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Multi-objective optimization of hybrid PV/wind/diesel/battery systems for decentralized application by minimizing the levelized cost of energy and the CO_2 emissions

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The main objective of this paper is to propose a methodology to design and optimize a stand-alone hybrid PV/wind/diesel/battery minimizing the Levelized Cost of Energy (LCE) and the CO_2 emission using a Multi-Objectives Genetic Algorithm approach. The methodology developed was applied using the solar radiation, temperature and the wind speed collected on the site of Potou located in the northwestern coast of Senegal. The LCE and the CO_2 emission were computed for each solution and the results were presented as a Pareto front between LCE and the CO_2 emission. These results show that as the LCE increases the CO_2 emission decreases. For example, the solution A (left solution on the Pareto front) presents 2.05 €/kWh and 11.89 $kgCO_2$/year, however the solution E (right solution on the Pareto front) shows 0.77 €/kWh and 10,839.55 $kgCO_2$ /year. It was also noted that the only PV/battery or Wind/ battery was not an optimal configuration for this application on the site of Potou with the use of the load profile and the specifications of the used devices. For all solutions, the PV generator was more adapted to supply the energy demand than the wind turbines.

Key words: Hybrid system, optimization, genetic algorithm, cost of energy, CO_2 emission.

INTRODUCTION

The scarcity of conventional energy resources, the rise in the fuel prices and the harmful emissions from the burning of fossil fuels has made power generation from conventional energy sources unsustainable and unviable. It is estimated that this supply demand gap will continue to rise exponentially unless it is met by some other means of power generation. Further, inaccessibility of the grid power to the remote places and the lack of rural

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electrification have prompted to use other sources of energy (Prabodh and Vaishalee, 2012). In the remote regions, far from the grids, electric energy is usually supplied using diesel generators. In most of cases, supplying demand energy using diesel fuel is so expensive and increases the amount of CO_2 emitted. So, renewable energy resources (e.g. solar and wind energies) have become the better alternatives for conventional energy resources. However, the use of a single renewable energy source such as wind energy or solar energy is not adequate to meet the demand for long periods due to the intermittent nature of the renewable energy high, the cost of system as well as storage subsystem (Ayong et al., 2013; Bekele and Palm, 2010; Diaf et al., 2008 ; Ekren-O and Ekren- by, 2010; Kalantar and Mousavi, 2010; Kanase-Patil et al., 2011; Saheb-Koussa et al., 2009; Zhou et al., 2010). To meet this challenge, the renewable sources such as wind and solar energy can be used in combination with the conventional energy systems making a hybrid PV/wind/diesel/battery system. These kinds of systems could allow dropping the investment, operation and the maintenance costs of systems (Colle et al., 2004).

Hongxing et al. (2009); Kyoung-Jun et al. (2013); Mukhtaruddin et al. (2015) have designed PV/wind hybrid systems coupled or now to battery bank and diesel generator by using different methods. A performance and feasibly study of hybrid renewable hybrid system coupled to batteries was done in the work of Kyoung-Jun et al. (2013); Ajay et al. (2011); Suresh-Kumar and Manoharan (2014) and Ismail et al. (2014, 2013). However, in the most case, the system was PV/diesel, PV/wind or PV/wind/batteries system. Also, in these studies, the type of devices was not taking into account in the optimization.

Several others studies on the feasibility, performance, and economic viability of hybrid power systems have been conducted using Homer (Hybrid Optimization Modeling Software) in the works of Chong et al. (2013); Bahtiyar (2012); Mir-Akbar et al. (2011); Sanjoy and Himangshu (2009); Patrick et al. (2014); Ahmad et al. (2010); Rohit and Subhes (2014); Ahmed et al. (2011); Zeinab et al. (2012); Mei and Chee (2012); Dalton et al. (2009); Belgin and Ali (2011); Eyad (2009); Alam and Manfred (2010) and Muyiwa et al. (2014). With the use of Homer, the best hybrid renewable energy configuration is which have the lower cost. However, Homer does not take into account the number of components such as variable. Also, Homer uses the monthly meteorological data variation (solar and wind speed). With the hourly solar and wind speed variation, the configuration chosen is more adapted to supply the demand.

Iterative methods of optimization have used to minimize the Annualized Cost of System (ACS) (Yang et al., 2008, 2007, 2003; Yang and Lu, 2004; Diaf et al., 2008; Shen, 2009; Kellogg et al., 1998; Koutroulis et al., 2006). These methods made possible to study the optimization and the performance of a hybrid system. In the works of Duffo-Lopes and Bernal- Agustin (2005, 2008); Senjyu et al. (2007); Ekren and Ekren (2008) and Hongxing et al. (2009), authors have studied the performance of hybrid systems using genetic algorithms minimizing the cost of the system. The methods outlined in these works did not take into account all devices of the system such as wind turbine, PV module, regulator, battery, inverter and diesel generator. Ould Bilal et al. (2010) have designed and optimized hybrid PV/wind/battery systems minimizing the ACS and the Loss of Power Supply Probability (LPSP). The authors did not take into account the diesel generator. So, the CO_2 emission was not evaluated. Since the presented problem is a Multi-objective Optimization Problem (MOP), it requires a multi-objective method for solving. This paper utilizes a Pareto-based approach which can obtain a set of optimal solutions instead of only one (Mohammad et al., 2014). The objectives to be minimized in this paper are the levelized cost of energy and the CO_2 emission.

The developed methodology was applied using the solar radiation, temperature and the wind speed collected in the site of Potou located in the northwestern coast of Senegal. The decision variables included in the optimization process are the number of PV modules, the number of wind turbines, the number of batteries, the number of regulators, the number of inverters, the number of diesel generators and the type of each device.

