International Conference on Green Energy and Environmental Engineering(GEEE-2017)
International Journal of Control, Energy and Electrical Engineering - CEEE
Vol.4 pp.18-23

Particle Swarm Optimization Control of a Grid Connected Solar/Wind Energy System

Mouna BEN SMIDA#1, Anis SAKLY#1

Research Unit of Industrial Systems Study and Renewable Energy (ESIER),
National Engineering school of Monastir;
Ibn El Jazzar; Skaness; 5019; Monastir;Tunisia
mouna_bensmida@yahoo.fr
sakly_anis@yahoo.fr

***Abstract*—Hybrid renewable energy system has been introduced as a green and safe power system. The hybrid unit is widely used and therefore, optimization problem solving for this system is necessary. Research and development efforts in renewable sources are required to improve the hybrid system performances. In this study, we propose the control of an hybrid system comprising a wind turbine and a shaded photovoltaic generator using an evolutionary method based on particle swarm optimization.**

Keywords—hybrid; renewable; wind turbine; photovoltaic; shading; particle swarm optimization; grid

I. Introduction

During the last decade, energy consumption has increased considerably due to massive industrialization. The use of alternative resources such as solar and wind energy is a solution to meet the needs of large-scale power generation. Despite the above-mentioned renewable energy systems are considered as promising power-generating sources, the major drawback of these resources is their variable nature and dependence on the weather and climatic conditions. For this reason, a combination of some sources to form a single renewable energy system called as hybrid renewable energy system (HRES) [1], allows maximum optimization of power systems, both technically and economically. Indeed, integrating the mentioned resources in a suitable hybrid combination provides the potential to improve the system efficiency and the energy supply reliability.

In this framework, several researchers have studied the design, optimization, operation and control of HRES. Celik [2] presented a technique to evaluate the performance of hybrid solar/wind energy system using synthetically generated weather data. Nehrir et al. [3] proposed a new computer-modeling approach for evaluating the general performance of hybrid photovoltaic/wind energy system. Rajkumar et al [4] used adaptative neuro-fuzzy inference system to model the hybrid systems. In [5], Yang et al studied an optimal sizing method for stand-alone hybrid solar/wind system with the loss of power supply probability technology by using a genetic algorithm. In fact, due to the high complexity and high nonlinearity of the renewable systems, this work suggests metaheuristics called particle swarm optimization (PSO) [6] to control a grid connected photovoltaic/wind system. This method is used to control the pitch angle of the wind turbine system and to assure the maximum power point tracking (MPPT) of a shaded photovoltaic (PV) system. In our study, we started with the development of the studied HRES system, and then the concept of using PSO method in controlling the wind turbine pitch angle and global maximum power point (GMPP) tracking is detailed. Finally, before concluding, the performance of the developed control strategies is discussed using some simulation results.

II. The Studied Hybrid Renewable Energy System

A. Wind Turbine Model

The wind conversion system (WECS) is generally constituted of the rotor, the transmission system, and the power generator unit [7]. Fig.1 gives an overview of a horizontal-axis wind turbine. The rotor includes the blades that assure the aerodynamic conversion, the hub that connects the blades to the transmission and the pitch servos which are in charge to rotate the blades around their longitudinal axes. The transmission system assures the transfer of the captured mechanical power to the electric machine. It comprises the low- and high-speed shafts, the gearbox and the brakes. The gearbox increases the rotor speed to values more suitable for driving the generator. For the studied variable speed WECS, the wind turbine is directly coupled to the PMSG without a gearbox to convert the wind power into electrical one, the electric generator converts mechanical power into electricity.

