ISSN 2278-3083

**International Journal of Science and Applied Information Technology**, Vol.7. No.1, Pages : 17-22 (2017)
*Special Issue of ICSIC 2017 - Held during 23-24 September 2017 in Amman Arab University, Amman-Jordan*
***http://www.warse.org/IJSAIT/static/pdf/Issue/icsic2017sp03.pdf***

# Modelling and Simulation of Renewable Energy Systems in Algeria

**A. BENATIALLAH, D.Benatiallah, T.Ghaitaoui, A.Harrouz, S.Mansouri**
Labo EESI, Adrar university, Algeria benatiallah.ali@gmail.com

**Abstract**

This paper presents the study of methodology for calculation the output and performances of a PV wind system. A Long term data of wind speed and solar radiation for every hour of the day were used. These data were used to calculate the average power generated by a PV-Wind installation for every hour of a typical day in a month. A load of a typical house in south of Algeria (desert area) was used as a load demand of the system. For a given load and a mixed multiple-criteria integer programming problem, the types and sizes of PV generator, wind turbine generators (WTG) and storage system was calculated based on the minimum cost of system. In our research, we investigated the genetic algorithm (GA) for optimally a PV-wind power system.

We define that the objective function is the total cost, where the total cost is the sum of initial cost, an operation cost, and a maintenance cost. We determine an optimal configuration of wind generating systems, where total cost is more optimal using GA. A computer program has been developed to size system components in order to match the load of the site in the most cost. A cost of electricity, an overall system cost is also calculated for each configuration. The study was performed using a graphical user interface programmed in MATLAB/simulink environment.

**Keywords:** PV Wind system, optimal configuration, genetic algorithm, cost, modelling

## 1. Introduction

The rapid depletion of fossil-fuel resources on a world has necessitated search for alternative energy sources. Wind energy has been considered as promising toward meeting the continually increasing demand for energy. The solar and wind sources of energy are inexhaustible, the conversion processes are pollution-free, and their availability is free. For isolated systems such as rural electrification, the solar or wind energy has been considered as attractive and preferred alternative sources.

Generally the main objectives of the optimization design are power reliability and cost. In this paper an optimal sizing method using the genetic algorithm (GA) is proposed. The types and sizes of PV generator, wind turbine generators, the number of batteries can be optimized when sizing a standalone PV wind power system, which may be defined as a mixed multiple-criteria integer programming problem.

We propose the optimum configurations for PV wind generating systems in residences using hourly data over a year. We assume that a residence is one house consuming average electrical energy in south of Algeria (Sahara area). Genetic algorithm (GA) is used as an optimization method in this paper. The purpose of this study is to minimize the objective function of GA. The objective function is the total cost of PV wind system.

The purpose of methodology is to suggest a list of commercially available system devices, the optimal number and type of units ensuring that the 25-year round total system cost is minimized subject to the constraint that the load energy requirements are completely covered. The 25- year round total system cost is equal to the sum of the respective components capital and maintenance costs. The decision variables included in the optimization process are the number and type of PV, Wind turbine and batterie and installation height of the WGs. The minimization of cost (objective) function is implemented employing a genetic algorithms (GA) approach, which compared to conventional optimization methods, such as dynamic programming and gradient techniques, has the ability to attain the global optimum with relative computational simplicity.

The present work provides the results of a study on the optimization of PV wind system to meet a certain load distribution demand in the city of Bechar (Algeria). The method is applied to the satisfaction of a domestic load demand.

## 2. System Configuration

The configuration of stand alone PV wind power systems is shown in Fig. 1. In this paper, we investigated the case that a system has PV module, wind turbine, batteries and inverter of stand alone energy conversion installation.

