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Techno-Economic Optimization of a Grid-Connected Hybrid Energy System Considering Voltage Fluctuation

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Abstract – This paper proposes an optimization approach of a grid-connected photovoltaic and wind hybrid energy system including energy storage considering voltage fluctuation in the electricity grid. A techno-economic analysis is carried out in order to minimize the size of hybrid system by considering the benefit-cost. Lithium-ion battery type is used for both managing the electricity selling to the grid and reducing voltage fluctuation. A new technique is developed to limit the voltage perturbation caused by the solar irradiance and the wind speed through determining the state-of-charge of battery for every hour of a day. Improved particle swarm optimization (PSO) methods, referred to as FC-VACPSO which combines Fast Convergence Particle Swarm Optimization (FCPSO) method and Variable Acceleration Coefficient Based Particle Swarm Optimization (VACPSO) method are used to solve the optimization problem. A comparative study has been performed between standard PSO method and PSO based methods to extract the best size with the benefit cost. A sensitivity analysis has been studied for different kinds and costs of batteries, by considering variable and constant state-of-charge of battery. The simulations, performed under Matlab environment, yield good results using the FC-VACPSO method regarding the convergence and the benefit cost of the hybrid system.

Keywords: Hybrid energy systems, Optimization, Storage system, State-of-charge, Voltage fluctuation

1. Introduction

Nowadays, renewable energy has gained widespread acceptance in several areas, predominantly photovoltaic (PV) and wind systems as grid-connected or autonomous system modes. Integration of storage energy battery to these hybrid systems is very important and necessary for storing energy and assuring system stability. Hybrid renewable energy systems (HRES) are designed for the electrical power generation using a combination of a number of power generation components e.g. wind turbine, PV and/or other conventional generators along with storage batteries. HRES capture the best features of each energy resource and can provide "grid-quality" electricity as well as improving the overall economy and reliability of renewable power generation to supply its load [1]. To precisely sizing the different devices of HRES, simulations of the system under real operating conditions, such as appropriate weather, insolation, wind speed and loads, are necessary [2-4].

Solar and wind powers are naturally intermittent. They can create technical challenges to the grid power supply, particularly when the amount of solar and wind power integration increases or the grid is not strong enough to handle rapid changes in generation levels. Hence, a combination of these two sources improves overall energy output, especially when they are connected to the grid. A proper optimization is required to ensure having optimal number and size of PV and wind turbine. A review of optimization of hybrid renewable energy system with more focus on wind and PV systems was carried out in [4,5] using different optimization methods, i.e., conventional, unconventional, hybrid and software tools used in optimum sizing of hybrid wind-solar systems. Reference [6] discussed the effect of voltage fluctuation of a grid-connected wind farm. Stored energy by vanadium redox flow type of battery was used and connected with the wind farm to control the stability and the power quality of the grid. Simulation and experimental results have demonstrated that the injected power to the grid is stable and does not fluctuate even the wind power was fluctuated. Nacer et al. [7] presented a techno-economic optimization of a solar/wind hybrid energy system connected to a grid for a cattle farm located in the north of Algerian desert. Using HOMER software, optimization of the net present cost of hybrid system was done and three scenarios were proposed to estimate system configuration relating its effect on techno-economic study of the farm. Kaabeche and Ibtiouen [8] improved an optimal sizing design through a repeated process to minimize the cost and the size of autonomous PV/wind/diesel/battery hybrid system. Simulation results have demonstrated that the hybrid

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PV/wind/diesel/battery system is an economical and reliable system than solar/wind/battery system and diesel generator alone. In reference [9], the authors studied an optimal control and sizing of stand-alone wind/PV/diesel system including battery storage energy. Particle swarm optimization (PSO) method was used to solve the optimization problem and compared with other improved based PSO algorithms. The obtained results were evaluated through an economic factor, the system cost, to treat the real-world system. Recently, Durairasan et al [10] proposed a new hybrid technique for locating and sizing of renewable energy like wind and PV in power system. The proposed method consists on the combination of performances of both the Biography Based Optimization (BBO) and PSO techniques. These techniques were used for optimizing the optimum location and capacity of the DG sources for radial distribution network. Initially, the availability of these sources was analyzed in the 24 hours using ANN technique. After that, the voltage, power and power loss were analyzed in the normal and faulty conditions. The optimal location and capacity of the DG sources were initially determined by using BBO, then the BBO input parameters were classified into the sub parameters and allowed as the PSO input. A PSO algorithm was used to find the optimum location and capacity of DG. Finally, the best results were taken among the techniques.