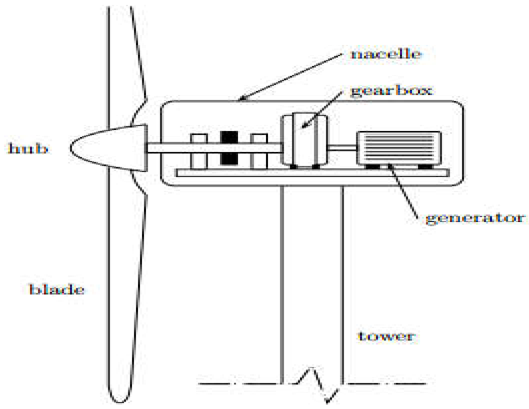

Fig.1. overview of a horizontal-axis wind turbine

The general model for the whole WECS is structured by several interconnected subsystem models as it is given in fig.2. The aerodynamic subsystem outlines the transformation of the three-dimensional wind speed field into forces on the blades which initiate the rotational movement. The mechanical subsystem includes the drive-train and the support structure. In fact, the drive-train transmits the aerodynamic torque on the blades to the generator shaft and the structure, composed of the tower and foundations, sustains the thrust force. The electrical subsystem permits the conversion of mechanical power at the generator shaft into electricity. Concerning the actuator subsystem, it models the pitch servo behaviour [8].

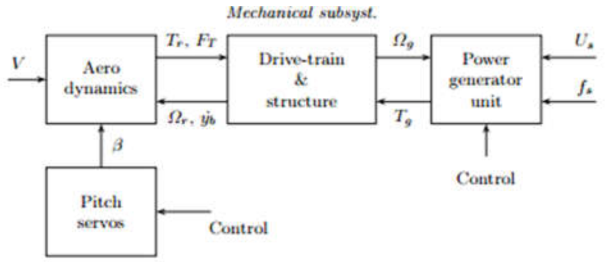

Fig.2. Subsystem-level block diagram of a variable-speed variable-pitch WECS

The output power of the wind turbine is expressed by:

$$P_w = \frac{1}{2}\rho\pi R^2 V_w^3 C_p(\lambda,\beta) \tag{1}$$

Where:

ρ is the air density

A is the turbine swept area

V_W is the wind speed

The power coefficient C_p is a non-linear function depending on the tip speed ratio λ and β blade pitch angle. It is given by:

$$C_p(\lambda,\beta)=0.53\left[\frac{151}{\lambda_i}-0.58\beta-0.002\beta^{2.14}-13.2\right]\times exp\left(\frac{-18.4}{\lambda_i}\right) \tag{2}$$

Where:

$$\lambda_i = \frac{1}{\dfrac{1}{\lambda-0.02\beta}-\dfrac{0.003}{\beta^3+1}} \tag{3}$$

The tip speed ratio (TSR) is explicit by the following expression:

$$\lambda = \frac{R\Omega}{V_w} \tag{4}$$

By using (2), the typical Cp versus λ curve is shown in Fig.3.

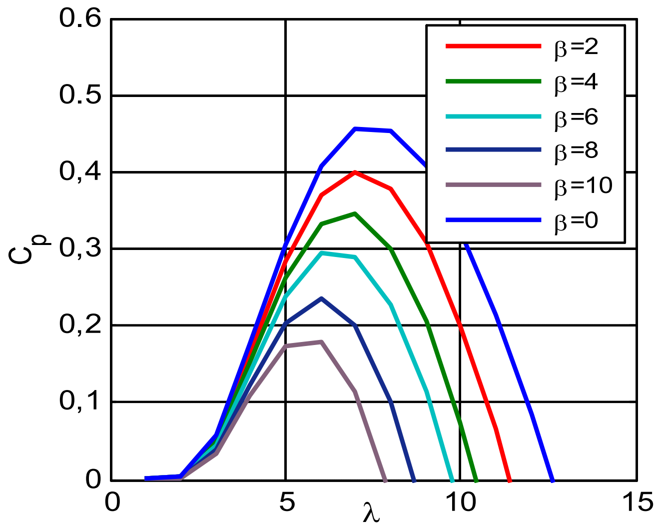

Fig.3.Cp versus λ curve

The turbine torque is defined as the ratio of the mechanical power to the rotational speed:

$$T_m = \frac{P_w}{\Omega} \tag{5}$$

The mechanical speed of the turbine is determined from the fundamental equation of the dynamics as:

$$J\frac{d\Omega}{dt} = T_m - T_{em} - f\Omega \tag{6}$$

B. Shaded PV system model

The studied system comprises two PV array connected in series where one of them is shaded, each of which consists of 5 modules where each one contains 54 serial cells delivering under uniform climatic situations 2000W.