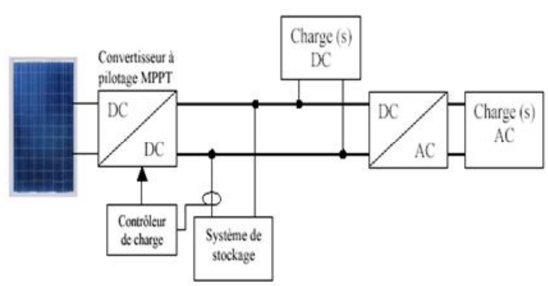



Fig. 1: PV wind system

ISSN 2278-3083

**International Journal of Science and Applied Information Technology**, Vol.7. No.1, Pages : 17-22 (2017)
*Special Issue of ICSIC 2017 - Held during 23-24 September 2017 in Amman Arab University, Amman-Jordan*
***http://www.warse.org/IJSAIT/static/pdf/Issue/icsic2017sp03.pdf***

## 3. MODELLING OF PHOTOVOLTAIC SYSTEM

Photovoltaic conversion is the direct transformation of solar energy into immediately usable direct electric current. From a technical standpoint, PV power systems have the potential to meet a large portion of energy demand worldwide [1]. A photovoltaic system contains the following components:

- Photovoltaic Array (Generator)
- Controller
- Voltage transformer
- Inverter to convert DC produced to AC current
- Storage battery

### 3.1 Modeling of PV Array :

A PV generator consists of modules connected in series to increase the voltage and in parallel to increase electrical output (Fig.1). The relationship between current and voltage is expressed by the following relationship:

$$\frac{I}{M_p} = I_{cc} - I_o\left[e^{\left(\frac{c_2}{n}\left(\frac{V}{Ms} + \frac{Rs\,.I}{Mp}\right)\right)} - 1\right] \qquad (1)$$

Where:
I = output current
Icc = light generated current per module
Io = reverse saturation current per module
Rs = diode series resistance per module (ohms)
N = number of modules in each series string
Ms = number of module strings in strings in series
Mp = number of module strings in parallel

This relationship holds true only if the array cells are identical and having the same characteristic I = f(V).

### 3.2 Temperature modeling:

Cell temperature (Tc) varies according to global solar irradiance and ambient temperature according tot the following equation:

$$T_c = T_a + \left(\frac{Noct - 20}{800}\right).G_b$$

Noct : Normal cell operating temperature provided by manufacturer data
$T_a$ : Ambient Temperature
$G_B$ : Global Solar Irradiance

### 3.3 Modelling the battery:

Experimental testing of solar batteries leads to the following model for load and off-load [3]

$$V = V_0 \pm I.R$$

$$V = \left\{V_o + k.\frac{Q}{\frac{C_T}{1 + a.I}(1 + \alpha c.\Delta T + \beta c.\Delta T^2)}\right\} \mp \left\{\left(\frac{P_1}{1 + I} + \frac{P_3}{[1 - \frac{Q}{C_T}]P_4} + P_5\right)(1 - \alpha.c.\Delta T)\right\} \qquad (2)$$

where the + sign is for the charge and – sign for the discharge :

$V_0$ = initial voltage

K, $P_1$, $P_2$, $P_3$, $P_4$, $P_5$ are constant derived empirically

*In practice, the battery's output is usually maximized at 85%, the nominal voltage at 2V and the average capacity at 1000Ah. Power supplied by the battery is expressed as :*

$$P_{ba} = \eta_{ba}\,.\,P_g$$

where :
$P_g$ = power of generator

### 3.4 Modelling of the Inverter:

The single phase inverter is characterized by its efficiency which is dependent on the power output supplied. This is expressed by the following relationship:

$\eta c = P_s/P_b$

$\eta c = A_1.\exp(-Ps/Pn) \qquad (3)$

Where,

$A_1$ and $A_2$ = constant characteristics of converter supplied by manufacturer
$P_s$ = utilized power during usage of system
Pn = Nominal power.

The output power supplied by the transformer is:

$P_c = \eta_c\,.P_b$

or

$P_c = \eta_c\,.\,P_g\,.\,\eta g\,. \qquad (4)$

## 4. MODELLING OF WIND ENERGY SYSTEM COMPONENTS

Various modelling techniques are developed by researchers to model components of Wind system. Performance of individual component is either modelled by deterministic or probabilistic approaches [ ]. General methodology for modelling wind system components like wind turbine, machine generator, and inverter is described below:

### 4.1. Modeling of the Wind Speed

The wind speed is one of the most important variables in the modeling of a wind energy conversion chain and is the main input variable in the chain synoptic diagram. Consequently, the simulation's accuracy depends on the representation of wind speed. Unfortunately, it has a random behavior inducing a fluctuating characteristic. So, in order to reproduce accurately the wind speed dynamic behavior, two approaches can help us. The first consists in considering measurements of long duration on an actual wind site and the second consists on representing the wind characteristic by an analytical model. The first solution is obviously more precise. Nevertheless, it does not easily permit to simulate various types of configurations of wind sites.

