# Modeling and Control of a Wind/PV Hybrid System Grid-connected

Boucetta. Abdallah, Labed. Djamel

**Abstract**— ALTHOUGH an effective use of renewable energy attracts a great deal of attention globally to cope with the environmental and resource problems, especially, to reduce CO2 emission, an inappropriate application of distributed generators can be a cause of insecure power supply for example.
However, these renewable energy sources suffer from some deficiencies when used as standalone energy sources. The power generated by WT and PV systems is highly dependent on weather conditions. Natural variations in wind speed and sunlight causes power fluctuations in WT and PV systems, respectively. In addition, it is difficult to store the power generated by a PV or WT system for future use.
In This paper deals with power control of a wind and solar hybrid generation system for interconnection operation with electric distribution system .

**Index Terms**—Renewable Energy, WT, PV, Sunlight, electric distribution, wind speed

## 1 Introduction

Renewable energy resources, called sustainable or alternative energy, are energies generated from natural resources such as wind, sunlight, tide, hydro, biomass and geothermal which are naturally replenished. Energy crisis, climate changes such as atmosphere temperature rise due to the increase of greenhouse gases emission and the Kyoto Protocol restrictions in generation of these gases, coupled with high oil prices, limitation and depletion of fossil fuels reserves make renewable energies more noticeable. Moreover, since many remote rural areas in all over the world are not electrified, one of the interesting utilization of the renewable energies is to electrify many remote villages and rural areas or rugged terrain located so far from power stations and distribution networks.
Vulnerability to unpredictable climatic changes and h of renewable energy systems on weather conditions remain among their drawbacks

## 2 Proposed system description

The general block diagram of the proposed hybrid system is shown in Fig. 1. The system consists of wind turbine generators, system photovoltaic. The power supplied to the load is the sum of output powers from wind turbine generators and PV system. The mathematical models with first order transfer functions for wind turbine, PV system, shown in this section.


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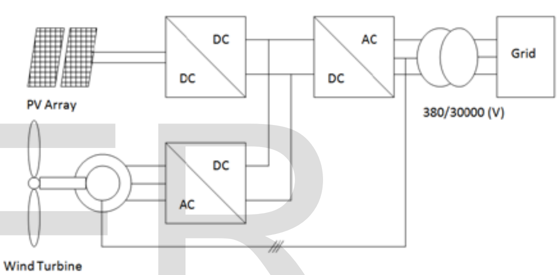



Fig. 1. Grid-connected hybrid system.



## 3 Modeling

### 3.1 The Turbine Is Modled

$$P_{wtp} = \frac{\rho.C_p.S.V_w{}^3}{2} \quad (1)$$

Where $P_{wtp}$ is the wind turbine output [W] is, ρ is the air density [kg/m3], $V_w$is the wind speed [m/s], and $C_p$is the power coefficient.
Now, the performance coefficient CP that is a function of the tip speed ratio A and the pitch angle θ will be investigated further.
The calculation of the performance coefficient requires the use of blade element theory. As this requires knowledge of aerodynamics and the computations are rather complicated, numerical approximations have been developed [10]. Here the following function will be used

$$C_p(\lambda,\theta) = 0.22\left(\frac{116}{\lambda_i} - 0.4\theta - 5\right)e^{\frac{-12.5}{\lambda_i}} \quad (2)$$

With :

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\theta} - \frac{0.035}{\theta^3+1} \quad (3)$$

### 3.2 Generator Equations

The equations describing a doubly fed induction machine can be found in literature [11]. When modeling the DFIG, the generator convention will be used, which means that the currents are outputs instead of inputs and real power and reactive power have a positive sign when they are fed into the grid. Using the generator convention, the following set of equations results,

$$\begin{cases} U_{sx} = -R_s I_{sx} + \frac{d\varphi_{sx}}{dt} - w_{os}\varphi_{sy} \\ U_{sy} = -R_s I_{sy} + \frac{d\varphi_{sy}}{dt} - w_{os}\varphi_{sx} \\ U_{rx} = R_r I_{rx} + \frac{d\varphi_{rx}}{dt} - (w_{os} - w_r)\varphi_{ry} \\ U_{ry} = R_r I_{ry} + \frac{d\varphi_{ry}}{dt} + (w_{os} - w_r)\varphi_{rx} \end{cases} \quad (4)$$

