the global system under Matlab Simulink software. Secondly we study the connection between photovoltaic and wind energy chains. The hybrid energy system is used to supply an isolated site. Simulation results permit to analyze the behavior of the global system, and provide the necessary information that leads to use it in the appropriate conditions.***
Keywords: Photovoltaic, Power converter, PWM rectifier, Renewable energy, Wind generator.

1. Introduction

The Global electricity consumption in recent decades is generally linked to the development of the industry. Renewable energy, allows a decentralized electrical energy production, which contributes to the solution of supplying isolated areas with the necessary energy.
The combination of renewable energy sources to optimize the electric power generation is studied in lot of researches such as [1]-[2]-[3]-[4]-[5]-[6]-[7], which focus on meteorological, technical and economic aspects.

The advantage of a hybrid system compared to wind system only or pure photovoltaic system depends on many fundamental factors: The primary energy availability and its cost, the difficulty of realisation of each system, the storage system and other factors of efficiency.

1.1 Wind energy - BETZ LAW

According to the theory of Betz, the kinetic power of the wind is expressed by [8]:

$$P_w = \frac{1}{2} S_{wind} .\rho .v^3$$

(1)

The wind turbine can only recover a portion of the wind power (P_{wind}). The power extracted from the wind P_m can be expressed according to the power's coefficient C_p and the power of the wind by:

$$P_m = C_p P_{wind}$$

(2)

According to Betz, the power coefficient C_P cannot be higher than 16/27. This coefficient, different for each wind, depends on the angle of slope of the blades βi and of the speed ratio λ, it can express itself by the following relation (3):

$$C_p(\lambda, \beta_i) = (0.44 - 0.0167\,\beta_i)\sin\left(\pi \frac{\lambda - 3}{15 - 0.3\beta_i}\right) - 0.00184(\lambda - 3)\beta_i$$

(3)

With R the radius of the turbine blades, Ω is the rotation speed, v the speed of the wind, λ the tip speed ratio of the wind Turbine [9]-[10].

$$\lambda = \frac{R.\Omega}{v}$$

(4)

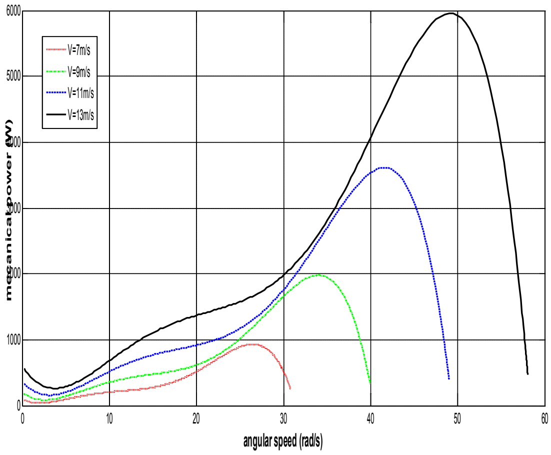

Figure 1: Theoretical power available for a given type of wind

2. Modeling of the Permanent Magnet Synchronous

AC machines are usually modeled by non-linear equations (differential equation.) This non-linearity is due to inductances and coefficients of dynamic equations that depend on the rotor position and time. A transformation 3 to 2 phase is necessary to simplify the model (reduce the number of equations). Based on some Simplifying assumptions the machine model is given as follow [11]:

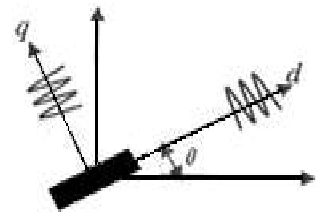

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Figure 2: Three fixed stator windings and the permanent magnet rotor

2.1 Electrical equations

$$V_d = R_s \cdot i_d + L_d \frac{di_d}{dt} - \psi_q \cdot \omega_r \quad (5)$$

$$V_q = R_s \cdot i_q + L_q \frac{di_q}{dt} + \psi_d \cdot \omega_r \quad (6)$$

With:

$$\psi_d = L_d \cdot i_d + \psi_f$$

(7) $\psi_q = L_q \cdot i_q$

(8)