APPROACH AND METHODOLOGY

Hybrid solar-wind-diesel power generation system coupled to the battery bank consists of a PV module, wind turbine, diesel generator, regulator, battery bank and an inverter. A schematic diagram of the basic hybrid system is shown in Figure 1. The PV module and the wind turbine work together to meet the load demand. When the energy sources (solar and wind energy) are sufficient, the generated power, after meeting the load demand, provides energy to the battery up to its full charge. The battery supplies energy demand to help the system to cover the load requirements, when energy from renewable energy is inferior to the load demand. The load will be supplied by diesel generators when power generation by both wind turbine and PV array is insufficient and the storage is depleted. The mathematical model of the components used in this study are detailed by the Ould Bilal et al. (2012a, b).

In this paper, the Levelized Cost of consumed Energy (LCE) was considered. We do not consider the cost of the energy generating because, in the remote village, most of the energy generated was lost. For example, if the PV generator or wind turbine generator produces energy during an hour when the electrical load is zero and the batteries are fully charged, then the energy produced was lost. In addition to that, the energy is also lost in the charge and discharge processes of the batteries.

OBJECTIVE FUNCTIONS

The objectives function to be minimized is the LCE and the pollutant emission (kg of CO_2 which is the main cause of the

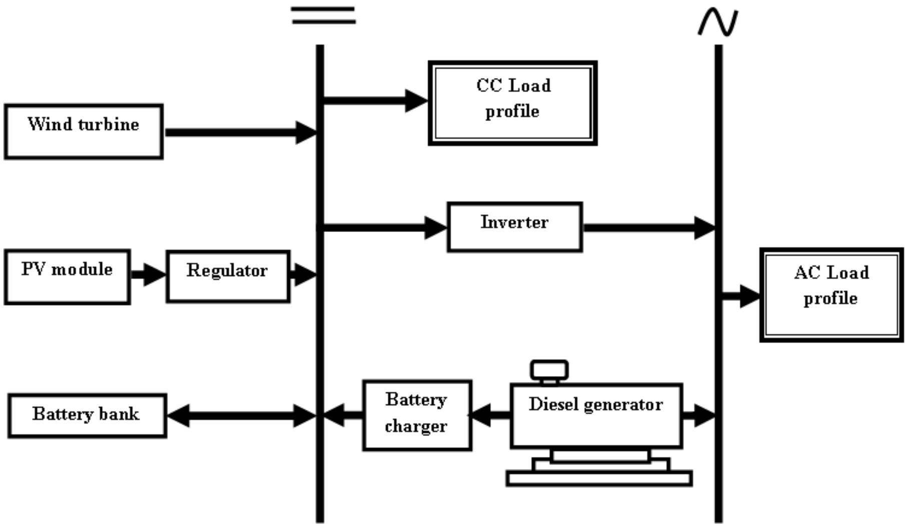

Figure 1. Bloc diagram of the hybrid solar/wind/diesel/battery system.

greenhouse effect).

Economic model based on LCE concept

The optimal combination of a hybrid solar-wind-diesel-batteries system can make the best compromise between the system pollutant emission and the total cost of energy. The economical approach, according to the concept of LCE is developed to be the best benchmark of system cost analysis in this study. According to the studied system, the LCE is composed of the capital levelized cost C_{acap}, maintenance and operation levelized cost C_{amain} and the replacement levelized cost C_{arep}.

Six devices of the hybrid system were considered: PV module, wind turbine, diesel generator, battery, regulator and inverter. The levelized cost of the kWh/year is defined as in Equation (1).

$$ACE = \frac{J(x)}{E_{annual}} \qquad (1)$$

J(x) is the levelized cost of energy given by Equation (2).

$$J(x) = C_{acap}(x) + C_{amain}(x) + C_{arep}(x) \qquad (2)$$

Where E_{annual} is the annual consumed energy (kWh/year), $x=[N_{pv},N_{ag},N_{dg},N_{rg},N_{bt}, N_{inv,pv},T_{pv}, T_{ag},T_{dg},T_{bt},T_{rg},T_{in}]$ is the decision vector of variables. Where T_{pv}, T_{ag}, T_{dg}, T_{bt}, T_{rg}, T_{in} are the types of PV module, wind turbine, diesel generators, batteries, solar regulators and inverters. C_{acap}, C_{amain} and C_{arap} are the levelized capital cost, levelized maintenance cost and the levelized replacement cost.

Pollutant emissions

The parameter considered in this paper to measure the pollutant emission is the (kg of CO_2). It represents the large percentage of the emission of fuel combustion (Sonntag et al., 2002). Further, CO_2 represents the main cause of the greenhouse effect. So, we evaluate the amount of the CO_2 produced by the diesel generator in the PV/wind/ diesel/battery system. The fuel consumption of the diesel generator depends on the output power. It is given by Equation (3).

$$Cons = B \cdot P_{NG} + A \cdot P_{OG} \qquad (3)$$

A=0.246 l/kWh and B=0.08145 l/kWh are the coefficient of the consumption curve, defined by the user in (l/kWh) (Belfkira et al., 2011). The factor considered in this work to assess the emission of CO_2 was 3.15 kgCO_2/l (Fleck and Huot, 2009).