This paper presents a new optimization approach of a grid-connected HRES in which the battery energy storage system (BESS) is used for both managing the electricity selling to the grid, and preventing voltage fluctuation in the grid. Two strategy cases are considered: storage and selling energy. PSO metaheuristic method is used to solve the optimization problem, and then compared with other PSO based methods. The simulation is performed under Matlab environment. Data of wind speed and solar irradiation are extracted from the site of the Renewable Energy Development Center (CDER) in Bouzaréah City, situated at (36°48'N, 3°1'E, 345m), in north of Algeria.

2. Grid-connected Hybrid System Overview

A schematic diagram of grid-connected PV/wind hybrid system with battery storage energy is illustrated in Fig. 1. The overall hybrid system is linked to a common DC bus through a converter DC/DC for the PV array and AC/DC for the wind system in order to obtain the maximum power point. Another DC/DC converter is used for the battery system to regulate the DC bus voltage. An inverter DC/AC is connected between the interface of DC bus and the grid. The operation strategy system consists to inject power to the grid. The battery energy storage system (BESS) is used to charge and store energy produced by the PV/wind hybrid energy system and to discharge this energy in order to sell it to the utility.

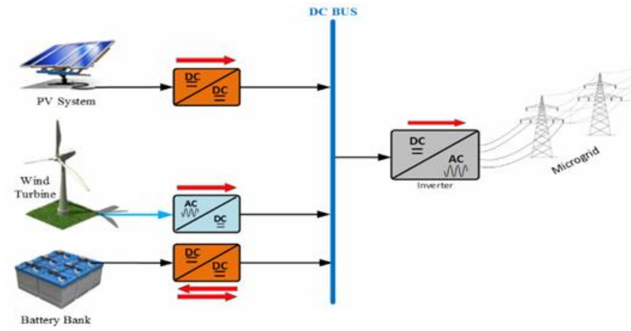

Fig. 1. Schematic diagram of grid-connected HRES

3. Modeling of Hybrid System

3.1 Photovoltaic system

Electric power, produced by the PV system, depends on the solar irradiance affected by weather conditions. It is computed using the following expression [11, 12]:

$$P_{pv} = P_{\max,ref} \times \frac{G_T}{G_{T,ref}} \left[1 + \gamma\left(T_c - 25\right)\right] \quad (1)$$

where G_T is the solar irradiance in the current time step (Wh/m^2), $G_{T,ref}$ is the solar irradiance at reference of 1000Wh/m^2, P_{pv} is the output power of PV array (kW), $P_{\max,ref}$ is the maximum power at $G_{T,ref}$ of PV array (kW); γ is the temperature coefficient of maximum power, taken to be -0.0035 $^{\circ}$C; and T_c is the ambient temperature (°C).

3.2 Wind system

The output electric power of a wind turbine can be expressed by the following set of equations [13-15]:

$$P_w = \begin{cases} 0 & v_w < v_{ci}, v_w > v_{co} \\ P_{w,\max} \times \left(\dfrac{v_w - v_{ci}}{v_p - v_{ci}}\right)^3 & v_{ci} \le v_w < v_p \\ P_{w,\max} + \left(v_w - v_p\right)\left(\dfrac{P_{f0} - P_{w,\max}}{v_{co} - v_p}\right) & v_p \le v_w \le v_{f0} \end{cases} \quad (2)$$

where $P_{w,\max}$, P_{f_0} are the output powers at rated and cut-out speeds (kW); P_w is the output power of wind turbine (kW) ; v_{ci}, v_{co} , v_p are respectively cut-in, cut-out and rated wind speeds (m/s); v_w is the wind speed at the height of the wind generator hub h_{hub} , estimated by:

$$v_w = v_{w,meas}\left(\frac{h_{hub}}{h_{meas}}\right)^{\alpha} \quad (3)$$

$v_{w,meas}$ is the wind speed measured at the reference height h_{meas} , (m/s); α depends on temperature, time of day, season and pressure , and is taken to be 0.14 [16].

The power, generated by the hybrid system, is given by:

$$P_{hyb} = N_w \left(\frac{P_{wr}}{P_{gw}} \right) P_w + N_{pv} \left(\frac{P_{pr}}{P_{gp}} \right) P_{pv} \tag{4}$$

where N_w, N_{pv} are respectively the numbers of wind and PV systems; P_{wr} , P_{pr} , P_{gw} , P_{gp} are rated power and generated power of wind generator and PV array in kW.