The speed of wind is a random process; therefore it should be described in terms of statistical methods. The wind speed data were recorded near the ground surface. To upgrade wind speed **data** to a particular hub height, the following equation is commonly used:

$$v = v_i.\left(\frac{h}{h_i}\right)^{\alpha} \qquad (5)$$

ISSN 2278-3083
**International Journal of Science and Applied Information Technology**, Vol.7. No.1, Pages : 17-22 (2017)
*Special Issue of ICSIC 2017 - Held during 23-24 September 2017 in Amman Arab University, Amman-Jordan*
***http://www.warse.org/IJSAIT/static/pdf/Issue/icsic2017sp03.pdf***

Where: v: wind speed at projected height, ***h***
$v_i$: wind speed at reference height, $\boldsymbol{h_i}$
***α:*** power-law exponent (- 1/7 for open land).

The wind speed distribution is assumed to be a Weibull distribution. Hence the probability density function is given by :

$$f(v) = \frac{k}{c}.\left(\frac{v}{c}\right)^{k-1}.\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad \textbf{(6)}$$

Where: $c$ : scale factor, unit of speed
$k$ : shape factor, dimensionless
v : wind speed.

The wind speed distribution functions were calculated for each hour of a typical day in every month.

### 4.2. Modeling of the Wind Turbine

The mechanical quantities which will connect the wind turbine with the generator are the wind turbine torque and the rotational speed on the shaft. It should be noticed that the torque depends on the rotational speed. The wind turbine modeling consists on modeling the torque induced by the blades.

The available maximum wind power for a given wind speed is expressed by [ ], [ ] :

$$P_w = \tfrac{1}{2}\rho S v^3 \quad (7)$$

where $S = \pi R^2$

$\rho$ is the air density, $R$ the blade radius and $S$ the frontal area of the wind turbine.

This maximum power is defined by global aerodynamic coefficients. These two coefficients are bond by the following relation:

$$C_p(\lambda) = \lambda C_\Gamma(\lambda) \quad (8)$$

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

$\lambda$ is the tip speed ratio, $\Omega$ the rotational speed of the shaft, $C_p$ the power coefficient and $C_\Gamma$ the torque coefficient.

The power and the wind turbine torque are then given by:

$$P_t = P_w C_p = \tfrac{1}{2}\rho\pi R^2 v^3 C_p \quad (9)$$

$$\Gamma_t = \frac{P_t}{\Omega} = \tfrac{1}{2}\rho\pi R^3 v^2 C_\Gamma \quad (10)$$

If the power or torque coefficient is provided by the manufacturer, modeling can be made by a N order polynomial regression [3 ], [4 ] :

$$C_\Gamma(\lambda) = a_0 + \sum_{i=1}^{N} a_i \lambda_i \quad (11)$$

The figure 2 illustrates the torque coefficient (a) and the wind speed torque (b) obtained by modeling with 6 order polynomial regression. The inconvenient of this type of modeling resides on the fact that it does not make it possible to vary the blade pitch angle. The torque model obtained depends only on the wind speed and the shaft rotational speed.

$$\Gamma_t(v,\Omega) = \tfrac{1}{2}\rho\pi R^3 v^2 C_\Gamma(\lambda) \quad (12)$$

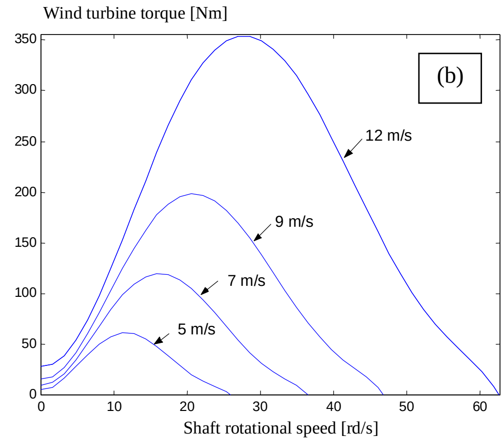



Fig. 2 . Torque coefficient (a) and wind turbine torque (b) versus shaft speed rotational with polynomial approach