System optimization model using multi-objectives genetic algorithm

The main objective of this work is to design and optimize hybrid PV/wind/diesel/battery systems by minimizing the LCE and the CO_2 emission. These objectives are antagonist e.g. the increase of the LCE implies the decrease of the CO_2 emission and vice versa. So, it is important to find an efficient way to solve this Multi-Objective Problem (MOP) which parameters are also independent. The Multi-Objective Genetic Algorithm, which has the important characteristics of the concept of optimal Pareto front (Coello et al., 2002) can be used to solve this problem. A Pareto front is a set of a possible solution obtained after a search process.

The Multi-Objective function used in this study was implemented by employing genetic algorithm (GA) developed by Leyland and Molyneaux (Leyland, 2002; Molyneaux, 2002). This tool was designed for the optimization of the engineering energy systems. That is generally non-linear and uses a statistical technique of grouping of the individual basis on the independent variable (creation of the families which evolves in independent manner). This method has the advantage of maintaining the diversity of the population and making coverage the algorithm towards optima even difficult to find (Sambou, 2008).

Multi-objective solution strategy

Multi-objective problem (MOP) refers to the simultaneous optimization of multiple conflicting objectives, which produces a set of solutions instead of one particular solution while some constraints should be met. In fact, most of time, we find a set of solutions, owning to the contradictory objectives. MOP can be formulated (Mohammad et al., 2013 ; Azizipanah-Abarghooee et al., 2012; Anvari Moghaddam et al., 2011) as:

$$\text{Minimize} \quad F(X) = \left(F_1(X),\ F_2(X), \ldots,\ F_{Nobj}(X)\right) \tag{4}$$

Subject to $u_i(X) < 0$, i=1, 2,…, H and $v_{i(}X) < 0$, i=1, 2,..., H
Where, Fi is the ith objective function, X is a determination vector that presents a solution, N_{obj} is the number of objectives. L and H are the number of the equality and the inequality constraints, respectively. In our cas $N_{obj} = 2$.

Operation system strategy

The PV generator and the wind turbine outputs are calculated according to the PV modules and the wind turbine system model by using the specifications of the PV module and the wind turbine as well as the solar radiation, the temperature and the wind speed data. The battery bank with the total nominal capacity φ_r is permitted to discharge up to a limit defined by the minimum state of charge. For a good knowledge of the real state of charge (SOC) of a battery, it is necessary to know the initial SOC, the charge or discharge time and the current. However, most storage systems are not ideal, losses occur during charging and discharging and also during storing periods (Hongxing et al., 2009). Taking these factors into account, the SOC of the battery at time t + 1 can be calculated by Equation (5).

$$SOC\,(t+1) = SOC\,(t)\cdot\left(1 - \frac{\sigma\cdot\Delta t}{24}\right) + \eta_{bt}\cdot\frac{P_{bt}(t)\cdot\Delta t}{U_{bt}\cdot\varphi_{bt}} \tag{5}$$

Where σ is the self-discharge rate which depends on the accumulated charge and the battery state of health (Guasch and Silvestre, 2003) and a proposed value of 0.2% per day is recommended, η_{bt} is the battery charging and discharging efficiency. It is difficult to measure separate charging and discharging efficiency, so manufacturers usually specify roundtrip efficiency. In this paper, the batteries charge efficiency is set equal to 80%, and the discharge efficiency is set equal to 100% (Duffos Lopes et al., 2005). U_{bt} (V) is the nominal batteries voltage, which is equal to the nominal system operating voltage and P_{bt} (t) is the power received by the battery from generators or requested by the demand. The minimum state of charge of the battery bank (SOC_{min}) can be expressed by Equation (6).

$$SOC_{\min} = (1 - DOD)\cdot SOC_r \tag{6}$$

Were DOD (%) is the depth of discharge and SOC_r is the rated state of charge of the battery bank. In our case, the DOD assumed equal to 60%. So, the minimum state of charge (SOC_{min}) that the battery bank can achieve is of 40% SOC_r.
The input/output battery bank power can be computed according to the following strategy:

(i) If $PT(t) = \frac{P_{ch}(t)}{n_{ond}}$, all the produced energy is consumed by the demand. So $P_{bt}(t)=0$

(ii) If $PT(t) > \frac{P_{ch}(t)}{n_{ond}}$, then the surplus of power $P_{bt}(t) = PT(t) - \frac{P_{ch}(t)}{n_{ond}}$ is used to charge the battery. The new battery state of charge is then calculated by using the Equation (5)

(iii) if $PT(t) < \frac{P_{ch}(t)}{n_{ond}}$, then the lack of power $P_{bt}(t) = PT(t) - \frac{P_{ch}(t)}{n_{ond}}$ is provided by the battery. The new battery state of charge is calculated by using the Equation (5).

(iv) if $PT(t) < \frac{P_{ch}(t)}{n_{ond}}$ and the battery bank are depleted ($SOC=SOC_{min}$) or the energy providing from the battery bank is not enough to supply the load, then the diesel generators supply needed by the load and the surplus energy (if any), is used to charge the battery bank (Gupta et al., 2011). PT (t) is he total output power of the wind turbine and PV module generators (Ould Bilal et al., 2012a, b). The initial assumption of system configuration will be a subject to the following inequalities constraints:

$$\begin{cases} SOC_{\min} \le SOC \le SOC_{\max} = SOC_r \\ I_{\max} \le I_{rrg} \\ P_{\max} \le P_{rond} \end{cases} \tag{7}$$

Where: SOC_{min} and SOC_{max} are the minimum and the maximum of the state of charge of the battery bank, I_{max} is the maximum current delivered by the PV generated, I_{rrg} is the nominal current of the designed regulators (A), P_{max} is the maximum power of the demand and P_{rond} is the nominal power of the inverter (W).