3.3 Battery energy storage system

A BESS is used for managing the energy between the HRES and the micro-grid. It stores energy, consumes it when the grid needs, reduces voltage fluctuation and ensures system stabilization. To achieve this last benefit, an average power, in kW, of a HRES is calculated for n observations by:

$$\overline{P}_a = \frac{1}{n} \sum_{i=1}^{n} \left(P_{hyb} \right)_i \tag{5}$$

The energy of the battery, in kWh, can be written as:

$$E = \left(P_{hyb} - \overline{P}_a \right) \Delta t \tag{6}$$

The minimum and maximum values of the battery's state-of-charge are given by:

$$\begin{aligned} SOC_{\min} &= \frac{E_{\min}}{N_b C_{db}} \\ SOC_{\max} &= 1 - \left(\frac{E_{\max}}{N_b C_{db}} \right) \end{aligned} \tag{7}$$

where N_b is the number of batteries; C_{db} is the battery capacity (kWh) and $E_{\max} = \max(E)$; $E_{\min} = \min(E)$.

4. Voltage Fluctuation

The use of PV and wind systems may cause a voltage fluctuation since they are influenced by weather conditions. The voltage perturbation can lead to instability of the entire grid. An estimation of voltage change through the power line is computed, in percent (%), by the following equation:

$$dv = \frac{R \Delta P + X \Delta Q}{V^2} \times 100\% \tag{8}$$

where R is the resistance of grid (Ω), X is the inductive reactance of grid (Ω), ΔP and ΔQ are active and reactive power variations (kW), V is voltage of the grid (V).

5. System Strategy and Energy Management

The operation strategies are considered to store and sell energy by the battery system and to estimate the state of charge of battery for each hour in order to reduce voltage perturbation.

5.1 Storage strategy

In this strategy, the producer of hybrid (PV/wind) energy system charges the BESS, when the buying prices of the micro-grid are decreased than the desired price (C_{gmax}= 0.3$/kWh). The power of battery charging can be computed as follows:

$$P_{ch,\lim}(t) = C_{db} N_b \frac{SOC_{\max}(t+1) - SOC(t)}{\eta} \tag{9}$$

$$P_{ch}(t) = \overline{P}_a(t) \tag{10}$$

$$P_{ch}(t) = \min\left(P_{ch}(t), P_{ch,\lim}(t) \right) \tag{11}$$

When the state-of-charge of BESS is lower than $SOC_{\min}(t+1)$, the power of charge is calculated by:

$$P_{ch,min}(t) = C_{db} N_b \frac{SOC_{\min}(t+1) - SOC(t)}{\eta} \tag{12}$$

$$P_{ch}(t) = \max\left(P_{ch}(t), P_{ch,\min}(t) \right) \tag{13}$$

$$P_{ch}(t) = \min\left(P_{ch}(t), N_b C_{db} c_{ch} \right) \tag{14}$$

Then, the battery's state-of-charge can be computed as follows:

$$SOC(t+1) = SOC(t) + \frac{\eta P_{ch}(t)}{C_{db} N_b} \tag{15}$$

5.2 Sell strategy

This strategy consists to sell the stored energy in the batteries to the micro-grid, when the buying prices of the micro-grid are increased compared the price required (C_{gmax}=0.3$/kWh). The expression of power discharge by battery can be given by:

$$P_{dch,\lim}(t) = C_{db} N_b \eta \left(Soc(t) - Soc_{\min}(t+1) \right) \tag{16}$$

$$P_{dch}(t) = P_{dch,\lim}(t) \tag{17}$$

When the state-of-charge $SOC(t)$ is higher than $SOC_{\max}(t+1)$, the discharge power is determined by:

$$P_{dch,\min}(t) = C_{db} N_b \frac{\left(Soc(t) - Soc_{\max}(t+1) \right)}{\eta} \tag{18}$$

$$P_{dch}(t) = \max\left(P_{dch}(t), P_{dch,\min}(t) \right) \tag{19}$$

$$P_{dch}(t) = \min\left(P_{dch}(t), N_b C_{db} c_{dch}\right) \quad (20)$$

With c_{ch} ,c_{dch} are the limit of the charge and discharge capacity of the battery bank, η is the charge/discharge efficiency of the battery bank take to be 0.9.

