# Optimal sizing study of hybrid wind/PV/diesel power generation unit using genetic algorithm

I. Tegani and A. Aboubou
MSE Laboratory,
Mohamed khider Biskra University, Algeria
i.tegani@mselab.org

M. Becherif
FCLab FR CNRS 3539
FEMTO-ST UMR CNRS 6174, UTBM
Belfort, France
mohamed.becherif@utbm.fr

M.Y. Ayad
Industrial Hybrid Vehicle Applications
France
ayadmy@gmail.com

O. Kraa and M. Bahri
MSE Laboratory,
Mohamed khider Biskra University, Algeria
o.kraa@mselab.org
m.bahri@mselab.org

O. Akhrif
GREPCI Research Group, Ecole de Technologie Supérieure, Montréal, QC, Canada.
ouassima.akhrif@etsmtl.ca

*Abstract*— **A methodology of sizing optimization of a stand-alone hybrid wind/PV/diesel energy system with battery storage is addressed in this article. The aim is to find the optimal number of units guaranteeing that the life time round total system cost/emission is minimized subject to the constraint that the load energy necessities are completely covered. The system is optimized using genetic algorithms and the formulation of the problem is detailed. The optimization focusses on the total system cost and the reduction of $Co_2$ emission for the given hybrid design. Finally, an optimal configuration is obtained with a lifetime of 20 years. The optimized parameters are also given.**

***Keywords- Genetic algorithm; hybrid; wind; photvoltaic; diesel; optimization; sizing; stand-alone; total system cost; emission.***

## I. INTRODUCTION

Alternative energy resources such photovoltaic (PV) and wind generator (WG) power sources are extensively used in order to supply power to consumers in isolated areas. However, the common disadvantage with photovoltaic and wind energy is their intermittence nature and dependence on weather changes [1]. Therefore, such systems are usually equipped with diesel generators to meet the requirement load demand during the system's life time. Hybrid systems which contain a diesel generator, often have a lower installation cost than renewable-only systems [2]. On the other hand the lower cost of energy's hybrid system usually involves higher gas emissions.

A several researches have been performed for the optimal design of hybrid PV/WG/diesel systems [3–4]. Alternative energy sources such as PV/WG systems are unpolluted, free and renewable. But the high capital cost made its progress a slow one. In recent years, thanks to the advance materials, better engineering developments have decreased their capital costs making them more attractive. Another way to try to decrease the cost of these systems is by using the hybrid designs that use wind, photovoltaic and diesel combination.

In fact, a various researches have been performed on the optimization of the hybrid renewable-energy/diesel systems [5–6, 7]. Furthermore, many approaches have been employed to reach the optimization objective [9-10, 11]. So, the problem is on defining which structure will be the most cost effective while supplying demand, also which structure will provide the most reduction of $Co_2$ emission. This paper presents an optimization methodology to design hybrid PV-wind-diesel for stand-alone systems using genetic algorithm (GA) in order to find the most effective manner to use wind, solar energy and diesel generator at the lowest possible cost and $CO_2$ emission.

## II. STRUCTURAL DESIGN OF THE HYBRID SYSTEM

The model of the hybrid PV–wind power generation system includes PV arrays, wind turbines, diesel generator, batteries bank, inverters, controllers, and other devices and cables. A representation diagram of the basic hybrid system is shown in Fig. 1. The PV array, wind turbine and diesel generator deliver power to reach the load demand. Once the generated power by the PV-wind-diesel sources meets the load demand, this energy will be oriented to supply the batteries until it is

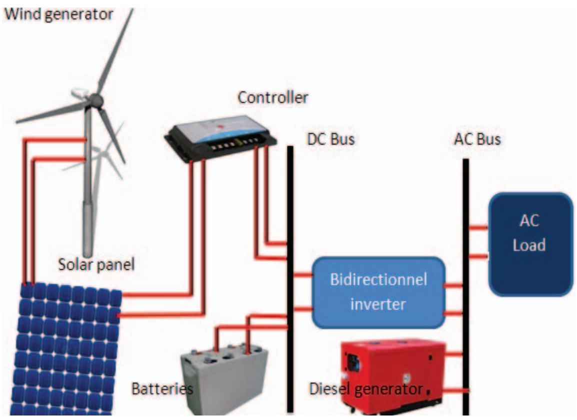


Figure 1. PV–wind-diesel-batteries stand-alone hybrid system

completely charged. In the other case, when energy generated by PV-wind-diesel sources is less than the load demand, the batteries will help to supply the power lack and support the power generated from the principal source until energy stored in batteries is depleted.