Application on the site of Potou in Senegal

Presentation of the site

The methodology developed was applied using the solar radiation, the temperature and the wind speed collected for eight month on the site of Potou (16.27° of longitude West, 14.3° of latitude North and 21 m of altitude) located in the Northwestern coast of Senegal. This region is characterized by a wind potential adapted to small wind turbines (about 0. 2 to 10 kW) on the one side and on the other side, this region is characterized by a very sunny weather which can be used to produce energy with the use of PV module.

In this area an anemometer, a pyranometer and temperature sensor have been installed to collect the solar radiation, temperature and the wind speed. A data acquisition system was used to record the parameters every one second. Then, the data are averaged over 10 min intervals and was recorded in the memory of the datalogger. The used data were averaged over each one hour. Results presenting the real distribution and the theoretical distribution of Weibull of the mean wind speed are shown in Figure 2. Figure 3 shows the hourly radiation for a typical day on the site of Potou. The wind power density and the solar energy are 95 W/m² and 3.90 kWh/m²/d respectively.

Load profile

The daily load profile is represented by a sequence of powers and it is considered as constant over a time-step of 1 h. The used load profile (Figure 4) denotes the consumption of a typical isolated town which fluctuation during the day corresponds to the operation of public and domestic equipments (refrigerators, television, radio, domestic mill, welding machines, sewing machine and other equipment). The peak of demand observed at night corresponds to the use of the domestic equipment (refrigerators, lighting, television, radio) and some commercial equipment (refrigerator and lighting in

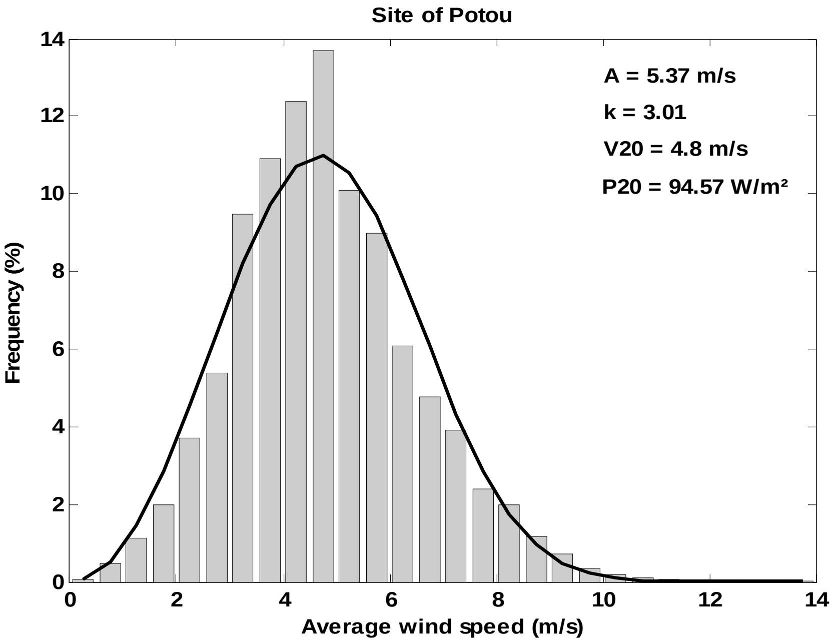

Figure 2. Real distribution and Weibull distribution on the site of Potou.

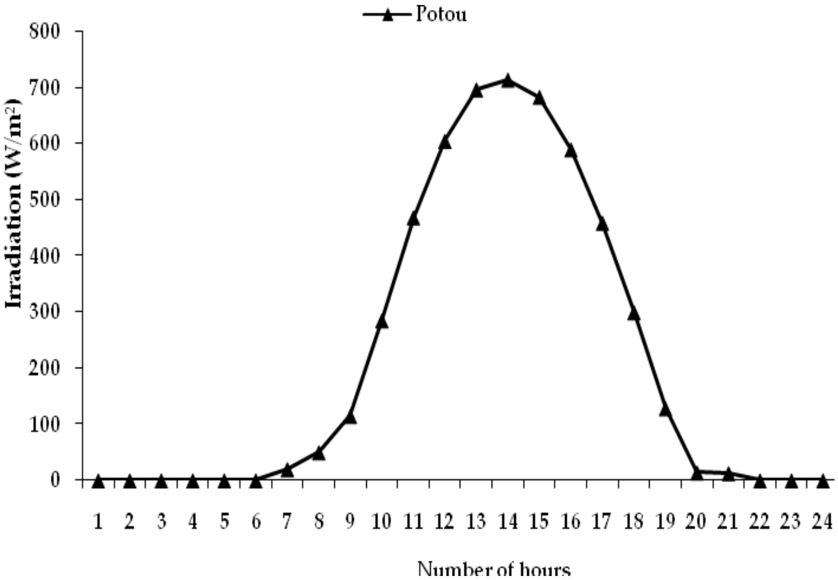

Figure 3. Solar Irradiation profile on the site of Potou.

the shops). The light and the television are the main element used overnight in the remote village. The total consumption energy of the used load profile is 94 kWh/d.

Components characteristics

The specifications of the components used to design and optimize hybrid PV/wind/diesel/battery are presented in Table 1. Five types of wind turbines and four types of: PV modules, batteries, regulators, inverters and diesel generators were used respectively.