The state-of-charge of battery can be determined by:

$$SOC(t+1) = SOC(t) - \frac{P_{dch}(t)}{C_{db} N_b \eta} \quad (21)$$

The total output power of the PV/wind/battery hybrid system can be computed by:

$$P_{tot}(t) = \overline{P_a}(t) + P_{dch}(t) - P_{ch}(t) \quad (22)$$

5.3 Economic optimization

An economic optimization has been applied, for the hybrid PV/wind/battery energy system, to select the optimal sizing with saving a benefit cost of system through selling energy to the micro-grid. The suggested objective function based on the capital cost, replacement and maintenance cost and the grid cost during 20 years of life, is given by [17, 18]:

$$NPC = \sum_{i}^{k} N_i \times \left(CC_i + K \times RC_i + PWA \times MC_i\right) \quad (23)$$

Where NPC is the net present cost of the system components, k is number of the renewable energy sources, N_i is the capacity of the ith unit in (kW); CC, RC, MC are respectively the capital, replacement and maintenance costs of the components. Replacement cost represents the exchange of cost for each component in its end of life, with K defines the constant of this cost and is evaluated by [19, 20]:

$$K = \sum_{i=1}^{L_1} \frac{1}{\left(1+i_r\right)^{k \times L_2}} \quad (24)$$

With L_1, L_2 are respectively the number of the life span and replacement of HRES for the life span of the project, i_r is the real interest rate and is equal to 6%, PWA is a coefficient applied to convert the total cost of operation and maintenance to the present cost and computed as mentioned in the following equation, for L the lifetime of the project, [20-23]:

$$PWA = \frac{\left(1+i_r\right)^L - 1}{i_r \left(1+i_r\right)^L} \quad (25)$$

The grid cost can be formulated by:

$$C_G = P_{tot}(t) \times C_g(t) \quad (26)$$

With $C_g(t)$ the buying prices of the grid for each hour during a day.

The benefit cost can be determined by:

$$C_B = NPC - C_G \quad (27)$$

The buying electricity prices of the grid are presented in [24]. The solution of the optimization problem considers the following constraints:

$$c_{ch}.C_{db} \le C_{db} \le c_{dch}.C_{db} \quad (28)$$

$$SOC_{\min}(t) < SOC(t) < SOC_{\max}(t) \quad (29)$$

$$SOC(t+1) < SOC(t) \quad (30)$$

$$N_i > 0 \quad (31)$$

The flow chart of the energy management between the (PV/wind) hybrid system and the micro grid through the battery is illustrated in Fig. 2.

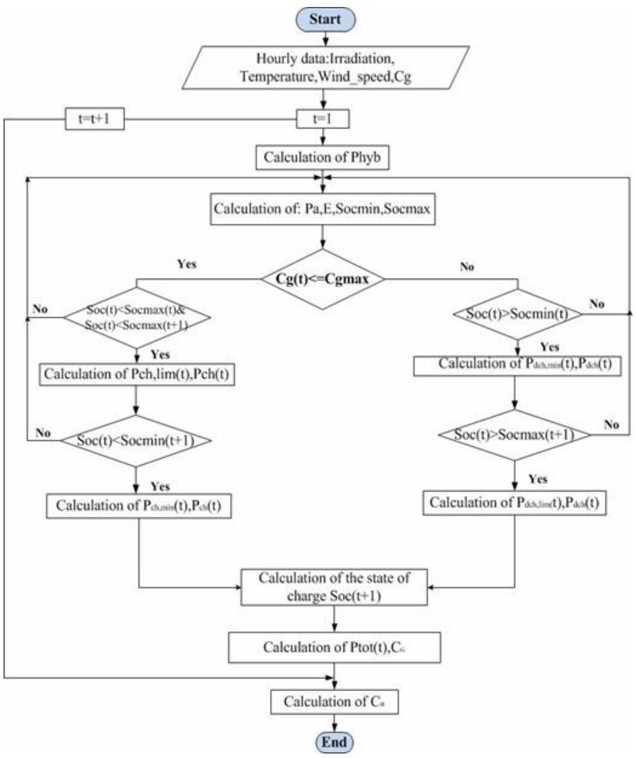

Fig. 2. Flowchart of the techno-economic optimization

6. Optimization method

A metaheuristic method is applied to solve the problem of optimization, in order to minimize the size of HRES and gain cost. A particle swarm optimization algorithm is used to simulate this problem since it provides a good result and execution time compared to the other metaheuristic methods. PSO algorithm uses a number of particles, which move through the solution space, and are evaluated according to some fitness criterion after each step to get an optimum [25]. The concept of swarm involves a several units that are able of interacting with every other solution in a complex behavior, and the intelligence suggests that this approach is successful.

In this work, other PSO based methods, such as Fast Convergence (FCPSO), Variable Acceleration Coefficient (VACPSO) and FC-VACPSO, are used and compared with standard PSO technique in order to select the best method providing the best result for the optimization problem.