This type of modeling is computational time consuming. However, it allows parametric studies of the variation of the blade pitch angle of the turbine. In this case, the torque depends on three quantities : the wind speed, the rotational speed of the shaft and the blade pitch angle $\beta$.

$$\Gamma_t(v,\Omega,\beta) = \tfrac{1}{2}\rho\pi R^3 v^2 C_\Gamma(\lambda,\beta) \quad (13)$$

### 4.3. Modeling of the Generator

The element which ensures the conversion of mechanical energy into electric energy is the generator (Fig. 3). One can say that it is the fundamental element of the conversion. In this study, a synchronous permanent magnets machine is used as a generator. The PMSG generator is modeled with the assumption of fundamental component of the airgap flux density. So, the PM airgap flux is assumed to be sinusoidal. Also, owing to the fact that the poles are considered smooth, the stator winding inductances are constant. Therefore, the stator phases voltages can be expressed as follows:

$$[v_g] = -\left\{[r_g][i_g] + [l_g]\frac{d}{dt}[i_g] + \frac{d}{dt}[\Phi_A]\right\} \quad (14)$$

where $[v_g] = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$; $[i_g] = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$; $[\Phi_A] = \Phi_M \begin{bmatrix} \sin(\theta) \\ \sin(\theta - 2\pi/3) \\ \sin(\theta + 2\pi/3) \end{bmatrix}$;

$[r_g] = \begin{bmatrix} r_s & 0 & 0 \\ 0 & r_s & 0 \\ 0 & 0 & r_s \end{bmatrix}$; $[l_g] = \begin{bmatrix} l & m & m \\ m & l & m \\ m & m & l \end{bmatrix}$

$v_g$ is the stator voltages, $i_g$ the stator currents, $\Phi_A$ the permanent magnet flux, $\theta$ the angular position, $\Phi_M$ the amplitude of the flux linkages established by a permanent magnet $r_s$ the stator resistances, $l$ the main stator phase

ISSN 2278-3083
**International Journal of Science and Applied Information Technology**, Vol.7. No.1, Pages : 17-22 (2017)
*Special Issue of ICSIC 2017 - Held during 23-24 September 2017 in Amman Arab University, Amman-Jordan*
***http://www.warse.org/IJSAIT/static/pdf/Issue/icsic2017sp03.pdf***

inductance and *m* the stator mutual inductance between two stator phases.

To the previous equations, one must add the mechanical equation of the generator shaft:

$$\frac{d\Omega}{dt} = \frac{p}{J}\left(\Gamma_t - \Gamma_{em} - f\,\Omega\right) \quad (15)$$

### 4.4. Modeling of the Static Converters

The static inverter used is a full wave three-phases voltage inverter (Fig. 5) [10]. Each switch is made up of IGBT in antiparallel with a free wheel diode. The switches are admitted as ideals, thus as in the case of the rectifier, their conduction correspond to a short circuit and their blocking corresponds in its turn to an open circuit. On the other hand, the overlapping are taken here into account. The following figure represents the inverter feeding a three-phase load which has $Z_{ch}$ impedance.

At the output of the inverter, one obtains the three-phase and symmetrical voltage systems. The theory of the three-phase and symmetrical systems shows that the voltages and the currents of these systems have the following properties:

$$\mathbf{i_{ach} + i_{bch} + i_{cch} = 0\ ;\ u_{ab} + u_{bc} + u_{ca} = 0}$$

$$v_{ach} = \frac{u_{ab} - u_{ca}}{3}\ ;\ v_{bch} = \frac{u_{bc} - u_{ab}}{3}\ ;\ v_{cch} = \frac{u_{ca} - u_{bc}}{3} \quad (16)$$

$i_{jch}$ and $v_{jch}$ are respectively the load currents and load voltages where $j = a, b, c$.