Partial shading results when the PV array is exposed to different radiations, the system's electrical performance will be based on the cells specifications as well as the irradiation's conditions. In fact, the shaded modules utilize an amount of the generated power and behave as a load. This influences on the general power production and can engender hot spot problem. Therefore, additional bypass diodes are used to avoid the self-heating of PV modules. Many types of research have been performed to implement the photovoltaic model. The mathematical model of a solar module with N_s series cells is given by the equation below:

$$I_{pv} = I_{ph} - I_0(exp(V_{pv} + \frac{N_s R_s I_{pv}}{N_s V_T}) - 1) - V_{pv} + \frac{N_s R_s I_{pv}}{R_{shg}} \tag{7}$$

The system is simulated under different irradiations of G1 and G2 .The I-V and P-V characteristics, given in Fig.4, accentuate the role of the second generator's illumination. In fact, it influences on the PV general aspect, particularly at the second peak.

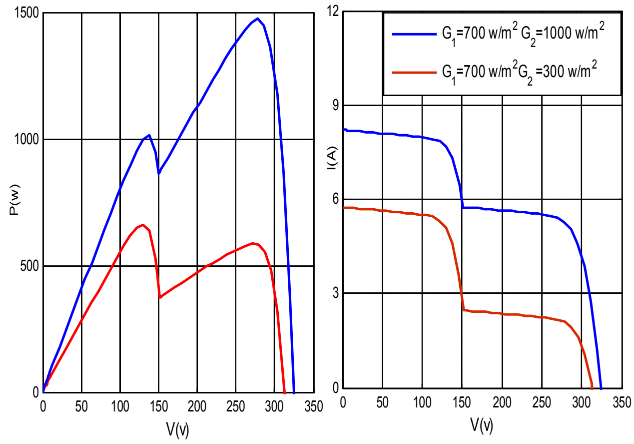

Fig.4. P-V and I-V characteristics of the studied shaded PV generator

C. *PQ inverter*

The DC/AC converter interfaces the photovoltaic source with the power structure. It behaves as a power controller between the DC-link and the grid by assuring the regulation of the amount of active and reactive power injected into the utility network [12]. Fig.5 gives its configuration.

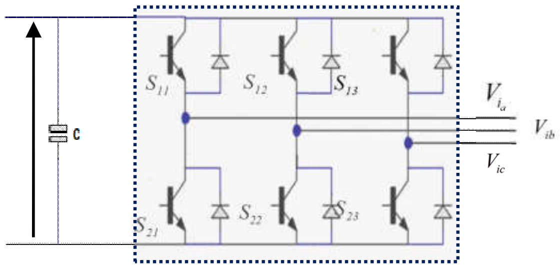

Fig.5. Configuration of the studied inverter

The converter's leg involves a group of two IGBTs connected with the same phase. The two conditions for the switching variable γ_k of each leg *k are* given by:

$$\gamma_k = \begin{cases} 1, & (S_{1k} = 1 \text{ and } S_{2k} = 0) \\ 0, & (S_{1k} = 0 \text{ and } S_{2k} = 1) \end{cases} \quad k \in \{1,2,3\} \tag{10}$$

As ideal power switches are considered:

$$\sum_{j=1}^{2} S_{jk} = 1 \qquad k \in \{1,2,3\} \tag{11}$$

The inverter's voltages V_{ia}, V_{ib}, V_{ic} are related to the switching states S_{11}, S_{12} and S_{13} according to the following matrix.

$$\begin{bmatrix} V_{i_a} \\ V_{i_b} \\ V_{i_c} \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_{11} \\ S_{12} \\ S_{13} \end{bmatrix} \tag{12}$$

D. *The line-side converter's control*

The grid dynamic model is expressed by:

$$\begin{cases} V_{g_d} = V_{i_d} - R_g i_{g_d} - L\dfrac{di_{g_d}}{dt} + \omega l_g i_{g_q} \\ V_{g_q} = V_{i_q} - R_g i_{g_q} - L\dfrac{di_{g_q}}{dt} - \omega l_g i_{g_d} \end{cases} \tag{13}$$