6.1 Standard particle swarm optimization

In PSO algorithm, each random solution of the studied problem corresponds to an artificial particle that moves together with its kinds in the super-organism. Particles in a population adapt by returning stochastically toward previously successful regions in the search space, and are influenced by the successes of their topological neighbors. In other words, each individual particle represents a potential solution which moves its position in the search space and updates its velocity according to its own flying experience and that of its neighbor's, aiming for a better position for itself at the next move. The PSO algorithm is presented as follows:

1. Each particle i has a current position in search space X_i, a current velocity V_i and its best position in search space P_i.
2. The individual best position corresponds to the position in search space, where particle i presents the smallest error as determined by the objective function (fitness).
3. The global best position represents the position yielding the lowest error among the entire Pi's.

To reach the optimal point, particles must update their next displacement according to their own velocities. The velocities and positions are defined by:

$$V_i^{k+1} = \omega.V_i^k + c_1.rand_1\left(P_{best,i} - X_i^k\right) + c_2.rand_2\left(G_{best} - X_i^k\right) \quad (32)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (33)$$

Where V_i^k is the velocity of particle at k^{th} iteration; X_i^k is the current position of particle at k^{th} iteration; ω is the inertia weight , c_1 and c_2 are factors acceleration terms, which pull every particle towards the $P_{best,i}$ and G_{best} positions, $rand_1$ and $rand_2$ are two random functions in the range of [0,1]; $P_{best,i}$ is the best previous experience of i-th particle that is recorded and G_{best} is the best particle among the entire population.

Eq. (32) is used for computing the i^{th} particle's velocity considering the particle's previous velocity and the distance between the particle's best previous and the current position. The second part defining the distance between the best particle position in the swarm and the i^{th} particle's position.

The inertia weight ω is used to allow a particle to balance between global and local detections. In general, the inertia weight ω is calculated according to the following equation:

$$\omega = \omega_{\max} - \left(\frac{\omega_{\max} - \omega_{\min}}{iter_{\max}}\right) iter \quad (34)$$

Where $iter$ is the current number of iterations and $iter_{\max}$ is the maximum number of iterations.

6.2 Fast convergence based particle swarm optimization

To improve the PSO performance, this method introduces a new parameter, called particle mean dimension (*Pmd*). The basic PSO can converge rapidly, but apt to drop into local minimum solution easily. Then, to solve this problem, a study has been made considering the following improvements.

When the particle updates from the g^{th} generation to $(g+1)^{th}$ generation, through pursue the $P_{best,i}$ and G_{best}, the particle can follow the Pmd_i which is selected from the particles search. The new parameter Pmd_i of i^{th} particle expression is generated by the following equation:

$$Pmd_i = \left(x_{i1} + x_{i2} + ... + x_{iD}\right)/D \quad (35)$$

Where D is the dimension of particles in the search space and x is the particles swarm, the velocity is calculated by the following expression [26].

$$\begin{aligned} V_i^{k+1} &= \omega.V_i^k + c_1.rand_1\left(P_{best,i} - X_i^k\right) \\ &+ c_2.rand_2\left(G_{best} - X_i^k\right) + c_3.rand_3\left(Pmd_i - X_i^k\right) \end{aligned} \quad (36)$$

Where c_3 is the average best coefficient, with $\left(c_1 + c_2 + c_3\right) \geq 4$; $rand_1$, $rand_2$ and $rand_3$ are random numbers between 0 and 1.

Then, including Pmd_i into the velocity expression, $P_{best,i}$, G_{best} and Pmd_i give information to the next generation together and increase the number of information. Therefore, it is possible to get rapidly the optimal solution. At the same time, the suggested weight factor of Pmd_i is weak, which is equivalent to disturbance information and increases the diversity of particles. G_{best} is used to enhance the convergence. The parameter Pmd_i can move the particles to a better position and decrease the attraction of the G_{best} to local minima.

6.3 PSO based time varying acceleration coefficients

The PSO technique with time varying inertia weight provides good solution location at a significantly fast rate. The concept of time varying acceleration coefficients (TVAC) based PSO is to improve and converge towards the global optima in the optimization formulation in the swarm. This is achieved by time varying the acceleration coefficients c_1 and c_2 in such a manner that the cognitive components are reduced while the social component is increased in the search space. The expressions of the accelerations coefficients are:

$$\begin{cases} c_1 = c_{1i} + \left(c_{1f} - c_{1i}\right)\dfrac{iter}{iter_{\max}} \\ c_2 = c_{2i} + \left(c_{2f} - c_{2i}\right)\dfrac{iter}{iter_{\max}} \end{cases} \tag{37}$$