978-1-4673-6392-1/13/$31.00 ©2013 IEEE

## III. Optimization Formulation

The strength of the GAs algorithms is to guarantee the global optimum; generally all the meta-heuristic algorithms find the better solutions [14]. In this study, the objective function of the PV-wind-diesel system design is the total design cost $C_T$ which involves the total capital cost $C_{cpt}$ and the total maintenance cost $C_{Mtn}$ and $CO_2$ emission (COE). To minimize the total design cost $C_T$ and COE using the GA, the general form of the objective function should be expressed as follows:

$$\text{Minimize: } f(x) \quad (1)$$

$$\text{Subject to: } g(x) = 0 \quad (2)$$

$$H(x) \leq 0 \quad (3)$$

Where, $f(x)$ is the objective function; $g(x)$ is the equality constraints and $H(x)$ is the inequality constraints.

According to the equations (1), (2) and (3), the mono-objective optimization problem can be expressed as follows:

$$\text{Minimize } C_T = C_{cpt} + C_{Mtn} \quad (4)$$

$$\text{Minimize } ECO = YCO \times \left(\frac{N_g \times L \times D_L}{8760}\right) \quad (5)$$

Where ECO is the $CO_2$ emission in (kg) , YCO is the yearly $CO_2$ produced in (kg) and (8760) represent the total hours in a year

$D_L$ is the diesel engine lifespan (hours) and $L$ is the lifespan of the system. $N_g$ is a decision variable which is the number of diesel generator.

Subject to:

$$\sum_1^{24} (P_{pv}^t \times \Delta t) + \sum_1^{24} (P_{wind}^t \times \Delta t) \geq \sum_1^{24} (P_{dmd}^t \times \Delta t) \quad (6)$$

$$\text{total wattage installed} \leq \sum_d P_{inv} \times N_{inv} \quad (7)$$

$$\text{photovoltaic maximum power STC} \leq \sum_e P_{contr} N_{contr} \quad (8)$$

Where,

$$P_{pv}^t = N_{pv} \times P_s^t \quad (9)$$

And

$$P_{wind}^t = N_{wind} \times P_w^t \quad (10)$$

$N_{pv}$ is a decision variable which is the number of the solar panels and $P_s^t$ is the power generated by each solar panel at time t. It can be obtained using insolation data and insolation-power characteristic curve [10]. The $P_{wind}^t$ is the power generated by wind turbine, $N_{wind}$ is a decision variable which is the number of wind turbine and $P_w^t$ is the power generated by each wind turbine can be obtained using wind speed data, turbine hub height correction function, and wind speed-power characteristic curve [10].

To calculate the total wattage installed, one should sum all the power of all the loads.

$$\text{total wattage installed} = \sum P_{\text{loads}} \quad (11)$$

$P_{inv}$ is the maximum power that can be supplied by the inverter and $N_{inv}$ is a decision variable which represents the number of the required inverters.

### A. Photovoltaic panels sizing

The initial capital cost (ICC) of PV system may vary from 6000 \$/kW to 10.200 \$/kW [15-16]. In this work, the model of KYOCERA KD215-LPU with a cost of 322 \$/panel have been chosen, where the PV maximum power is 215W under the Standard Test Conditions (STC: Irradiance 1000W/m2, AM1.5 spectrum, ambient temperature of 25°C). Operational and maintenance (O&M) cost for PV array is considered 0.5 cent/kWh and its lifetime is of 20 years.

### B. Wind turbines sizing

A vast range of wind turbines is available. Capital costs for a commercially available wind turbines range is from 1500\$ for the size of 1kW to 3 500 000\$ for the size of 1800 kW [17-18]. In this analysis wind turbine cost is taken to be 17.681, 25\$/kW, the model of API-10kW with blades diam 3-7.0m and height 16m has been used. Operation and maintenance costs for the wind turbine are considered to be equal to 2 cents/kWh and its lifetime is of 20 years.

### C. Converters sizing

The converter cost may vary from 200 \$/kW to 6500 \$/kW. The cost used in the current work is of 3597 \$/kW for bidirectional inverter model of 48/220-10kW and a life time of 20 years. The efficiency of converting the direct current to alternative one of most inverters is of 90 percent or more. Many inverters claim to have higher efficiencies but for this study the efficiency that will be used is of 90%.