Where V_{i_d} and V_{i_q} are the d-q inverter voltage components, L_g and R_g are the grid inductance and resistance, respectively and i_{g_d} and i_{g_q} represent the d-q grid current components. The active and reactive powers are determined from equations (14) and (15).

$$P = \frac{3}{2}\left(V_{g_d} i_{g_d} + V_{g_q} i_{g_q}\right) \tag{14}$$

$$Q = \frac{3}{2}\left(V_{g_q} i_{g_d} - V_{g_d} i_{g_q}\right) \tag{15}$$

The elementary structure of the grid side control is given in figure 6; two PI controllers are proposed to regulate the injected power flow. A *d-axis PI regulator* assures the control of the active power, while a *q-axis PI regulator* regulates the reactive power. The exchange of reactive power is not considered in this work, so the total power extracted from the hybrid system is transmitted to the network.

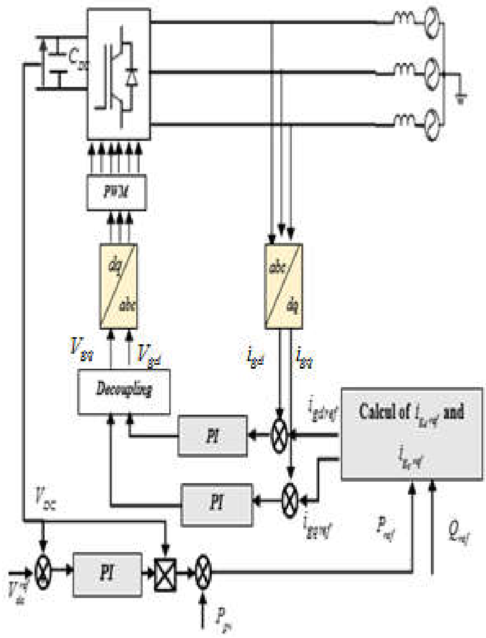

Fig.6. The different grid side control loops

III. Particle swarm optimization for the studied hybrid renewable

A. Basic PSO algorithm

PSO is based on the behavior of a colony or swarm of bees, a train of fish or a group of birds [7] [8]. It imitates the comportment of theses social organizations. Each individual or particle in a swarm behaves in a distributed approach using its own intelligence and the collective one of the swarm. Thus, if one particle finds a good path to food, the others will also be able to follow it instantly even if their position is far away in the swarm [9] [10]. Optimization processes based on swarm intelligence are called evolution-based techniques. For multivariable optimization structure like renewable systems, swarm is supposed to be fixed with each particle located initially at random positions in multi-dimensional space. Each particle has a position and a velocity [11] [12]. Each particle moves in the design space and remembers the best position it has discovered. The particles communicate information or good positions to each other and adjust their individual positions and velocities based on the information received for the good positions. For the standard algorithm, the velocity v and position x of each particle in iteration k can be computed as follows:

$$\mathrm{V}_{k}^{(m)} = \omega \mathrm{V}_{k-1}^{(m)} + c_1 r_1 \left(p_{best}^{(m)} - \mathrm{X}_{k-1}^{(m)}\right) + c_2 r_2 \left(g_{best} - \mathrm{X}_{k-1}^{(m)}\right) \quad (16)$$

$$\mathrm{X}_{k}^{(m)} = \mathrm{X}_{k-1}^{(m)} + \mathrm{V}_{k}^{(m)} \quad (17)$$

The parameters c1 and c2 set the relative pull of p_{best} and g_{best}. The parameters r_1 and r_2 which are uniformly distributed random variables in the range of [0, 1] help in stochastically varying these pulls.

B. Pitch angle control using PSO

In this part, a regulation of the wind turbine pitch angle via a regulator based on the PSO is proposed. In fact, the proposed controller calculates the appropriate pitch angle by setting the angle reference βref. This angle is considered to be the particle and the optimization function is calculated using the following equation:

$$FIT = \left|P_{g,\mathrm{nom}} - P_g\right| \quad (18)$$

The initial positions of the evolutionary parameters, particles, are given by a vector comprising $\beta_{ref\,j}^{\;k}$.