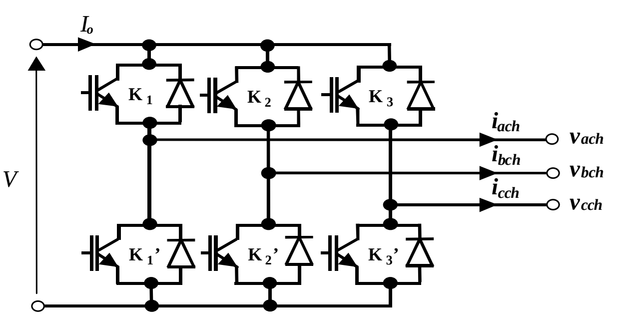



Fig. 3: Electric scheme of the inverter

$K_i = (T_i, D_i)$, $K_i' = (T_i', D_i')$, $i = 1, 2, 3$ and $I_0$ is the inverter input current.

*a. Modeling of the wind energy converter*

This part consists on implementing the wind energy converter (Fig. 6) by connecting the studied components. For that, the below equations are established in order to supplement the previous established equations.

The generator is connected with the rectifier by the following equation :

$$\frac{dI}{dt} = \frac{1}{2(l - m)}\left(-\frac{d\Phi_{+A}}{dt} + \frac{d\Phi_{-A}}{dt} - 2rI - V\right) \quad (17)$$

$\Phi_{+A}$ and $\Phi_{-A}$ corresponds respectively to the PM flux passing by the stator phases which has the most positive potential and the most negative potential.

A filtering capacity is placed in the continues part, between the rectifier and the inverter . This is expressed as follows :

$$\frac{dV}{dt} = \frac{1}{C}\left(I - I_0\right) \quad (20)$$

The input inverter current is then obtained by this equation. For each case of Table II, this current is equal to the load current which corresponds to the load voltage which has the most positive potential (absolute value).

### b. Load modelling:

There are two types of load utilization:
Constant Load: Used for fixed consumption such as in telecommunication systems. The relationship between consumption and time is this linear.

Variable Load: This is the case when the load is variable according to daily demand where it is maximum during early morning hours (7-9 AM), at mid-day (12-14 PM) and during evening hours (after 19 PM).

### 5. Simulation results

The proposed method has been applied to the design of a stand alone wind system in order to supply a house located in the south of Algeria (Bechar, Sahara area).

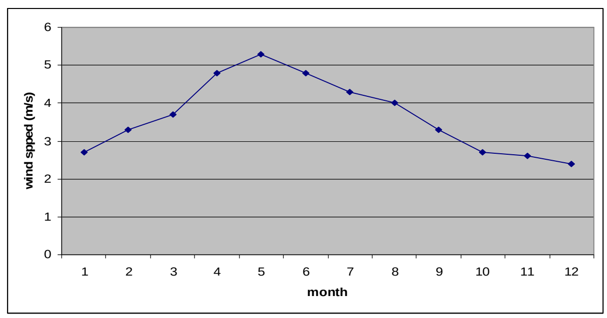



Fig 4: Monthly average Wind speed in Bechar (Algeria).

The crossover rate is 0.85. The mutation rate is 0.05. Number of possible different wind types is 3, number of inverter types is 2. The wind turbine lifetime is 15 years. The inverter lifetime is 6 year. The effective interest rate considered is 3%. The wind price (< 5$kw_c$ ) is 10 Euro/$w_c$. The O&M cost of wind is 1 c€/Wc/year. The cost of the invertors is given related to power [10], [11], [12]:

$$C_{inv}(euro) = \begin{cases} 1178 \ \rightarrow if\ , P_{inv} \le 1kvA \\ 1074\ .P_{inv} + 104 \ \rightarrow if\ ,1kvA \prec P_{inv} \le 4kvA \\ 500\ .(P_{inv} - 4) + 4400 \ \rightarrow if\ , P_{inv} \succ 4kvA \end{cases}$$

(18)

The developed method was used to calculate the optimum number of wind turbine and titles for a stand-alone wind system of the Bechar cite, Algeria. Wind speed data for Bechar obtained from the National Meteo ONM were utilized. The Simulation was specified at the value of 1 year. The load of typical house in Bechar cite, profile plot is shown in Fig.6.[7]

ISSN 2278-3083

**International Journal of Science and Applied Information Technology**, Vol.7. No.1, Pages : 17-22 (2017)
*Special Issue of ICSIC 2017 - Held during 23-24 September 2017 in Amman Arab University, Amman-Jordan*
***http://www.warse.org/IJSAIT/static/pdf/Issue/icsic2017sp03.pdf***