In the case of a stand-alone system, the number of inverters can be calculated as follows

$$N_{inv} = \frac{P_{load}}{P_{inv}} \quad (12)$$

Where, $P_{load}$ is the maximum continues power load, and $P_{inv}$ is the maximum power that can be supplied by the inverter.

### D. Batteries sizing

The Surrette 12CS11Ps (12 V, 375 Ah) storage batteries are utilized in this system. Cost of one battery is 1300 \$ with a replacement cost of 900 \$. The battery stack may contain a number of batteries (0, 4, 6, 8, 10, 15, 20, 25, 30 or 32). The usage% of the battery rated capacity is of 80% and the battery's rated capacity is 4.28kW/h. The life time of the Surrette 12CS11Ps is 10 years.

The batteries number can be determined by the following function [10]:

$$N_{batt} = Roundup\left[\frac{S_{req}}{\rho \times S_{batt}}\right] \quad (13)$$

Where, $S_{batt}$ is the rated capacity of each battery and $\rho$ is usage % of rated capacity which guarantees battery's life span.

$S_{req}$ is the required storage capacity, which can be calculated by the following equation:

$$S_{req} = \Sigma_{t=1}^{\max t}\left(P_{pv}^{t} + P_{wind}^{t} + P_{g} - P_{dmd}^{t}\right)\times\Delta t - \Sigma_{t=1}^{\min t}\left(P_{pv}^{t} + P_{wind}^{t} + P_{g} - P_{dmd}^{t}\right)\times\Delta t \quad (14)$$

Where $P_g$ is the output diesel generator (kW), $\max t$ is the time when the energy generated is at the maximum; $\min t$ is the time when the generated energy is lowest; and $\Delta t$ is the unit of time (here it's considered 1 hour). $P_{dmd}^{t}$ is the power (kW) demanded at time t.

*E. Controller sizing*

MPPT controller sizing consists in calculating the number of MPPT controllers necessary for the PV system. In small PV system, one controller may be sufficient to supply the demand, but for larger PV system more controllers may be needed. The controller output voltage rating must be equal to the nominal battery voltage. Also the Maximum PV voltage should be less than the maximum controller voltage rating.

The number of the MPPT controller required can be calculated by the following function:

$$N_{contr} = \frac{P_{\max pv}}{P_{\max cntr}} \quad (15)$$

Where

$$P_{\max pv} = \text{photovoltaic maximum power STC} \times \mathrm{N}_{\mathrm{pv}} \quad (16)$$

And $P_{\max cntr}$ is the controller maximum power.

Also the controller maximum power can be calculated by the following function:

$$P_{\max \text{contr}} = V_{batt} \times I_{contr} \quad (17)$$

Where $V_{batt}$ is the voltage of the battery pack.

And $I_{contr}$ is the max current that controller can handle from the PV system to the battery pack.

*F. Diesel generator :*

kg of $CO_2$ is considered to measure the pollutant gas emissions, because it represents the larger percentage of all gas's emissions when fuel combusts [21]. In this study, the total quantity (in kg) of $CO_2$ produced by the diesel generator throughout the system life time is shown in equation (5), it can be used as the second mono-objective to be minimized.

The developed algorithm has as input data the following values:

TABLE I. THE DIESEL GENERATOR PARAMETERS

| Parameter | Value |
|---|---|
| DIESEL GENERATOR RATED POWER ( KW) | 30 |
| DIESEL GENERATOR COST ($/KW) | 800 |
| DIESEL FUEL PRICE ($/L) | 1.73 |
| DIESEL ENGINE LIFE (HOURS) | 24000 |
| YEARLY FUEL CONSUMPTION (LITER) | 5708.5 |
| YEARLY $CO_2$ PRODUCED (kg) | 14271 |

However, the total capital cost takes place in the establishment of a project at the beginning, contrary the maintenance cost which occurs along the project life. Therefore, costs at different times cannot be directly compared, and a discount factors that convert a monetary cost at one time to an equivalent value at another time is used [12, 13]. The initial capital cost I is converted into annual capital cost A using the following capital-recovery factor:

$$C_{conv} = \frac{i(1+r)^{L}}{(1+r)^{L} - 1} \quad (18)$$

Where, (L) is the life span of the system and (r) is the annual interest rate.