With v the voltage [U], R the resistance [Ω], i the current [A], $w_{os}$, the stator electrical frequency [rad/s], φ the flux linkage [Us] and s the rotor slip.
The flux linkages in (4) can be calculated using the following set of equations in per unit [11]

$$\begin{cases} \varphi_{sx} = -L_s I_{sx} + M_{sr} I_{rx} \\ \varphi_{sy} = -L_s I_{sy} + M_{sr} I_{ry} \\ \varphi_{rx} = L_r I_{rx} - M_{sr} I_{sx} \\ \varphi_{ry} = L_r I_{ry} - M_{sr} I_{sy} \end{cases} \quad (5)$$

With M the mutual inductance and $L_s$, and $L_r$, the stator and rotor leakage inductance respectively.
A more complex model of the system studied, taking into a count the $\frac{d\varphi}{dt}$ terms of (4), can be found in [11].
Keeping the above in mind, the following voltage current relationship of the DFIG can be derived from (4) and (5)

$$\begin{cases} U_{sx} = -R_s I_{sx} - L_s \frac{dI_{sx}}{dt} + M\frac{dI_{rx}}{dt} + w_{os} L_s I_{sy} - w_{os} M I_{ry} \\ U_{sy} = -R_s I_{sy} - L_s \frac{dI_{sy}}{dt} - M\frac{dI_{ry}}{dt} - w_{os} L_s I_{sx} + w_{os} M I_{rx} \\ U_{rx} = R_r I_{rx} + L_r \frac{dI_{rx}}{dt} - M\frac{dI_{sx}}{dt} - (w_{os} - w_r) L_r I_{ry} + (w_{os} - w_r) M I_{sy} \\ U_{ry} = R_r I_{ry} + L_r \frac{dI_{ry}}{dt} - M\frac{dI_{sy}}{dt} + (w_{os} - w_r) L_r I_{rx} - (w_{os} - w_r) M I_{sx} \end{cases} \quad (6)$$

The active power P and reactive power Q generated by the DFIG[11]

$$P = V_{ds}.I_{ds} + V_{qs}.I_{qs} + V_{dr}.I_{dr} + V_{qr}.I_{qr} \quad (7)$$

$$Q = V_{qs}.I_{ds} - V_{ds}.I_{qs} + V_{qr}.I_{dr} - V_{dr}.I_{qr} \quad (8)$$

### 3.3 PV Modules

The PV cell can directly convert the sunlight to DC power through the photoelectric phenomena. The power output of a single diode solar cell is given by[12]

$$P = IV \quad (9)$$

The general formula for monocrystalline solar cell current is the current–voltage relationship for a single diode solar cell of an array is given as follow:

$$I = I_L - I_D = I_L - I_0\left(e^{\frac{V+IR_S}{a}} - 1\right) \quad (10)$$

Usually the PV manufacturer supply their products with a data sheet that contains values of V and I for three conditions namely, the short circuit, the open circuit and the maximum power for a given set of reference condition. The reference solar irradiation and temperature is GT,ref=1000 W/m2 and Tref= 25oC , respectively.
In short circuit condition, the diode current is very small and the light current is equal to the short circuit current.

$$I_L = I_{SC} \quad (11)$$

In open circuit condition, the current is zero and the '10' in Eq. (11) is small as compared to the exponential term. Because of this, the diode current is given by:

$$I_{0.ref} = I_{L.ref} e^{\frac{-V_{OC.ref}}{a_{ref}}} \quad (12)$$

The measured values for I and V at the maximum power point given by the manufacturer can be substituted into Eq.13 along with the diode and light current to find the series resistance, RS

$$R_S = \frac{a \ln\left(1 - \frac{I_{mp}}{I_L}\right) - V_{mp} + V_{OC}}{I_{mp}}$$

(13)