Relations (5) and (6) become

$$V_d = R_s \cdot i_d + L_d \frac{di_d}{dt} - L_q \cdot i_q \cdot \omega_r$$

(9)

$$V_q = R_s \cdot i_q + L_q \frac{di_q}{dt} + (L_d \cdot i_d + \psi_f) \cdot \omega_r$$

(10)

2.2 Expression of electromagnetic torque

$$C_{em} = p.((L_d - L_q).i_d + \psi_f).i_q$$

(11)

2.3 Mechanical equation

The mechanical equation is:

$$J \frac{d\Omega}{dt} + f\Omega = C_{em} - C_r$$

(12)

$$\Omega = \frac{\omega_r}{p}$$

2.4 Model of the static converter

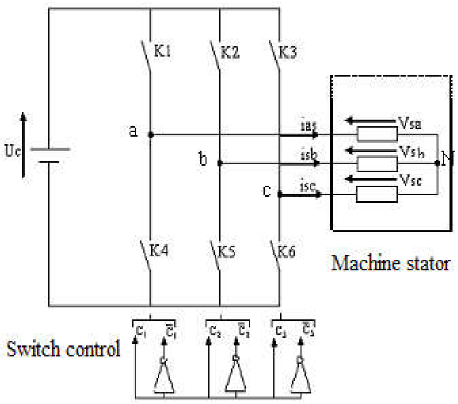


Figure 3: Three phase voltage converter supplying the stator of the machine

To simplify the modeling of the inverter we assume that the switches are ideal (no switching time, neglected losses). C_k is the control signals of the controlled interrupter [12], [13]. Where V_{sabc} is the vector of the simple voltages at the inverter output, and is given by:

$$[V_{sabc}] = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \frac{1}{3} \cdot U_c \cdot \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \cdot \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} = U_c \cdot [T_s] \cdot [C_K]$$

(13)

2.5 Rectifier model

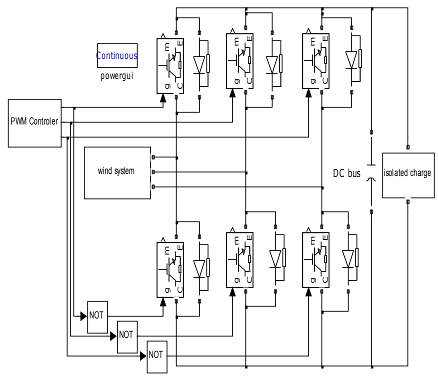


Figure 4: Shows the diagram of a rectifier blocks

Reversibility of the inverter voltage at two levels allows it to operate as current rectifier. The models developed for voltage inverters of two levels are valid for voltage rectifiers taking into account the new conventions of the two sources (networks and load).The rectifier bridge comprises three arms with two transistors (IGBT) bipolar antiparallel with diodes (Figure 4).These arms are shown as switches can be controlled by '1 as opening signal and 0 as closing signal.
The rectified voltage U_{dc} is based on the statements of these switches.
We can write the rectifier input voltages generally as follows: [14]
Hence we can deduce the phase voltages :

$$v_a = f_a U_{dc}$$

$$v_b = f_b U_{dc}$$

$$v_c = f_c U_{dc}$$

(20)

$$U_{dc} = \frac{1}{3}\left(\frac{v_a}{f_a} + \frac{v_b}{f_b} + \frac{v_c}{f}\right)$$

(14) With:

$$f_a = \frac{2\,s_a - (s_b + s_c)}{3}$$

$$f_b = \frac{2\,s_b - (s_a + s_c)}{3}$$

$$f_c = \frac{2\,s_c - (s_a + s_b)}{3}$$

(15)

3. Model of the Photovoltaic Panel

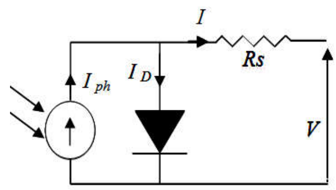


Figure 5: Model of photovoltaic panel

From figure 5 law nodes allows us to write the following relations:

$$I_{ph} = I_D + I$$

(16)