The total capital cost in equation (1) can be expressed by the following function:

$$C_{cpt} = C_{conv} \times \sum_{a} C_{pv} \times N_{pv} + \sum_{b} C_{w} \times N_{w} + \sum_{c} C_{batt} \times N_{batt} + \sum_{d} C_{inv} \times N_{inv} + \sum_{e}\left(C_{contr} \times N_{contrv}\right) + \sum_{f}\left(N_{dv} \times \left(Cgen + (C_{f} \times Y_{f}\right)\right) \quad (19)$$

Where, $C_{pv}$ , $C_{w}$ , $C_{batt}$ , $C_{inv}$ , $C_{contr}$ , $C_{gen}$ are the costs of solar panel, wind turbine, battery, inverter, MPPT controller and the diesel generator respectively. And $C_{f}, Y_{f}$ are the diesel fuel price and the yearly fuel consumption respectively.

Also, the maintenance cost in the eq. (1) can be:

$$C_{Mtn} = \left(C_{mtn}^{pv} \times \sum_t^{24} (P_{pv}^t \times \Delta t)\right) \times 365 + \left(C_{mtn}^{wind} \times \sum_t^{24} (P_{wind}^t \times \Delta t)\right) \times 365 \quad (20)$$

Where, $C_{mtn}^{pv}$ is the maintenance cost (kWh) for PV array; and $C_{mtn}^{wind}$ is the maintenance cost (kWh) for wind turbine.

## IV. THE GA'S SIZING OPTIMIZATION METHODOLOGY

In the sizing design optimization, there are a lot of variables and parameters that have to be considered. Therefore, the sizing of the hybrid PV–wind-diesel system is much more complicated than the single source power producing system. This type of optimization includes economic objectives. Hence, in order to reach the optimal system configurations for the minimization of a cost objective function and $CO_2$ emission, the GA is used.

The basic algorithm by which GAs operate is reasonably well established. GA is inspired by the evolutionary theory explaining the origin of species. In nature, weak and unfit species within their environment are faced with extinction by natural selection.

The strong ones have greater opportunity to pass their genes to future generations via reproduction. In the long run, species carrying the correct combination in their genes become dominant in their population. Sometimes, during the slow process of evolution, random changes may occur in genes.

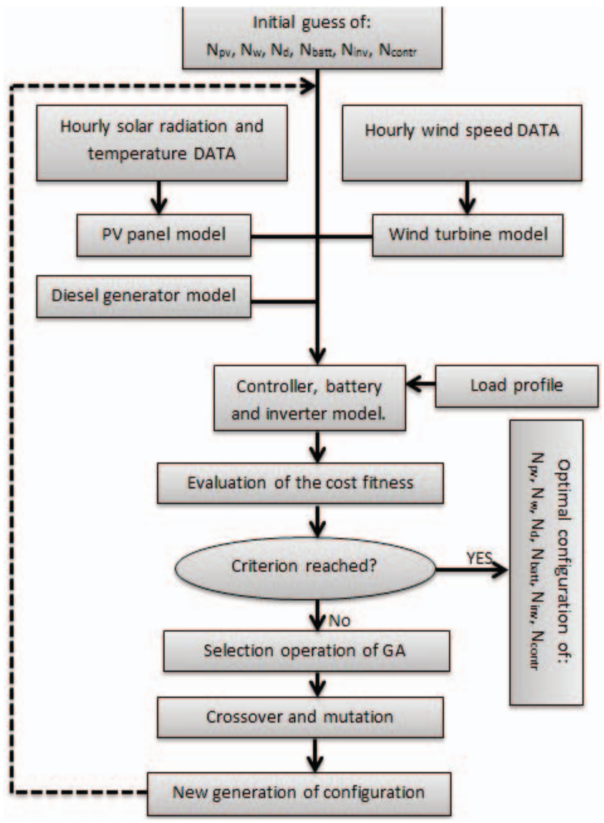


Figure 2. Flowchart of the optimal sizing design PV-wind using GA.

If these changes provide additional advantages in the challenge for survival, new species evolve from the old ones. Unsuccessful changes are eliminated by natural selection.

These algorithms encode a potential solution to a special problem on a simple chromosome like data structure and apply recombination operators to these structures so as to preserve critical information.