RESULTS AND DISCUSSION

The optimization of PV/wind/diesel generator/battery hybrid systems by minimizing the LCE and the CO_2

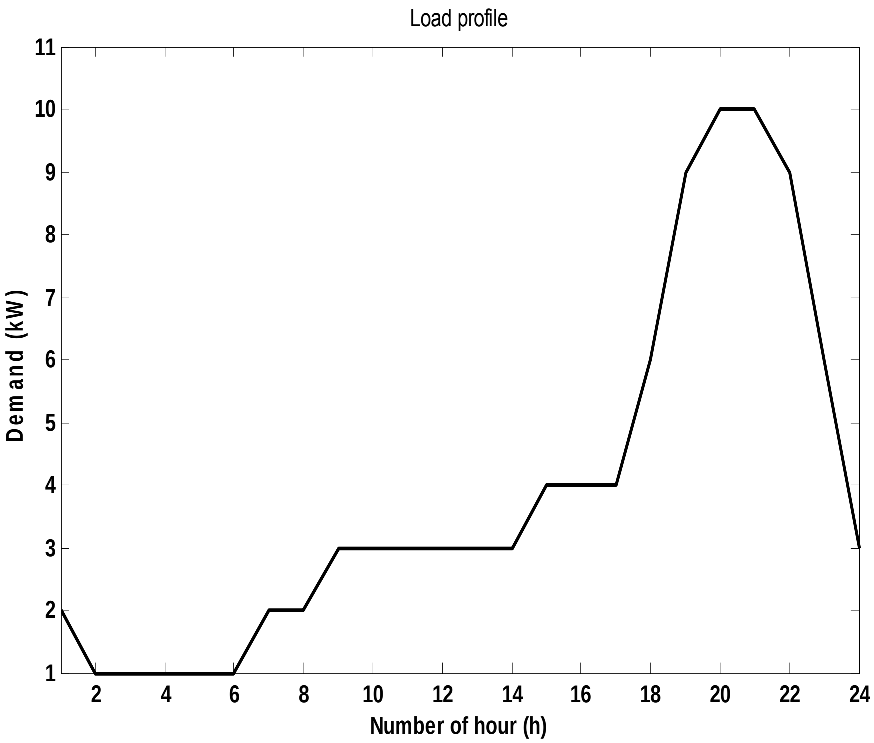

Figure 4. load profile of the demand energy.

emission were carried out by using multi-objectives genetic algorithm approach. Obtained results have appeared as an optimal Pareto front. Every solution of the best Pareto front was formed by a combination of hybrid systems and control strategy, with a different LCE and the pollutant emission.

Figure 5 shows the optimal Pareto front between the LCE and the CO_2 emission. It was noted that the increasing of LCE implies the decreasing of the CO_2 emission. To illustrate the results given by Figure 5, five solutions (A, B, C, D and E) on different position of the Pareto front curve were indicated.

Table 2 depicts the size and the output energy of these five optimal solutions. It can be noted that the optimal type of the PV module, wind generator, battery bank, regulator, inverter and diesel generator was respectively the N°4, N°5, N°3, N°1, N°3, N°1 and N°3. It is, also, possible to note that the LCE decreases by 27 and 40% while passing from the solution A to solutions B and C respectively. That is because of the diminution of the components numbers of the system, specially the PV modules and the wind turbines in the systems. In the contrast, the diesel generator was more solicited, thus, the operation hours of diesel generator increases. For example the operations hours of the diesel generators pass from 6 h to 31 and to 119 h when the solution passes to B and C from A. So, the CO_2 emission increases by 89.40 $kgCO_2$/year and by 750.19 $kgCO_2$/year respectively when the solutions pass to B and to C from A. From Table 2, it can be seen as the PV modules and wind turbines decrease, the size of diesel generator increases. It can be also noted that the output energy from the wind turbine was lower (with fraction of 46% for the solution-A, 11% for the solution-B and 0% for the solution-C, D and E) compared to the output energy from PV generator. That can be explained by the higher potential of the solar and its variations which are more suitable to the variation of the load profile. The output energy from the diesel generators was lower for the solution A, B and C compared to solutions D and E. The highest fraction of the output energy observed for these three solutions was 16% observed for the solution C. The corresponding hours of operation was 119 h. However, the output energy from diesel generators was higher for the latest solutions (D and E) which are solutions without renewable energies (fraction of renewable energy was 0%). While, the amount of the CO_2 emitted was higher (4,870.37 and 10,839.55 $kgCO_2$/year respectively).

It can be noted from Table 2 that the battery bank was more solicited for the solution C (PV/diesel system). Figure 6 (solution-C) shows the distribution of the state of charge of this solution. It can be seen that the battery bank discharges up to 60 for 35% of the time. The lowest SOC was 43 observed for the solution-B, but this state of charge was observed for only 0.06% of time. The lowest average state of charge (SOC) was 75% observed for the

Table 1. Specifications of the components.

Specifications of the wind turbine						
Type of wind turbines	**Cut-in wind speed Vci (m/s)**	**Rate wind speed Vr (m/s)**	**Cut-off wind speed Vco (m/s)**	**Rated power Pr (W)**	**Output voltage (V)**	**Cost (€)**
1	2	9	12	500	48	3051
2	3.5	11	13	600	48	1995
3	3.5	12	12	1500	48	2995
4	2.5	14	25	5600	48	8870

Specifications of the PV module						
Type of of PV module	**Rate voltage (V)**	**Nominal peak power k (W)**	**Current of short-circuit ¶(A)**	**Voltage of open circuit (V)**	**Fill factor**	**Cost (Euro)**
1	12	75	4.70	21.50	0.74	590
2	12	80	5.31	21.30	0.71	540
3	12	100	6.46	20.00	0.77	559
4	12	150	8.40	21.60	0.74	900