With j = (1,2,3,4) is the index of the particles.

For each iteration k, the j reference angle values are sent to the system and impose a torque to the turbine and therefore a generated power. The studied algorithm is tuned on line. The developed algorithm is described by the following flowchart:

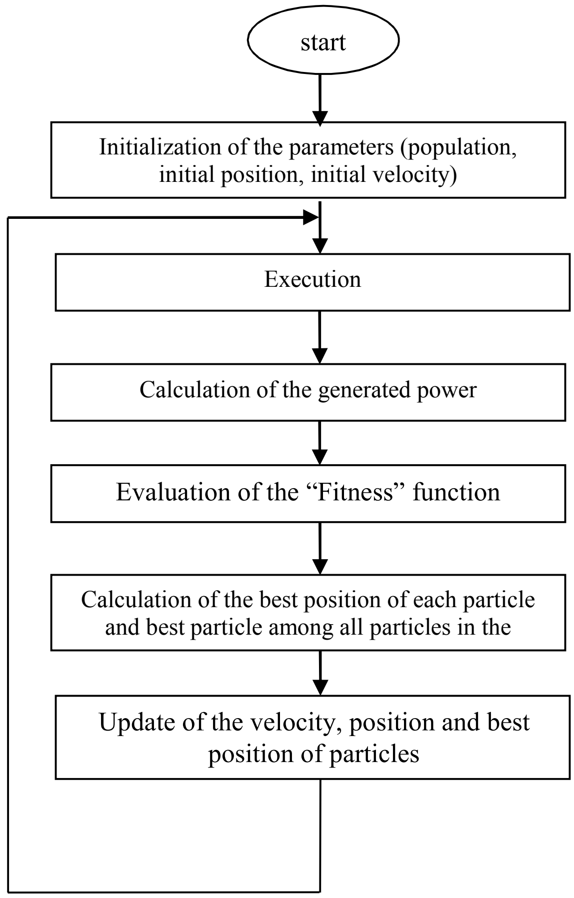

Fig.7. Flowchart of pitch angle control using PSO

C. PSO method for GMPP tracking

In this work, the PSO algorithm is used to ensure the MPPT control of the studied shaded photovoltaic generator.

In fact, the algorithm acts on the cyclic ratio of the converter by controlling the output voltage of the GPV, considered as the particle at each iteration.

For the studied algorithm, 4 particles are considered. The initial position of the population are given by the vector below:

$$x=[0.2\ 0.4\ 0.6\ 0.8]\times 2Voc \quad (19)$$

The fitness function to be maximized presents the generated PV power. It is developed as in (9):

$$Fitness=Vpv{*}I\,pv \quad (20)$$

Due to the change in operations conditions, the GA algorithm is modified in order to search the new MPP again by resetting the initial population whenever it detects a variation of solar irradiance, temperature, and load.

Accordingly, the GA is reinitialized while the following two conditions are satisfied:

$$\left|V_{pv}(k+1)\right| \langle -\Delta V \quad (21)$$

$$\frac{P_{pv}(k+1)-P_{pv}(k)}{P_{pv}(k)}\rangle \Delta P \qquad (22)$$

The flowchart of the proposed PSO algorithm for GMPP tracking is given in Fig.8.