A general block diagram representing the cost optimization methodology with (GA) is shown in Figure. 2. The optimization algorithm have a database containing the technical and economical (prices) characteristics of the commercially devices used in the system with their associated per unit maintenance costs. The type of PV module and WG, battery with nominal capacity, inverter type etc., are stored in the input database.

The next step of the optimal sizing procedure consists of a method employing GAs, which dynamically searches for the system configuration, usually; the GA uses three operators (selection, crossover and mutation) to imitate the natural evolution processes. The first step of a genetic evaluation is to determine if the chosen system configuration passes the functional evaluation, provides service to the load where the system constraints are satisfied by the initial configuration. A population of strings (called chromosomes or the genotype of the genome), which encode candidate solutions (called individuals, creatures, or phenotypes) to an optimization cost problem, is evolved toward better solutions. The evolution usually starts from a population of randomly generated individuals, and happens in generations. In this work, it is chosen to determinate an initial population, where all the decision variables have been defined with specified values. In each generation, the cost fitness or the emission fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their cost/emission fitness), and modified (recombined and randomly mutated) to form a new population. The new population is then used in the next iteration of the algorithm. The lowest objective fitness value obtained at the previous iterations is considered to be the optimal solution for the minimization problem in this iteration.

This optimal solution is replaced by better solutions, if any, produced in subsequent GA generations during the program evolution. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory cost fitness level has been reached for the population.

## V. RESULTS AND DISCUSSION

The proposed method has been applied to the design of a stand-alone hybrid PV-WG-diesel system in order to power supply an AC loads.

In this study the loads is considered as a small isolated area constituted of few houses located in Algeria.

To estimate energy consumption, one needs to determine the average daily electrical energy used in watt hours as well as the total power demand in watts. The system will be more economical if high efficient, low power consumption loads are used.

To calculate the kWh that a type of load consumes in a day [19]:

$$\frac{Kwh}{Day} = \frac{N \times P_{Load} \times H_{day} \times D_{week}}{7} \quad (21)$$

The parameters of GA method proposed for the system are detailed as follow:

TABLE II. THE GA'S PROPOSING PARAMETERS

| Parameter | Value |
|---|---|
| CROSSOVER PROBABILITY | 0.9 |
| MUTATION PROBABILITY | 0.08 |
| SELECTION METHOD | "ROULETTE" |
| GENERATION NUMBER | 100 |
| POPULATION SIZE | 80 |
| CROSSOVER METHOD | TWO-POINTS |
| VARIABLES TYPE | INTEGER |

Hybrid solar–wind-diesel systems usually meet well load demands well because of the good complementary effect of the solar radiation and wind speed, also fuel consumption.

The simulation results have been divided to two cases, in the first one, when the example was solved as a mono-objective optimization to minimize the total cost design, the optimal solution for the cost of the system was US$47,550.339, with $N_d = 2$ and COE=58,1066.990(Kg).

The optimal solution vector is as follows:

TABLE III. THE OPTIMAL SIZING RESULTS (CASE ONE-A)

| Variable type | Value |
|---|---|
| PV | 82 |
| WG | 15 |
| DIESEL GENERATOR | 2 |
| MPPT CONTROLLER | 25 |
| BATTERY | 40 |
| INVERTER | 5 |
| TOTAL COST US$ | 47,550.339 |
| $CO_2$ EMISSION VALUE(KG) | 58,1066.990 |

Therefore, in order to make a more realistic optimization for the system problem, the output wind power was reduced to 75% of its original power as follows:

$$P_w^t = 0.75 \times P_w^t \quad (22)$$

The optimal solution vector is as follows:

TABLE IV. THE OPTIMAL SIZING RESULTS (CASE ONE-B)

| Variable type | Value |
|---|---|
| PV | 100 |
| WG | 14 |
| DIESEL GENERATOR | 2 |
| MPPT CONTROLLER | 30 |
| BATTERY | 40 |
| INVERTER | 5 |
| TOTAL COST US$ | 45,394.821 |
| $CO_2$ EMISSION VALUE(kg) | 58,1066.990 |

In the second case, the example was solved as a mono-objective optimization to minimize the $CO_2$ emission; furthermore in this second case, the output wind power was reduced to 75% of its original power. The optimal solution for the cost of the system was US$51,947.958, with $N_d = 0$ and COE=0 (kg).