Where c_{1i} , c_{1f} are the initial and final the social acceleration coefficients respectively, and c_{2i} , c_{2f} are the initial and final cognitive coefficients respectively. The inertia weight is formulated as follows [27]:

$$\omega = \omega_{\min} + \left(\omega_{\max} - \omega_{\min}\right)\left(\frac{iter_{\max} - iter}{iter_{\max}}\right) \tag{38}$$

6.4 PSO based fast convergence with time varying acceleration coefficients

This novel modified PSO method is proposed in order to enhance the solution quality and robustness of standard PSO. It introduces a new parameter named (Pmd) in the velocity formula by considering a time varying of acceleration coefficients c_1, c_2 and c_3 in Eq. (36). The acceleration coefficients are varied according the following formulas:

$$\begin{cases} c_1 = c_{1i} + \left(c_{1f} - c_{1i}\right)\dfrac{iter}{iter_{\max}} \\ c_2 = c_{2i} + \left(c_{2f} - c_{2i}\right)\dfrac{iter}{iter_{\max}} \\ c_3 = c_{3i} + \left(c_{3f} - c_{3i}\right)\dfrac{iter}{iter_{\max}} \end{cases} \tag{39}$$

The inertia weight, computed through Eq. (38) and the PSO algorithm parameters for each method, are shown in Table 1.

The parameters of each component of the hybrid energy system, with the different types of battery bank used in this paper are presented in Table 2.

7. Simulation Results and Discussion

In this study, standard PSO and improved PSO methods are applied for simulating the problem formulation of HRES connected to the utility grid including BESS with the aim to obtain an optimum with a better solution. Simulations are performed using Matlab software. Data of solar irradiation and wind speed for the year 2014 are used

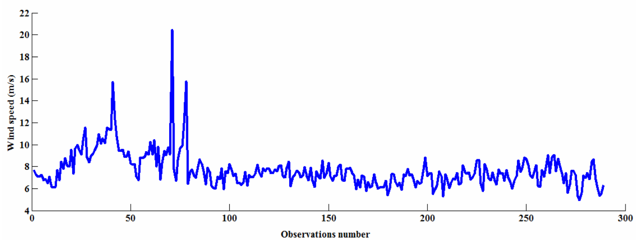

Fig. 3. Wind speed profile for one day

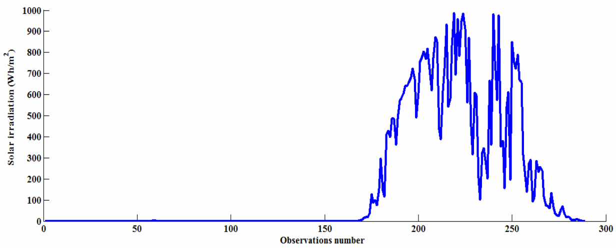

Fig. 4. Solar irradiation profile for one day

Table 1. Parameters of PSO algorithms

	Population = 30				Iteration =50			
PSO & FCPSO	ω_{min}	ω_{max}	c_1	c_2	c_3			
	0.1	0.9	1.5	1.5	1.5			
VACPSO	ω_{min}	ω_{max}	c_{1f}	c_{1i}	c_{2f}	c_{2i}		
	0.4	0.9	0.5	2.5	2.5	0.5		
VACPSO & FC-VA CPSO	ω_{min}	ω_{max}	c_{1f}	c_{1i}	c_{2f}	c_{2i}	c_{3f}	c_{3i}
	0.1	0.9	0.5	2.5	2.5	0.5	1.5	0.5

Table 2. Parameters of individual components of HRES

			Battery types			
	PV array	Wind turbine	Lithium-ion	Lead acid	Ni-Cd	VRB
Type	Sanyo HIP 225-HDE1					
P_{max}, kW	2.55	6.5				
Rated power	10kW	60kW	10.8kWh			
Capital cost	2000$/kW	3000 $/kW	1500 $/kWh	300 $/kWh	1200 $/kWh	600 $/kWh
Replacement cost	0	0	1500 $/kWh	300 $/kWh	1200 $/kWh	600 $/kWh
Maintenance cost	20 $/kW	90 $/kW	50 $/kWh	10 $/kWh	40 $/kWh	20 $/kWh
Life of time (year)	20	20	15	5	20	10