The following equations are good approximations for the temperature effect on many PV modules.

$$I_L = \frac{G_T}{G_{T.ref}}\left(I_{L.ref} + \mu_{Isc}(T_C - T_{C.ref})\right) \quad (14)$$

$$a = a_{ref}\frac{T_{C.ref}}{T_C} \quad (15)$$

$$I_0 = I_{0.ref}\left[\frac{T_C}{T_{C.ref}}\right]^2 e^{\left[\frac{\varepsilon N_s}{a_{ref}}\left(1 - \frac{T_{C.ref}}{T_C}\right)\right]} \quad (16)$$

$$V_{OC} = V_{OC.ref} + \mu_{VOC}(T_C - T_{C.ref}) \quad (17)$$

$$a_{ref} = \frac{\mu_{VOC}.T_{C.ref} - V_{OC.ref} + \varepsilon N_S}{\frac{\mu_{ISC}.T_{C.ref}}{I_{L.ref}} - 3} \quad (18)$$

## 4 METROLOGICAL DATA

The main input parameters for the solver are solar radiation and wind speed. The daily average solar radiation and wind speed data for the region of Batna in Algeria were collected from l'Atlas Solar from Algeria

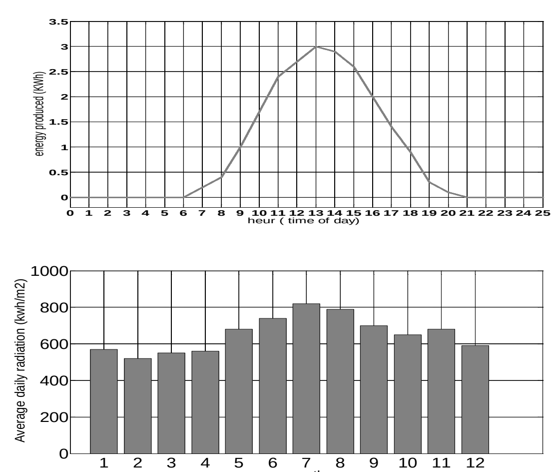



Fig. 2. Solar irradiation distributions during the year and day for Batna.

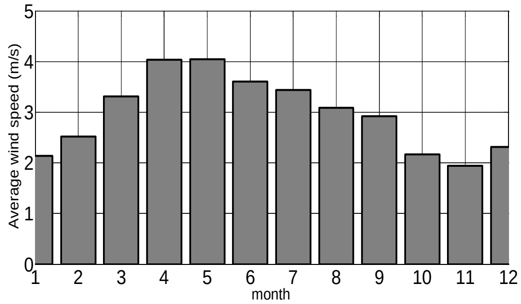



Fig. 3. wind speed distribution during the year for Batna .

## 5 Control Systems Design

The PV array must operate electrically at a certain voltage which corresponds to the maximum power point under the given operating conditions, i.e. temperature and irradiance. To do this, a maximum power point tracking (MPPT) technique should be applied. Various MPPT techniques have been proposed and implemented, e.g. look-up table methods, perturbation and observation (P & O) methods and computational methods [12]. Incremental conductance method has been implemented in this study. If the array is operating at voltage V and current I, the power generation is P=VI. At the maximum power point, dP/dV should be zero and the sign of dP/dV may be identified by equation (8). Increase or decrease in the PV array voltage is determined by judging the sign of equation (19). Fig. (4) presents the flow of the incremental conductance technique implemented

$$\frac{1}{V}\frac{dP}{dV} = \frac{d(VI)}{V(dV)} = \frac{1}{V} + \frac{dI}{dV} \qquad (19)$$