The optimal configurations are shown as follows:

TABLE V. THE OPTIMAL SIZING RESULTS (CASE ONE-B)

| Variable type | Value |
|---|---|
| PV | 100 |
| WG | 16 |
| DIESEL GENERATOR | 0 |
| MPPT CONTROLLER | 30 |
| BATTERY | 47 |
| INVERTER | 5 |
| TOTAL COST US$ | 51,947.958 |
| $CO_2$ EMISSION VALUE(kg) | 0 |

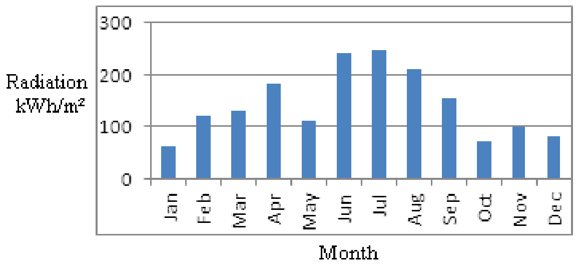


Figure 3. Beam radiation on horizontal surface kWh/m² for city of Biskra (Algeria).

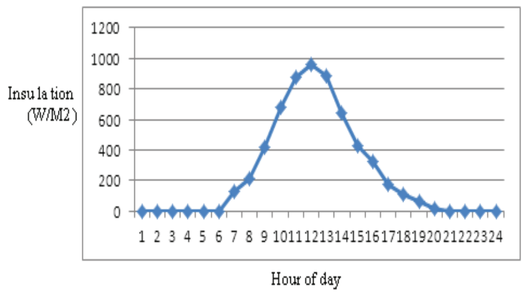


Figure 4. Solar radiation in 24 hours.

Figure. 1 shows the beam radiation on horizontal surface kWh/m² for city of Biskra (Algeria) [20]; Figure. 5 shows the annual average solar power generated by each solar panel; Figure. 6 shows the annual average wind power generated by each wind turbine.

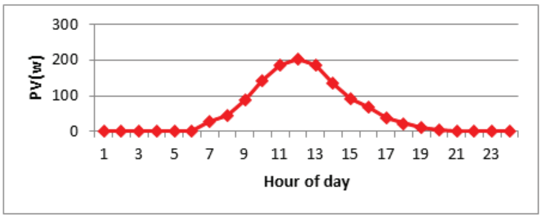


Figure 6. Average hourly power generated by a solar panel in a day.

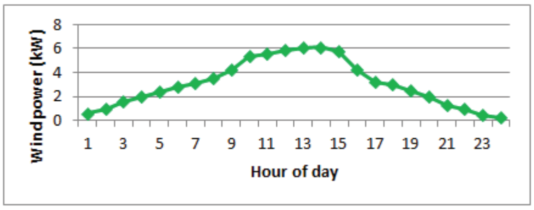


Figure 7. Average hourly power generated by a wind turbine in a day.

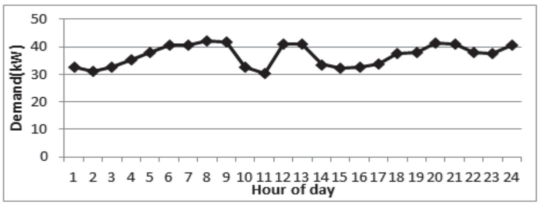


Figure 5. Average hourly electrical demand in a day.

## VI. CONCLUSIONS

In this paper, a methodology for optimal sizing design of stand-alone PV-WG-Diesel system has been presented. Using the genetic algorithm, the purpose of the proposed methodology is the selection of the optimal number of PV modules, WGs, diesel generator and batteries, the MPPT controllers and the inverters, so an attempt is made to explore the possibility of utilizing power of the wind and solar radiation to reduce the gas's emission dependence on fossil fuel to meet the energy requisite of a small stand-alone system.

It is shown in the present study that the uses of diesel generator causes an important $Co_2$ emission, in the other hand, the total cost design is reduced. It was also shown that in the case of using only renewable energies for the corresponding hybrid system; cost turns out to be too high.