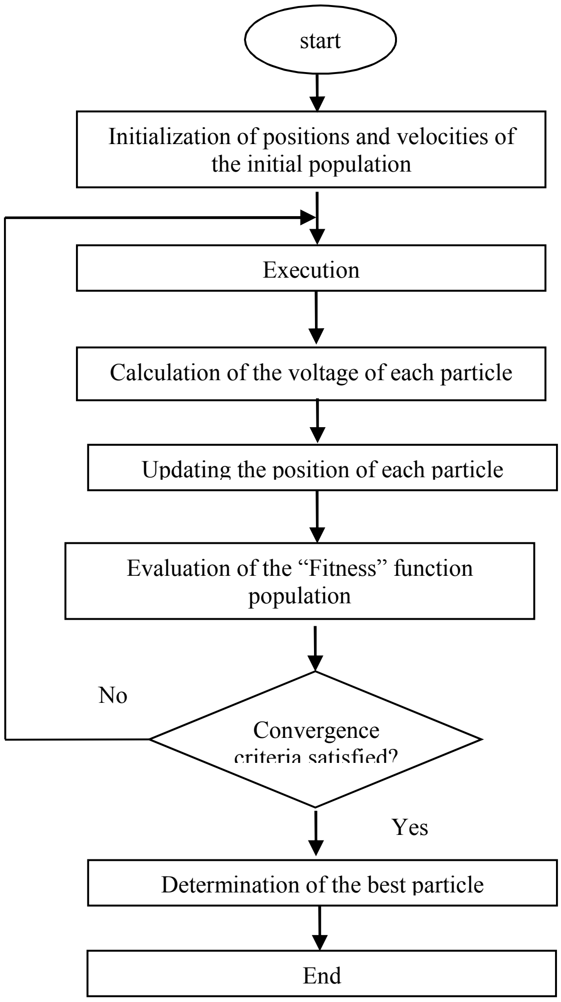

Fig.8. Flowchart of GMPP tracking using PSO

IV. SIMULATIONS RESULTS

The behavior of the wind generator associated with the GPV and connected to the grid is illustrated using numerical simulations carried out under Matlab -Simulink. The variable-speed wind generator, controlled by the PSO approach, is exposed to a variable wind given in fig.9. It then generates the Peol wind power, shown in fig.10. The shaded photovoltaic generator controlled by the MPPT technique based on the PSO is exposed to a variable illumination illustrated in fig.11. Fig.12 shows its generated power. The P-V characteristic of the GPV is illustrated in Fig.13. It is clear that the PSO algorithm follows the maximum power point for the different states. Fig.14 shows the evolution of the power generated by renewable energy sources. The DC bus voltage given infig.15 is constant and well-regulated at its 400V set point and thus proves the efficiency of the implanted regulator. Fig.16 and Fig. 17 illustrate the evolution of the currents and the voltages injected into the grid.