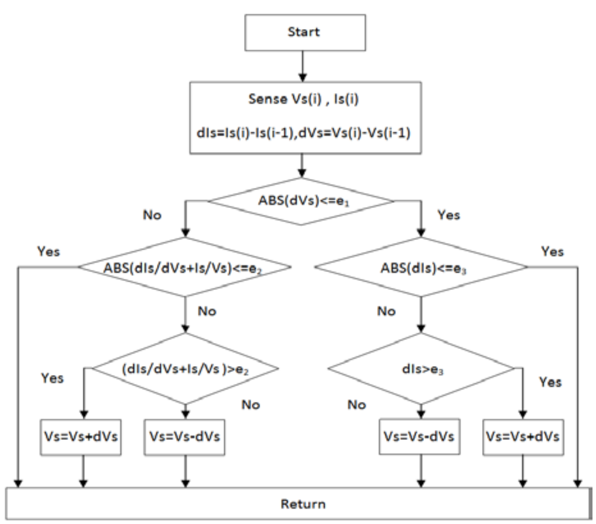



Fig. 4. Flow chart of the MPPT technique implemented

Fig. 5 presents the current control scheme of the grid inverter. The control strategy of the grid interface inverter is as follows.

- The common dc voltage Vdc is maintained constant so that real power from the wind and PV system can pass through into the grid.
- Various control modes including power factor, kVar, current and voltage can be used for determining the amount of necessary reactive power generation. In the study, constant power factor control has been implemented.

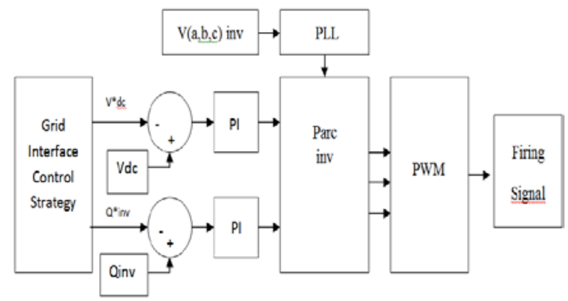
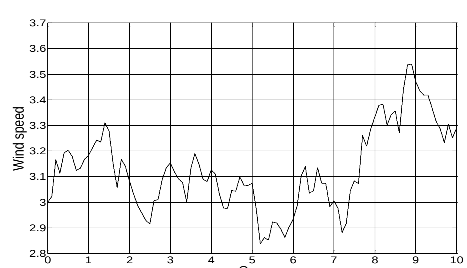



Fig. 5. Current control of grid interface inverter.

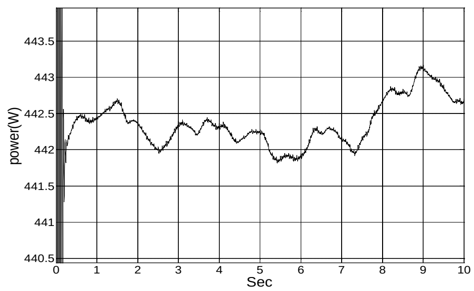
## 6 Simulation Results

Fig. 6 shows the simulation results. The hybrid system is in unity power factor operation under the wind speed and solar radiation condition shown in Fig. 6(1) and 6(3), respectively. Temperature is assumed to be 25o

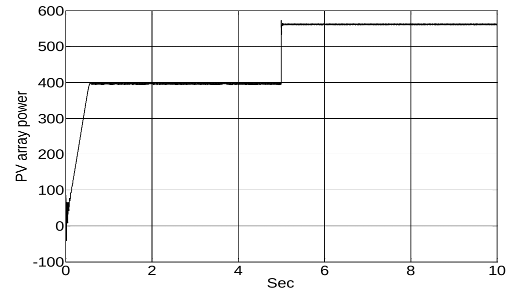
Fig. 6(2) shows the real power extracted at unity power factor from the wind generator by the wind-side converter. The real power has varied smoothly compared to wind speed change. PV array current traces the desired level well response to solar radiation changes as shown in Fig. 6(5) but the PV array voltage does not change with solar radiation changes as shown in Fig. 6(4) . The PV array power is shown in Fig. 6(6). Real pwer generation of the grid inverter is shown in Fig. 6(7) 6(8)a,b. The voltage waveforms at grid inverter terminal shown in Fig. 6(9).