The photovoltaic current is proportional to the illumination can be given by:

$$I_{ph} = I_{ph}(T_1) \times [1 + K_0 \times (T - T_1)]$$

(17)

$$I_{ph}(T_1) = I_{cc}(T_1) \times \left(\frac{G}{G_0}\right)$$

(18)

$$K_0 = \frac{I_{cc}(T_2) - I_{cc}(T_1)}{T_2 - T_1}$$

(19)

The junction current I_D is given by:

$$I_D = I_S (e^{\left(\frac{V_D}{V_T}\right)} - 1)$$

(20)

V_T Thermodynamic voltage given by:

$$V_T = \frac{nKT}{q}$$

(21)

$$V_D = V + R_S I$$

(22)

Replace in (16) equations, the characteristic equation becomes:

$$I = I_{ph} - I_S \left(e^{\left(\frac{q(V + R_S I)}{nKT}\right)} - 1 \right)$$

(23)

3.1 Modeling the booster chopper

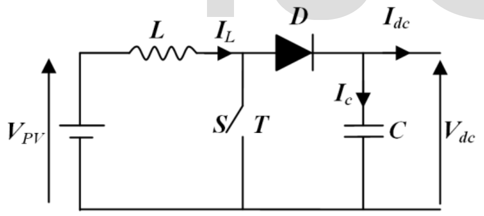


Figure 6: Diagram of converter

Modeling of this converter requires an analysis of the different operating sequences

By asking(S = 1) when the switch is closed and T(S =0) for open T, we can represent the converter by a single system of equations, which we call snapshot model. We consider the perfect switches.

$$V_{PV} = L\frac{dI_L}{dt} + V_{dc}(1 - S)$$

(24)

$$(1 - S)I_L = c\frac{dV_{dc}}{dt} + I_{ch}$$

(25)

4. Coupling the load with two generators (wind-photovoltaic)

The parallel solar-wind system can be architected as follows:

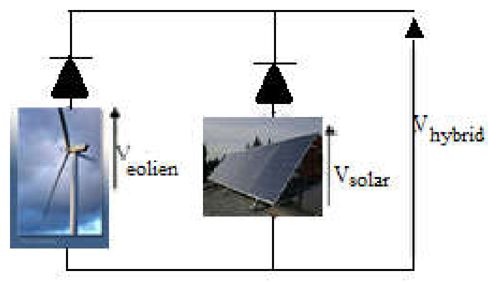
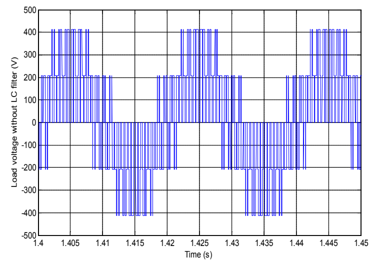
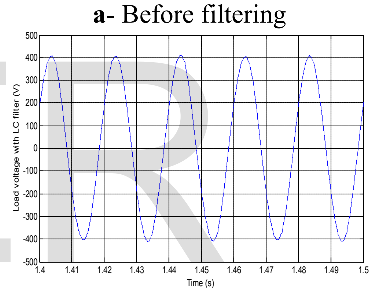


Figure 7: Diagram Scheme of a wind photovoltaic conversion chain overall (parallel connection)

The parallel connection of two strings conversion is performed such that the voltage delivered spells in charge all the time is the biggest of the two value chains. If for example the PV voltage is smaller, it acts as a receiver.