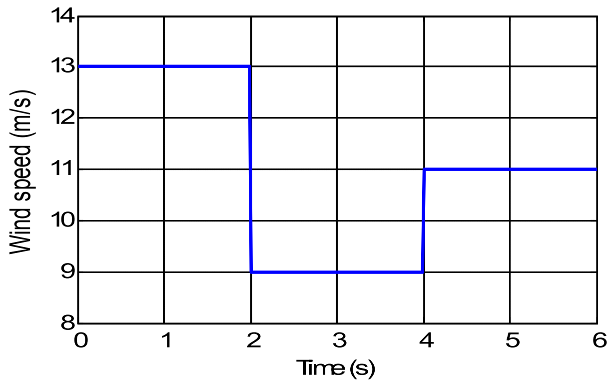

Fig.9. Wind profile

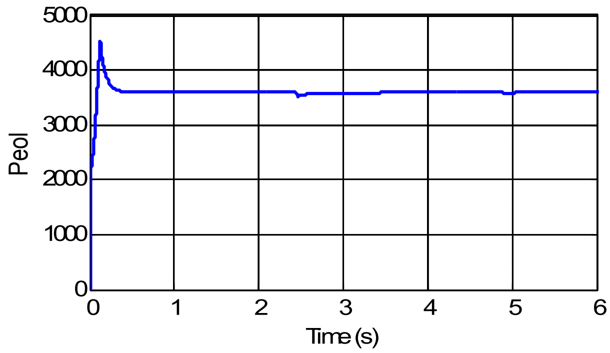

Fig.10. Wind turbinE generated power

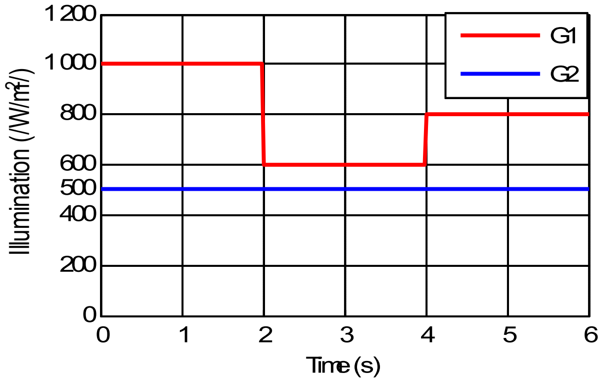

Fig.11 .Illumination profile

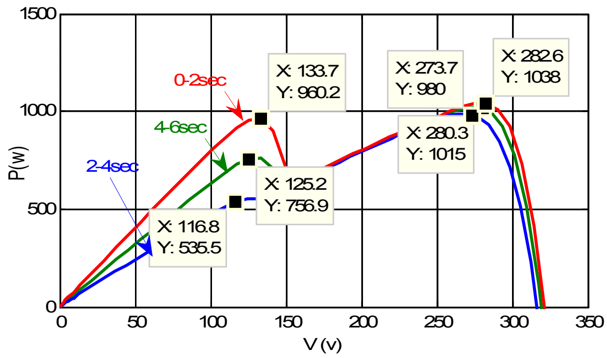

Fig.12 .P-V characterics for different studied scenarios

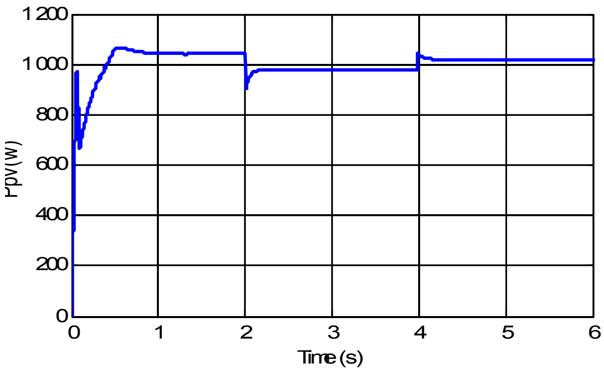

Fig.13. Photovoltaic generated power

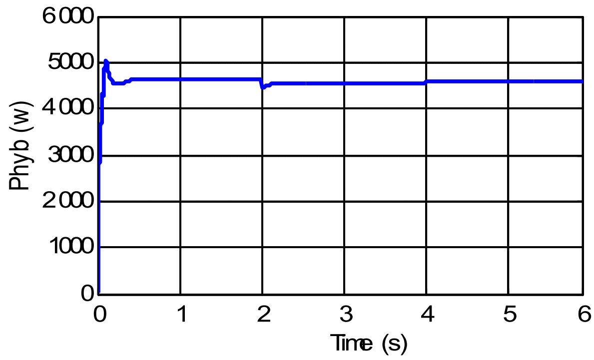

Fig.14. Response of the generated power by renewable energy sources

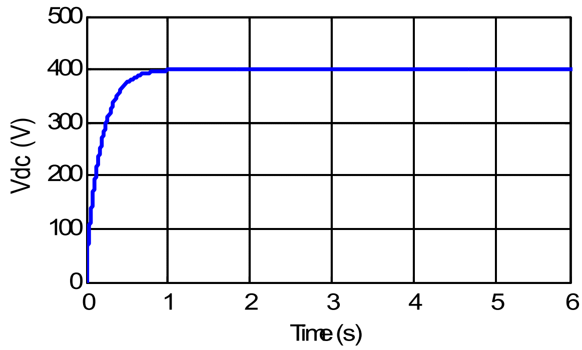

Fig.15. Response of the DC bus voltage

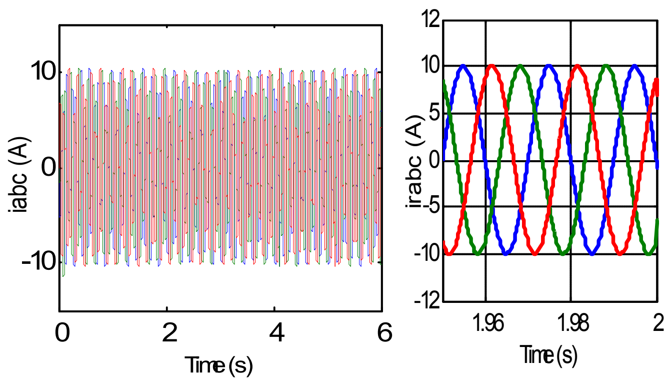

Fig.16. Grid currents response

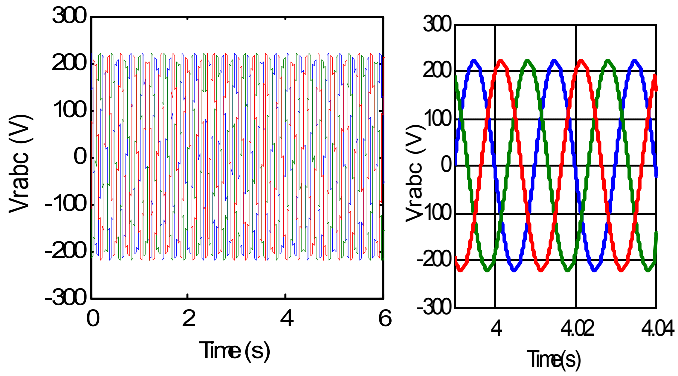

Fig.17. Grid voltage response

V. CONCLUSION

In this paper, a PSO technique is proposed to control an hybrid renewable system. The system consists of a shaded photovoltaic panel and a wind turbine generator connected to the grid via an inverter. First, the PSO technique is used to regulate the wind generated power around its rated value then this method is used to extract the maximum power delivered from the solar generator. The effectiveness of the studied method is demonstrated by the different simulations results.

REFERENCES

[1] Wang, L., & Singh, C. (2009). Multicriteria design of hybrid power generation systems based on a modified particle swarm optimization algorithm. IEEE Transactions on Energy Conversion, 24(1), 163-172J.

[2] Celik AN. Optimization and techno-economic analysis of autonomous photovoltaic–wind hybrid energy systems in comparison to single photovoltaic and wind systems. Energy Convers Manage 2002; 43(18):2453–68.