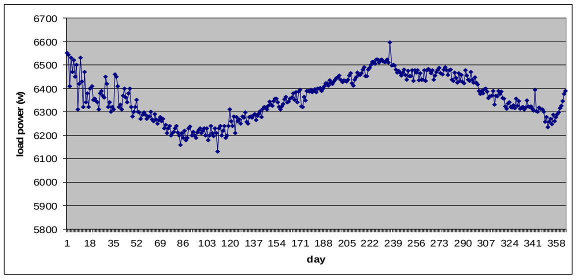


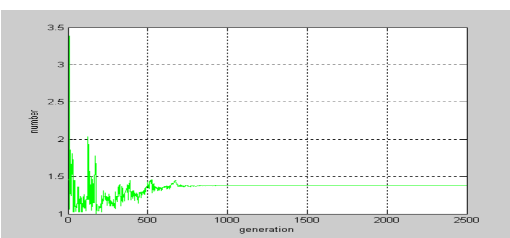

Fig.5

Load profile for one year.

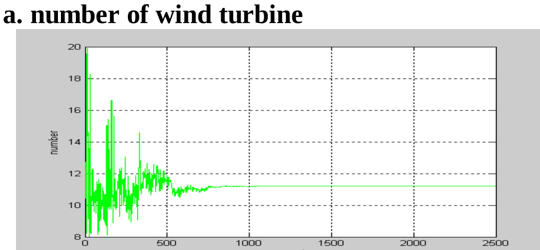
The highest load demand values occur in winter. Therefore, the higher of the wind generator was optimising for winter for the considered site. With the use of the program described in the former section, we calculated a series of possible combinations of the number of wind, higher and inverter. For a given unit price of turbine and machine, an optimum solution that minimizes the cost of the system was found. The optimum numbers of wind and higher as indicated in Fig.7.

The numbers of wind turbine and higher are determined previously. The Genetic Algorithm's results are [1.3, 11] with the total capital cost of wind system as 4715 Euro. The type wind turbine yields the lowest cost for the system.

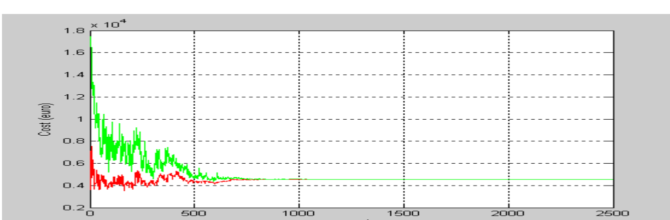
The optimal configuration is [2, 11]. The cost of Power Supply in the simulation is shown in Fig.7, and this is in accordance with the situation that both the solar energy and wind energy are abundant in summer at this location




**a. number of wind turbine**




**b. higher of turbine**




**c. Total cost (average 'green' and minimum 'read'),**

Fig.6. system cost

## I. Conclusions

A methodology of sizing standalone wind power systems using the genetic algorithm is proposed in this paper. Studies have proved that the genetic algorithm converges very well and the methodology proposed is feasible for sizing standalone wind power systems.

A procedure for optimizing the size of a wind-energy system was presented. The procedure was applied for the sizing of wind system that is considered to produce a power to domestic load in the Bechar area, Algeria. The analysis indicates that a wind system power output can be optimized to suit specific applications with variable or constant power loads. For the specific system considered in this study, the results indicate that the optimal wind system that resulted in the minimum capital cost is (2, 11).

A methodology of sizing standalone PV power systems using the genetic algorithm is proposed in this paper. Studies have proved that the genetic algorithm converges very well and the methodology proposed is feasible for sizing standalone PV power systems.

A procedure for optimizing the size of photovoltaic energy system was presented. The procedure was applied for the sizing of solar system that is considered to produce a domestic load in the Bechar, Algeria. The analysis indicates that a PV system power output can be optimized to suit specific applications with variable or constant power loads. For the specific system considered in this study, the results indicate that the optimal solar system that resulted in the minimum capital cost is 3540 euro.