Specifications of the batteries			
Type of batteries	**Nominal capacity (Ah)**	**Nominal voltage (V)**	**Cost (Euro)**
1	80	12	195
2	100	12	215
3	200	12	416
4	720	2	2059

Specifications of the regulators			
Type of the regulators	**Nominal current (A)**	**Nominal voltage (V)**	**Cost (Euro)**
1	30	48	230
2	40	48	250
3	45	48	289
4	60	48	295

Specifications of the inverters			
Type of the inverters	**Nominal power (W)**	**Nominal voltage (V)**	**Cost (Euro)**
1	3500	48	2799
2	2400	48	2165
3	4500	48	4185
4	5000	48	5350

Specifications of the diesel generators		
Type of diesel generator	**Nominal output power**	**Cost (Euro)**
1	3050	668
2	4000	862
3	4600	879
4	4860	895

solution-C and the highest (89%) was observed for the solution A. Figure 6 (solution-A), shows that the battery bank remain at the SOC 100% for 42% of time. So, the battery bank is less solicited. That allows the increasing of the lifetime of batteries, thus the diminution of the replacement cost of batteries.

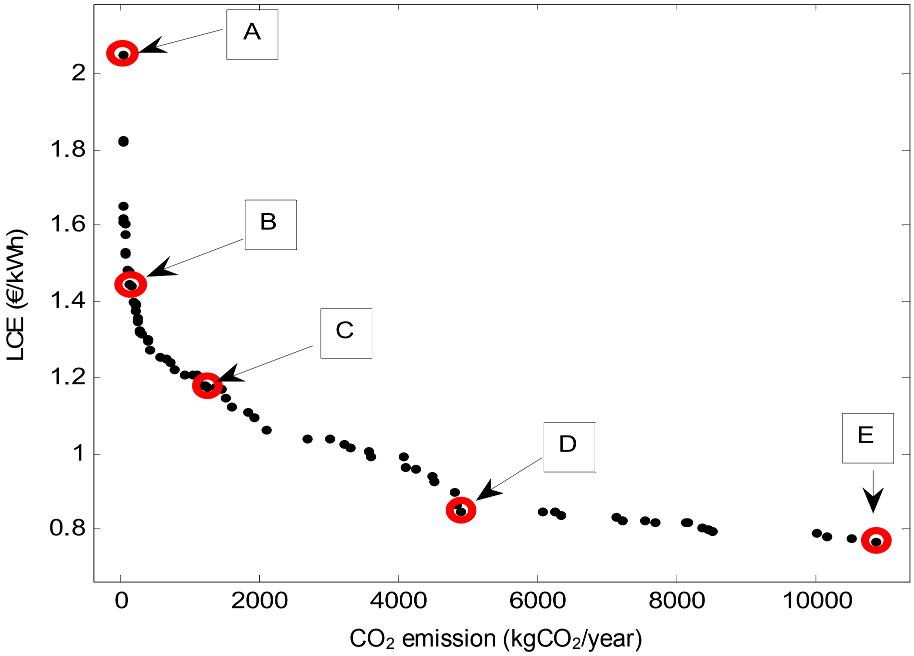

Figure 5. Optimal Pareto front of hybrid PV/wind/diesel/battery system

Table 2. Five solutions of the optimal pareto front.

Solution	Solution A	Solution B	Solution C	Solution D	Solution E
Number of PV modules	28	40	28	0	0
Number of Wind turbine	5	1	0	0	0
Number Batteries	60	60	64	48	24
Number of Regulators	2	3	2	0	0
Number of Inverters	5	5	5	5	5
Number Diesel generators	1	2	5	10	10
Type of Wind turbines	5	5	--	--	--
Type of PV modules	4	4	4	4	4
Type of Batteries	3	3	3	3	3
Type of Regulators	1	1	1	--	--
Type of Inverters	1	1	1	1	1
Type of diesel generators	3	3	2	3	3
Annual electrical energy delivered by PV generator (kWh/year)	26994.00	38563.00	26994.00	0.00	0.00
Annual electrical energy delivered by wind turbine (kWh/year)	23843.00	4768.60	0.00	0.00	0.00
Annual electrical energy delivered by diesel generator (kWh/year)	14.93	114.38	689.93	24102.70	25116.10
Annual operating hours of diesel (h)	6	31	119	4357	4589
Annual excess of energy (kWh/year)	28386.934	20980.38	5217.93	1636.70	2650.10
SCO_{min} (%)	56	43	55	61	60
Mean of SCO (%)	89	78	75	80	77
Annualized cost system of energy (€/kWh)	2.05	1.48	1.22	0.85	0.77
CO2 emission (kg CO2/year)	11.89	99.29	762.08	4870.37	10839.55

In order to highlight the hourly behavior of the obtained optimal configuration, the solution B (hybrid PV/wind/diesel/battery) has been used. A simulation was conducted on a period from 1st January to 19th February