[3] Nehrir MH, LaMeres BJ, Venkataramanan G, Gerez V, Alvarado LA. An approach to evaluate the general performance of stand-alone wind/photovoltaic generating systems. IEEE Trans Energy Convers 2000;15(4):433–9.

[4] Rajkumar, R. K., Ramachandaramurthy, V. K., Yong, B. L., & Chia, D. B. (2011). Techno-economical optimization of hybrid pv/wind/battery system using Neuro-Fuzzy. Energy, 8(36), 5148-5153.

[5] Yang, H., Zhou, W., Lu, L., & Fang, Z. (2008). Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using a genetic algorithm. Solar energy, 82(4), 354-367

[6] Khare, A., & Rangnekar, S. (2013). A review of particle swarm optimization and its applications in solar photovoltaic system. Applied Soft Computing, 13(5), 2997-3006.

[7] Zhan, Z. H., Zhang, J., Li, Y., & Chung, H. S. H. (2009). Adaptive particle swarm optimization. IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics), 39(6), 1362-1381.

[8] TU, Zhenguo et LU, Yong. FE model updating using artificial boundary conditions with genetic algorithms. Computers & Structures, 2008, vol. 86, no 7, p. 714-727.

[9] Hung, J. C. (2013). Modified particle swarm optimization structure approach to direction of arrival estimation. Applied Soft Computing, 13(1), 315-320.

[10] MIRANDA, Vladimiro et FONSECA, Nuno. EPSO-evolutionary particle swarm optimization, a new algorithm with applications in power systems. In : Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES. IEEE, 2002. p. 745-750.

[11] Clerc, M., & tKennedy, J. (2002). The particle swarm-explosion, stability, and convergence in a multidimensional complex space. IEEE transactions on Evolutionary Computation, 6(1), 58-73.

[12] Eberhart, R., & Kennedy, J. (1995, October). A new optimizer using particle swarm theory. In Micro Machine and Human Science, 1995.

ISSN 2356-5608