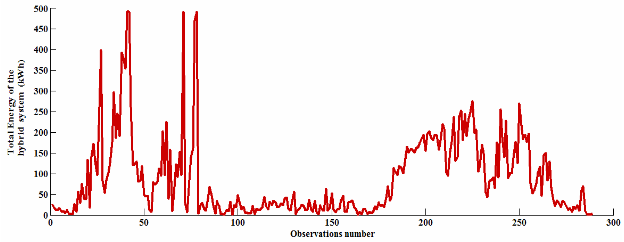

Fig. 5. Total energy of (PV/wind) hybrid system for one day

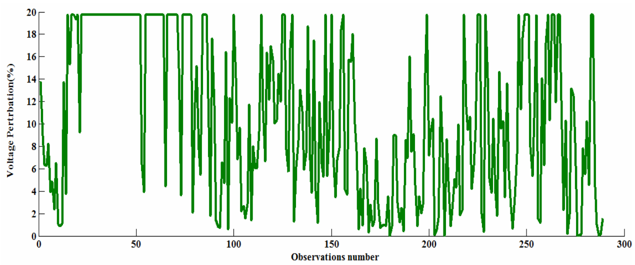

Fig. 6. Voltage change without connection of battery

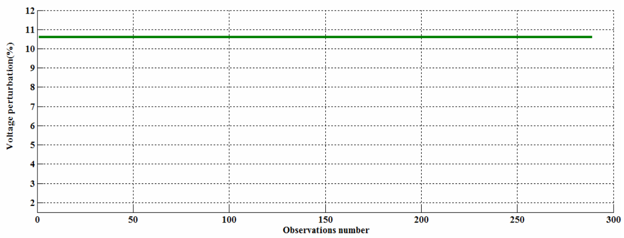

Fig. 7. Voltage change with connection of battery

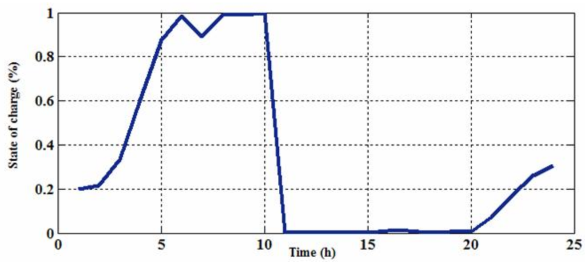

Fig. 8. State-of-charge of the battery

in this study. Profiles of solar irradiance and of wind speed for one day in January month are chosen and applied in this simulation.

The performance of metaheuristic method, such as PSO algorithm, cannot be evaluated by a single run due to the inherent randomness involved in the optimization process. Therefore, the robustness of each PSO algorithm is evaluated based on many different runs. The algorithm is robust when it capable to produce consistence results. The convergence of the above described metaheuristic methods is well shown in Fig. 9.

The number of optimal sizing of hybrid energy system of PV panel, wind turbine and battery system with the

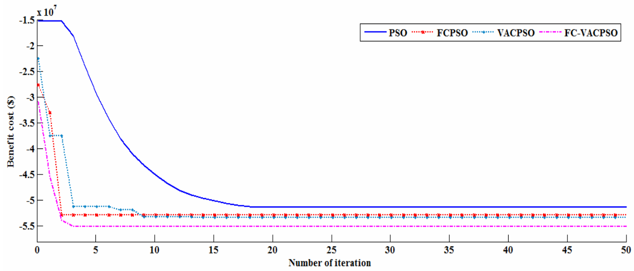

Fig. 9. Convergence of the metaheuristic methods

Table 3. Sizing and cost of hybrid system

Method	N_{pv}	N_w	N_b	Benefit cost (MUS$)
PSO	31	11	08	51.3
FCPSO	15	23	20	52
VACPSO	18	20	28	53.0
FC-VACPSO	24	19	24	55

Table 4. Variable state of charge – Case 1-

Battery type	Price ($/kWh)	N_{pv}	N_w	N_b	benefit cost (MUS$)
Li-ion	1500	22	08	60	38.3
	1500x5	04	46	96	77.0
Ni-Cd	1200	11	21	44	49.8
	1200x5	09	09	32	27.0
VRB	600	25	22	56	69.0
	600x5	05	33	28	62.8
Lead-acid	300	49	05	44	60.6
	300x5	06	09	40	26.6

Table 5. Constant state of charge – Case 2

Battery type	Price ($/kWh)	N_{pv}	N_w	N_b	benefit cost (MUS$)
Li-ion	1500	22	08	60	36.1
	1500x5	04	46	96	79.0
Ni-Cd	1200	05	16	08	34.5
	1200x5	09	09	32	26.4
VRB	600	26	22	56	67.0
	600x5	05	34	28	63.6
Lead-acid	300	31	25	08	76.0
	300x5	46	05	44	52.0

benefit cost of system is illustrated in the Table 3.