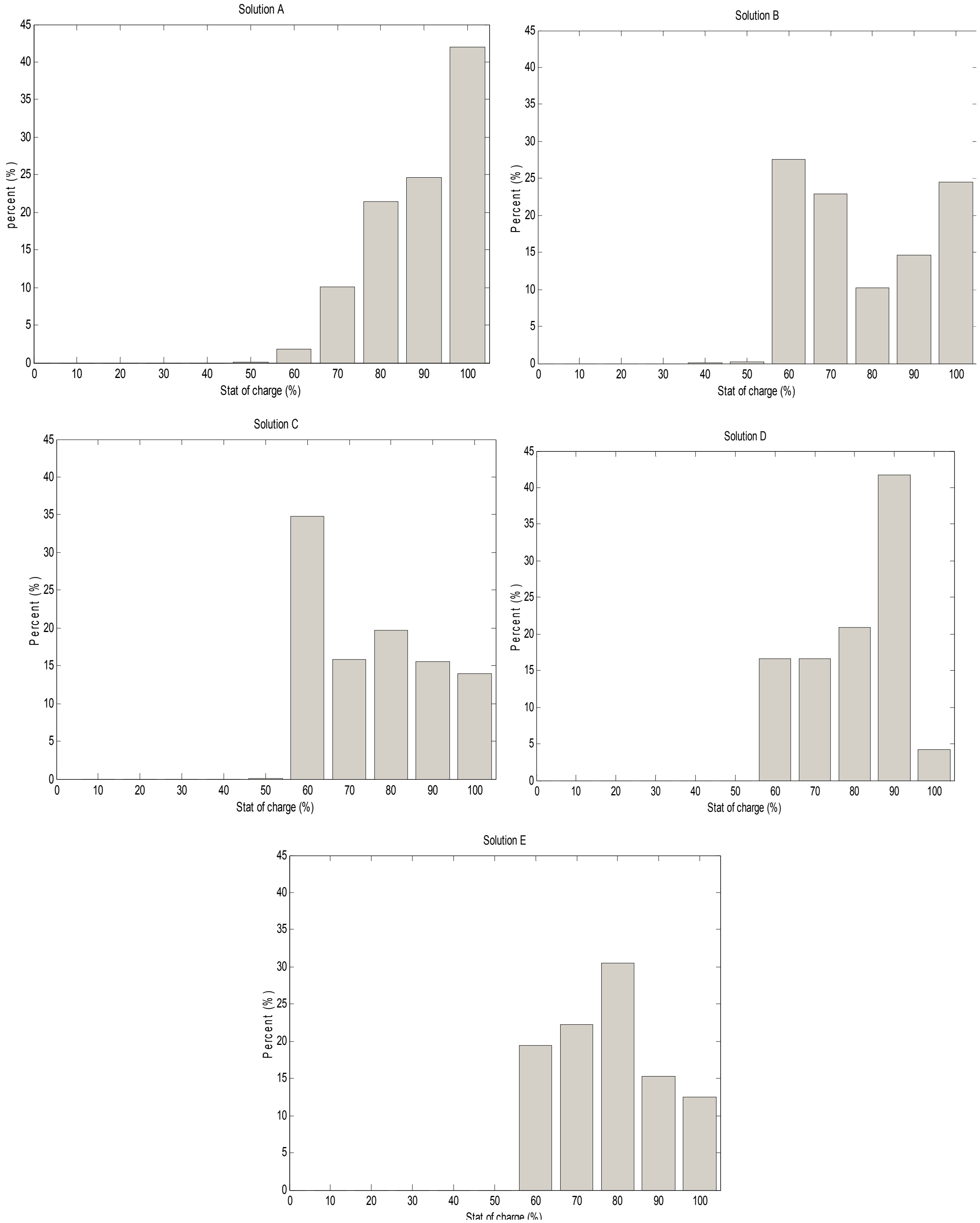

Figure 6. State of charge of the five solutions (A, B, C, D and E) of the Pareto front.

(12:00 hours) and is reported in Figure 7. Figure 7a, b, c and d show the output power from PV generator, wind turbine, the diesel generator and the output/input battery bank power. Figure 8 gives the state of charge of the battery bank for the indicated period.