## References

[1] E. J. R. Sambatra, G. Barakat, B. Dakyo, X. Roboam "Safety operation locations of PM synchronous machine for stand alone wind energy converter", *EPE'03*, CD-ROM, 2 - 4 September 2003, Toulouse, France

[2] J.K. Kaldellis, G.Th. Vlachos, "Optimum sizing of an autonomous wind–diesel hybrid system for various representative wind-potential cases", Applied Energy 83 (2006) 113–132.

[3] S.R. Vosen, J.O. Keller, "Hybrid Energy Storage Systems for Stand-Alone Electric Power Systems: Optimization of System Performance and Costs Through control Strategies," *International Journal of Hydrogen Energy*, Vol 24, No. 12, December 1999.

[4] L.A. Torres, F.J. Rodriguez, P.J. Sebastian, "Simulation of a Solar-Hydrogen-Fuel Cell System: Results for Different Locations in Mexico," *International Journal of Hydrogen Energy*, Vol. 23, No. 11, November 1998.

[5] Th.F. El-Shatter, M.N. Eskandar, M.T. El-Hagry, "Hybrid PV/Fuel Cell System Design and Simulation," *Renewable Energy*, Vol. 27, No. 3, November 2002.

[6] M. Wang, M. H. Nehrir, D. B. Nelson, "A Simulink-Based Model for a Stand-Alone Wind-Photovoltaic/Fuel Cell Generating System", *Proceedings*, NAPS 2001, Texas A&M University, College Station, October 15-16, 2001.

[7] B.S. Borowy, Z.M. Salameh, "Methodology for Optimally Sizing the Combination of a Battery Bank and PV Array in a Wind/PV Hybrid System", *IEEE Transactions on Energy Conversion*, Vol. 11, No. 2, June 1996.

[8] F. Giraud, Z.M. Salameh, "Steady-State Performance of a Grid-Connected Rooftop Hybrid Wind-Photovoltaic Power System with Battery Storage," *IEEE Transactions on Energy Conversion*, Vol. 16, No. 1, March 2001.

[9] F.M.A. Ghali, M.M. ADB El Aziz, F.A. Syam, "Simulation and Analysis of Hybrid Systems Using Probabilistic Techniques",

**ISSN 2278-3083**

**International Journal of Science and Applied Information Technology**, Vol.7. No.1, Pages : 17-22 (2017)
*Special Issue of ICSIC 2017 - Held during 23-24 September 2017 in Amman Arab University, Amman-Jordan*
***http://www.warse.org/IJSAIT/static/pdf/Issue/icsic2017sp03.pdf***

*Proceedings, Power Conversion Conference,* Vol. 2, Nagaoka, Japan, Aug 3-6, 1997.

[10] W.D. Kellogg, M.H. Nehrir, G. Venkataramanan, V. Gerez, “Generation Unit sizing and Cost Analysis for Stand-Alone Wind, Photovoltaic, and Hybrid Wind/PV Systems,” *IEEE Transactions on Energy Conversion*, Vol. 13, No. 1, March 1998.

[11] E. Riensche, U. Stimming, G. Unverzagt, “Optimization of a 200 kW SOFC Cogeneration Power Plant, Part I: Variation of Process Parameters”, *Journal of Power Sources*, Vol. 73, No. 2, June 1998.

[12] R. Chedid, H. Akiki, S. Rahman, “A Decision Support Technique for the Design of Hybrid Solar-Wind Power Systems”, *IEEE Transactions on Energy Conversion*,Vol. 13, No. 1, March 1998.

[13] M.T. Iqbal, “Simulation of a Small Wind Fuel Cell Hybrid Energy System,” *Renewable Energy*, Vol. 28, No. 4, April 2003.

[14] Richard W. Wies, Ron A. Johnson, Ashish N. Agrawal, ‘Simulink Model for Economic Analysis and Environmental Impacts of a PV With Diesel-Battery System for Remote Villages’, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 20, NO. 2, MAY 2005

## AUTHORS’ INFORMATION

Ali benatiallah was born in Adrar, Algeria, in 1966 , he received M.Sc, and Ph.D. degrees in electrical engineering from technology University of Oran, Algeria. Currently, he is working toward professor at ADRAR University, Algeria, head of energy laboratory and dean of science technology faculty.. His current research interests are photovoltaic system study, wind system, electrical system optimization, and modeling simulation of power system,