In this work the optimal number of each system component is calculated such that the 20-years round total system cost/emission is minimized subject to the constraint that the load power requirements are completely covered. The 20-years round total system cost is equal to the sum of the respective components capital and maintenance costs. For the both total system cost and gas's emission the objective-function minimization is implemented using genetic algorithms, when compared to conventional optimization methods, such as dynamic programming and gradient techniques, have the aptitude to attain the global optimum with relative computational simplicity. The proposed method is applied to the design of a hybrid PV-wind-Diesel power generation system in order to supply a residential household. The results verify that hybrid PV-WG-Diesel systems result in lower system cost compared to cases where either only WG-PV sources are used.

## REFERENCES

[1] A. Kaabeche, M. Belhamel, R. Ibtiouen, "Sizing optimization of grid-independent hybrid photovoltaic/wind power generation system" Energy vol. 36 issue 2 February, 2011. p. 1214-1222

[2] R. D. López, J. L. Bernal-Agustín, J. M. Yusta-Loyo, J. A. Domínguez-Navarro, I. J. Ramírez-Rosado, J. Lujano, I. Aso "Multi-objective optimization minimizing cost and life cycle emissions of stand-alone PV–wind–diesel systems with batteries storage" Applied Energy, Volume 88, Issue 11, November 2011, p. 4033-4041

[3] J. L. Bernal-Agustín,R. Dufo-López, D. M. Rivas-Ascaso, "Design of isolated hybrid systems minimizing costs and pollutant emissions". Renew Energy 2006;31(14):2227–34.

[4] D. Saheb-Koussa,M. Haddadi,M. Belhamel. "Economic and technical study of a hybrid system (wind–photovoltaic–diesel) for rural electrification in Algeria". Appl Energy 2009;86:1024–30.

[5] J. G. McGowan, J. F. Manwell. "Hybrid wind/PV/diesel system experiences". Renew Energy 1999;16(1–4):928–33.

[6] M. A. Elhadidy, "Performance evaluation of hybrid (wind/solar/diesel) power systems". Renew Energy 2002;26(3):401–13.

[7] M. A. Elhadidy,S. M. Shaahid. "Promoting applications of hybrid (wind+photovoltaic+diesel+battery) power systems in hot regions". Renew Energy 2004;29(4):517–28.

[8] A.G. Dutton ,JAM. Bleijs,H. Dienhart,M. Falchetta,W. Hug, D. Prischich,AJ. Ruddell."Experience in the design, sizing, economics, and implementation of autonomous wind-powered hydrogen production systems". Int J Hydrogen Energy 2000; 25(8):697–793.

[9] SM. Moghaddas-Tafreshi,SM. Hakimi. "Optimal sizing of a stand-alone hybrid power system via particle swarm optimization for Kahnouj area in south-east of Iran", 2009. Renewable Energy 2009; 34:1855–62.

[10] Z. W. Geem ."Size optimization for a hybrid photovoltaic–wind energy system".Electrical Power and Energy Systems 42 (2012) 448–451.

[11] H. X Yang,L. Lu,W. Zhou, "A novel optimization sizing model for hybrid solar–wind power generation system".2007 Solar Energy 81 (1), 76–84.

[12] LW. Mays,YK. Tung. "Hydrosystems engineering and management". New York: McGraw Hill; 1992.

[13] ZW. Geem. "Harmony search optimization to the pump-included water distribution network design". Civil Eng Environ Syst 2009; 26(3):211–21.

[14] ZW. Geem. "Harmony search in water pump switching problem. Lect Notes Comput" Sci 2005; 3612:751–60.

[15] M. Beccali,S. Brunone,M. Cellura,V. Franzitta. "Energy, economic and environmental analysis on RET-hydrogen systems in residential buildings". Renewable Energy March 2008; 33:366e82.

[16] B. E. Türkay,A. Y. Telli. "Economic analysis of standalone and grid connected hybrid energy systems". Renewable Energy 36 (2011) 1931e1943.

[17] K. Alphen,GJH. Sark,M. Hekkert . "Renewable energy technologies in Maldivesdetermining the potential". Renewable and Sustainable Energy Reviews Oct 2007; 11:1650e74.

[18] GJ. Dalton ,DA. Lockington,TE. Baldock. "Feasibility analysis of stand-alone renewable energy supply options for a large hotel". Renewable Energy July 2008;33:1475e90.

[19] Solar Energy International, "Photovoltaic Design and Installation Manual", New Society Publishers, 2007.

[20] R. E. Sonntag,C. Borgnakke,G. J. V. Wylen. Fundamentals of thermodynamics, 6th ed. New York: Wiley; 2002.