According to the strategy denoted above and to the

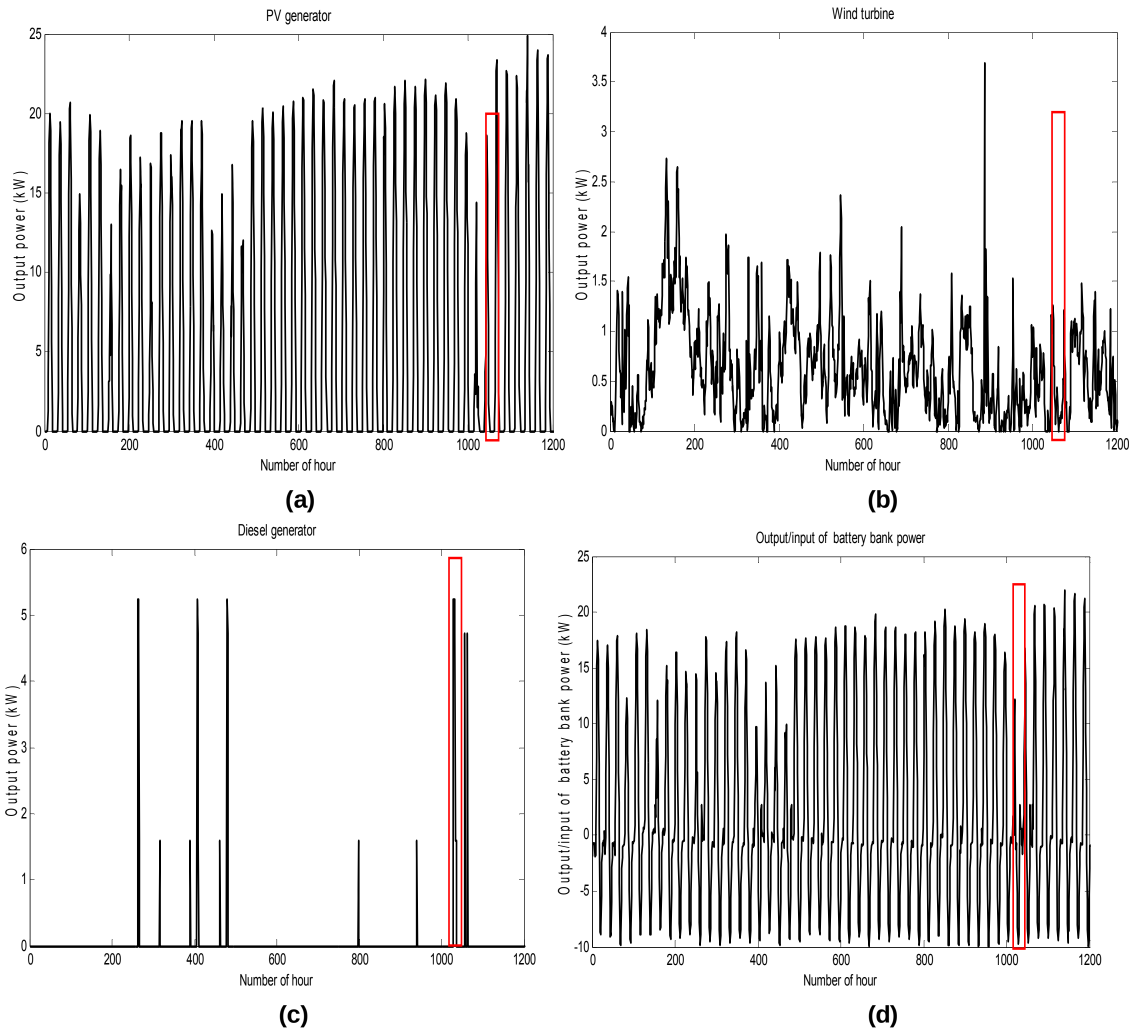

Figure 7. Behavior of the PV generator, Wind turbine, Diesel generator and the battery bank (solution B).

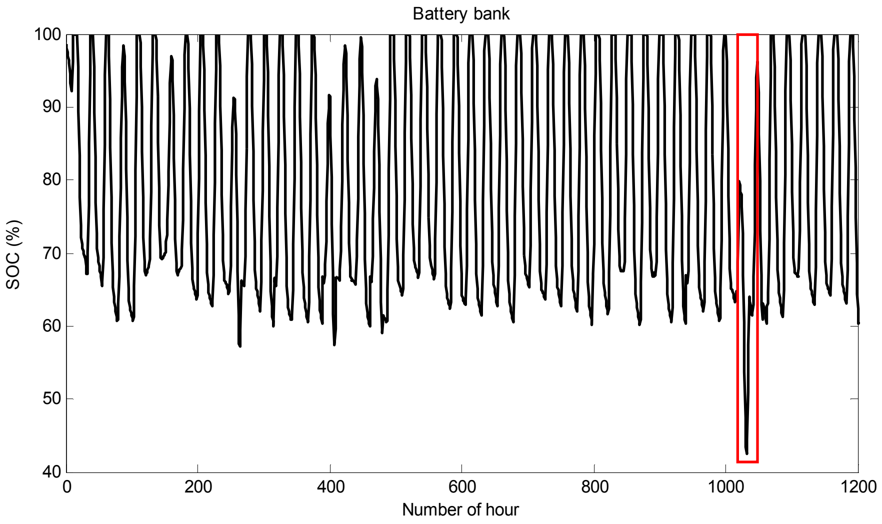

Figure 8. State of charge of the battery bank (solution B).

operation under the model constraints given by expression 7, it can be verified that, when the renewable sources power is greater than the power demand, the surplus power is stored in the battery bank, then $P_{bt} > 0$ (Figure 7a, b and d). When the renewable energy is smaller, the lack of energy is provided by the battery bank and or by the diesel generator (Figure 7c), then the $P_{bt} < 0$. Moreover, when the output energy from the PV generator and wind turbine is greater than the demand energy and the battery bank is fully charged then, the surplus of the energy produced can be used for the water pumping, water desalination, or to supply other demand of energy according to the needs of the village where the system is installed. From Figure 8, it can be seen that, the SOC remain between SOC_{max} (100%) and the SOC_{min} (40%). The minimum SOC achieved is 43% and observed for the 12th February at 23 h. In this hour of February day, it was noted 0 kW output energy from wind turbine and from PV generator. So the battery bank was deeply discharged and the diesel generator is operated to supply the load in the on hand and to charge the batteries in the other hand. The average of the SOC during this period of operations (1st January to 19th February) was 75% and the hour number of diesel generator time operation was 19 h.

Conclusion

The methodology for optimal sizing of multi-objective hybrid PV/wind/diesel/battery bank systems minimizing the LCE and the CO_2 emission by using a Genetic Algorithm approach was developed in this paper. The obtained results were depicted on the optimal Pareto front. From the results, we can outline the following points:

(i) The increasing of the LCE implies the decreasing of the CO_2 emission.
(ii) The LCE decreases by 27 and 40 % while passing from the solution A to the solutions B and C. In the contrast the CO_2 emission increases by 89.40 kgCO_2/year and 750.19 kgCO_2/year respectively when the solutions pass to B and C from A.
(iii) The PV generator was more solicited than the wind turbine generator for the hybrid PV/wind/diesel/batteries in the site of Potou. For the solutions, the highest fraction of the wind turbine was 46% observed for the solution A.
(iv) The only PV/battery or Wind/ battery were not an optimal configuration for this application on the site of Potou with the use of the load profile and the indicated specifications of the devices. It would be interested to perform modeling, incorporating the objectives of availability and reliability constraints of components to achieve a more accurate assessment of the cost of ownership system.

Conflict of Interest

The authors have not declared any conflict of interest.

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