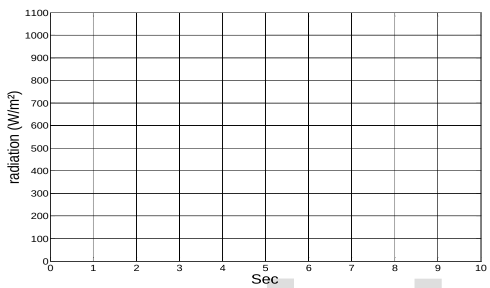

(1)Wind speed



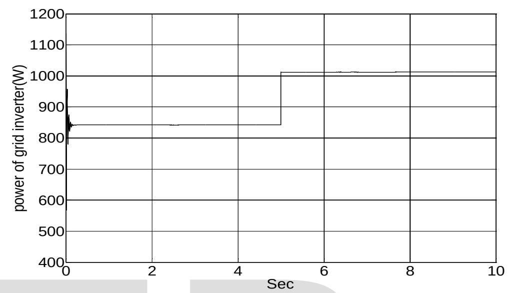

(2)Real power generation from wind generator



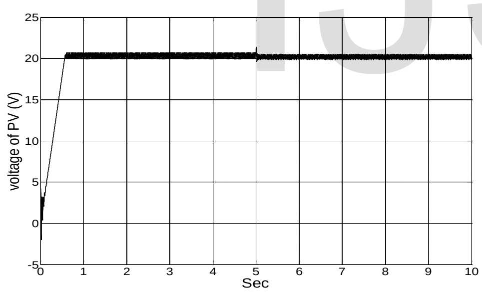

(6) PV array power



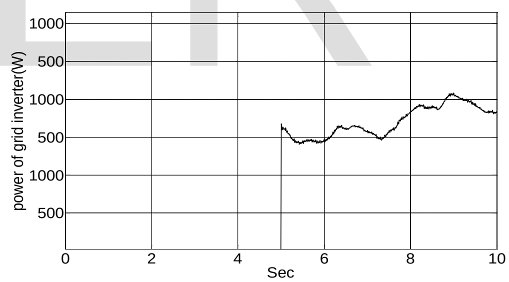

(3)Solar radiation



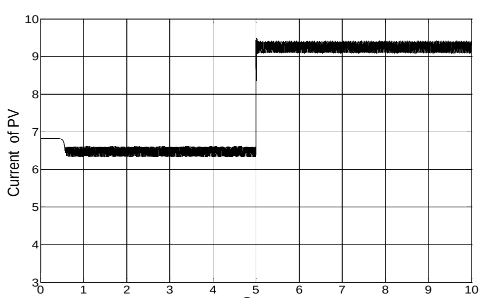

(7) Real power of grid inverter



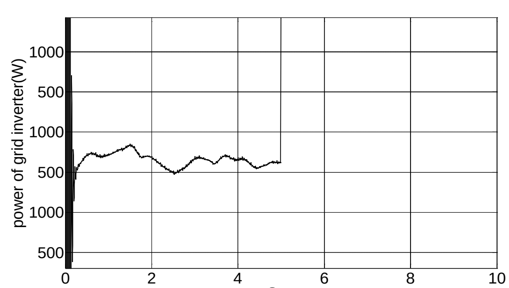

(4)Solar radiation



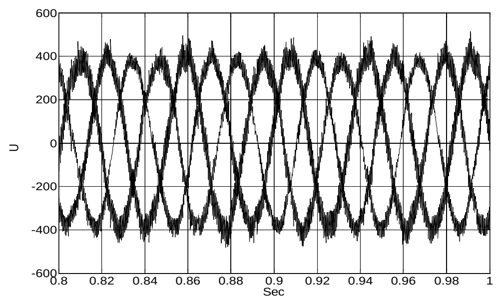

(8).a.Real power (Zoom)




(5) Desired and actual current of PV array




(8).b.Real power (Zoom)




(9)Voltage waveforms at grid inverter terminal

## 7 Conclusions

Feasibility study on power control of grid-connected wind/PV hybrid generation. The modeling and simulation study was carried out based on MATLAB. The simulation results showed the excellent performance of the wind/PV hybrid control in response to severe changes in wind speed and solar intensity conditions. Control and analysis of hybrid systems with fuel cell generation will follow in a future work.

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