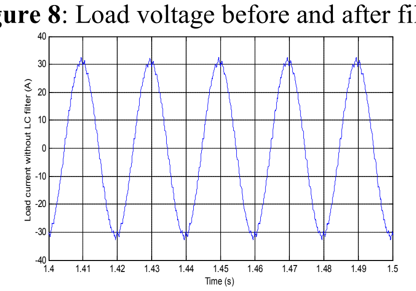


a- Before filtering

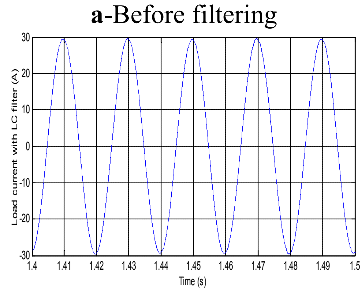


b- After filtering

Figure 8: Load voltage before and after filtering



a-Before filtering



b- After filtering

Figure 9: Load current before and after filtering

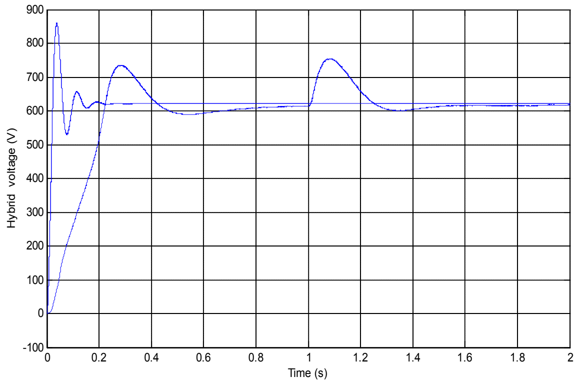


Figure 10: Wind input voltages (V_{wind}) and solar (V_{ph}) and parallel hybrid (V_{totale}) of a solar-wind power generation connected in parallel

In order to protect the lower source two diodes are used. The potential difference between the terminals of the diode is negative, so it is locked and provided protection against the return of current to the photovoltaic source, which has a destructive effect especially on solar panels [15].Connection conditions are explained by the following equation:

$$V_{hybrid} = \begin{cases} V_{Solar if\,(V_{Solar} \geq V_{eolien})} \\ V_{eolien if\,(V_{Solar} < V_{eolien})} \end{cases}$$

(26)

Interpretation

In figure 10 both channels start to provide energy with a transitional regime whose priority is the photovoltaic system because it is faster (purely electrical system) and the output voltage is equal to the voltage there of. When the wind system reached the peak values in transient tension is greatest and therefore becomes the most dominant.

When the variation of atmospheric conditions the wind system loses control of the solar system is replaced directly because it is not sensitive to these variations. When both systems stabilize, and caused the major drawback of strategy P and O (oscillation about the operating point) the wind energy system is the most stable. The inverter output voltage and represents an acceptable wave form but marred harmonic, remarkably influencing the shape of current.

To eliminate these harmonics is approximate the curves to the desired sinusoidal shape, an LC filter is used which corrects the wave form and increases the quality of the power to the site supplied as shown in figures 8 and 9.

5. Conclusions

The work presented in this paper focuses on combination of a wind energy conversion associated with photovoltaic chain. The wind system consisted of a turbine assure the conversion of the kinetic wind energy to a mechanical form, permanent magnet synchronous machine with static power converters to adapt the electrical energy form.

In the photovoltaic system, the photonic energy is directly converted to electric form via photovoltaic panels and the role of the static converter is to adapt this energy by MPPT technics. These sources are connected to a DC bus connected to an isolated network via a voltage inverter and an LC filter. Hybrid power systems (HPS) combine two or more sources. The renewable energy sources such as photovoltaic and wind provides a more continuous electrical output.

Nomenclature

ψ_f **:** Permanents magnet flux.
p: pole pairs number.
L_d, L_q are the transversal and longitudinal stator inductances.
ω_r: Angular speed (electrical pulse)
Ω: Mechanical speed.
C_r: Load torque.
J: Moment of inertia of the rotating part.
f: Coefficient of viscous friction.
I_{ph} : Photocurrent.
T_1: Reference temperature ($T_1=25°C=298°K$).
G_0: Reference illumination ($G_0=1000W/m^2$).
K_0: Coefficient of current variation.
I_{cc}: Shortcut circuit current (at temperature T_1 and T_2)
V_D: Diode voltage.
I_S : Saturation current.
q : Electron charge.
K : Boltz Mann's constant.
n: Ideality factor for the module.
T: Cell temperature.
V: Voltage at the cell terminals.
R_S: Séries résistances.

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International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
Index Copernicus Value (2015): 62.86 | Impact Factor (2015): 3.791

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