7.1 Sensitivity analysis

A sensitivity analysis has been performed about the type and cost of the battery. Four types of batteries are used such as lead acid, nickel cadmium (Ni-Cd), lithium-ion (Li-ion) and vanadium redox flow (VRB) [28, 29] as shown in the Table 2. Then, these prices have been increased five times and applied to the optimization process with the aim to evaluate the sensitivity of use of the battery. In this state, two study cases have been considered about the state-of-charge. In case 1, the state-of-charge has been taken variable which is calculated for each hour. In case 2, the state-of-charge is taken to be constant with a maximal and minimal value equal to 1 and 0 respectively. The obtained results show the difference between both cases about the sizing of hybrid system and the benefit cost as mentioned in the tables 4 and 5.

7.2 Discussions

Profiles of the wind speed and solar irradiance are illustrated in Figs 3 and 4 for one day with a time of five minutes per five minutes, and chosen under agreeable weather condition. The total energy of hybrid (PV/wind) system for one day is illustrated in Fig. 5. From this figure, a voltage perturbation appears. In this case, a study has been achieved for the (PV/wind) energy system with and without connection of a battery during one day with five minutes per five minutes of time. The voltage change, in percent, computed using Eq. (8) is illustrated in Figs. 6 and 7. It can be noted that the integration of lithium-ion type battery with the PV/wind hybrid energy system is very important and has a great advantage to reduce the voltage fluctuation as depicted in Fig. 7.

The state-of-charge of battery has been calculated for each hour of one day and the result has shown that it varies during the twenty-four hours depending on the charge and discharge of battery in order to reduce the voltage perturbation as mentioned in Fig. 8. Fig. 9 presents the convergence of PSO compared with the improved PSO algorithms. It can be noted that the improved FC-VACPSO method gives a better solution regarding the convergence and the cost (55 MUS$) of the hybrid PV/wind/battery energy system than other methods as shown in Table 3. The performance of this method is well proven as it produces a better solution than PSO, FCPSO and VACPSO techniques.

A sensitivity study has been considered about the sizing and the benefit cost of the (PV/Wind/Battery) hybrid system. Taking into account different prices and types of batteries, the simulation results show that the first case is better than the second one regarding the sizing and the benefit cost of the system, especially for the Li-ion battery type. Selected Li-ion battery type and the first case in this study determine their efficiency and are perfect for the sensitivity analysis and for the optimization study. The increase of the benefit cost depends on the rise of the sizing of the hybrid system mostly the number of batteries. Whenever the price of the Li-ion battery type is high, number of sizing of the battery and the benefit cost increase, and vice versa for the other types.

It can be concluded that the variation of the system sizing depends on the battery price, and the increase of the benefit cost depends on the rise of number of the hybrid system components typically the number of batteries. Therefore, in order to obtain an optimal size with an advantageous cost of the (PV/Wind/Battery) energy system, or for another system with a BESS, it is preferred to choose a reasonable price with type of battery. It should be noted that the minimal and maximal state-of-charge are calculated for each hour for reducing the voltage fluctuation.

8. Conclusion

In this paper, a techno-economic optimization has been treated on a hybrid (PV/wind) system, with a BESS connected to the micro-grid. The optimization study has been performed by considering the voltage fluctuation of the hybrid system caused by the solar irradiation and wind speed. The insertion of the BESS to the hybrid system has a significant benefit as it reduces voltage fluctuation, stores energy and discharges it when the grid needs. Overall, these advantages have been confirmed and demonstrated in the simulation results. A new technique has been done by the battery system about storing and selling energy to the grid, and defining the state-of-charge of battery for each hour for one day in order to reduce the voltage perturbation. The simulation results show that Li-ion battery type has a good performance in the optimization study, and is better than the other battery types. To get the best size and gain of the cost of the hybrid system, it is desirable to select a reasonable price as well as a battery type.

A metaheuristic method has been applied to solve the optimization problem for the hybrid (PV/Wind/Battery) connected to the micro-grid. A comparative study of basic PSO and improved PSO algorithms, termed as FCPSO, VACPSO and FC-VACPSO have solved the optimization problem of the hybrid system. The simulation results demonstrate clearly that the improved FC-VACPSO method gives rise to a better convergence. The optimal solution of the studied system is selected using the FC-VACPSO algorithm. This method proves its efficiency and it is better than PSO, FCPSO and VACPSO methods.

The proposed strategy management applied in the optimization process proves its effectiveness for the hybrid renewable energy system (PV/Wind/Battery) which gives a profitable system and it offers a benefit cost during its lifetime.

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