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Optimization of grid independent diesel-based hybrid system for power generation using improved particle swarm optimization algorithm

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Abstract

The power supply of remote sites and applications at minimal cost and with low emissions is an important issue when discussing future energy concepts. This paper presents modeling and optimization of a photovoltaic (PV)/wind/diesel system with batteries storage for electrification to an off-grid remote area located in Rafsanjan, Iran. For this location, different hybrid systems are studied and compared in terms of cost. For cost analysis, a mathematical model is introduced for each system's component and then, in order to satisfy the load demand in the most cost-effective way, particle swarm optimization algorithm are developed to optimally size the systems components. As an efficient search method, IPSO has simple concept, is easy to implement, can escape local optima, by use of probabilistic mechanisms, and only needs one initial solution to start its search. Simulation results indicate that, the role of the diesel generator decreases in hybrid (PV/wind/diesel/battery) energy systems..

Keywords: Stand-alone system; Hybrid PV-wind-diesel-battery system; Optimal sizing; Improved particle swarm optimization

1. Introduction

For remote systems, the hybrid energy systems have been considered as preferable. Such systems are usually equipped with diesel generators to meet the peak load demand during short periods, when there is a deficit of available energy. However, using diesel fuel is so expensive and increases the amount of carbon dioxide (CO_2) emitted. On the other hand, hybrid energy systems are best suited to reduce dependence on fossil fuel and without causing greenhouse gases using available wind speed and solar radiations. So, they can significantly contribute in decreasing the electricity generation cost in stand-alone systems which produce power independently of the utility grid. Combination of renewable energy sources and diesel generators makes a system with high reliability and low pollution.

For a PV/wind/diesel hybrid system, it is necessary to provide an energy storage device. The storage system meets the remaining demand when the renewable sources have low energy. Conventionally, deep-cycle lead acid batteries are used for energy storage. Using PV/wind/diesel/battery energy source leads to a reliable energy source and reduces the total maintenance cost. Such systems are usually installed in locations where fuel supplies are expensive and unreliable, or where strong incentives for the use of renewable energy exist [1].

In recent years, investigation of off-grid hybrid systems based on renewable sources and diesel generators have attracted significant attention [2-13]. One of the most important aspects of the hybrid systems which leads to having a cost-effective system is optimal sizing. Finding the optimum size means to determine the number of wind turbines, PV panels, diesel generators and batteries with the load demand so as to minimizing the total annual cost of the system. In the literature, Lujano-Rojas et al. [2] have presented a novel load management strategy for the optimal use of renewable energy in systems with wind turbines, a battery bank, and a diesel generator. Using predictions concerning wind speed and power, controllable loads are used to minimize the energy supplied by the diesel generator and battery bank, subject to constraints imposed by the user's behavior and duty cycle of the appliances. Kaldellis et al. [3] have determined the optimum dimensions of a stand-alone PV/diesel system, under the restriction of minimum long-term electricity generation cost, and accordingly obtain a comparison with diesel-only systems. Tazvinga et al. [4] have considered the daily energy consumption variations for winter and summer weekdays and weekends in order to compare the corresponding fuel costs and evaluate the operational efficiency of the hybrid system for a 24-h period. Previous studies have assumed a fixed load and uniform daily operational cost. A load following diesel dispatch strategy is employed in this work and the fuel costs and energy flows are analysed. Merei et al. [5] have presented the modelling and optimization of a stand-alone hybrid energy system. The system consists of photovoltaic (PV) panels and a wind turbine as renewable power sources, a diesel generator for back-up power and batteries to store excess energy and to improve the system reliability. Kaabeche and Ibtiouen [6] have focused on development of optimal sizing model based on an iterative approach to optimize the capacity sizes of various stand-alone PV/wind/diesel/battery hybrid system components for zero load energy deficit.

Although various aspects of diesel-based hybrid systems have been considered in the literature, an informative model and efficient optimization tool for optimal sizing and techno-economic analysis and environmental pollution are seldom found. To efficiently and economically use the energy sources integrated in the hybrid system, an appropriate sizing methodology is crucial. If the hybrid systems are optimally designed, they can be cost-effective and reliable. This paper presents the modelling and optimization of an off-grid hybrid energy system for electrification to a remote area located at Rafsanjan, Iran. The system consists of photovoltaic panels and wind turbines as renewable power sources, a diesel generator for backup power and batteries to store excess energy and improve the system reliability. The parameter considered in this paper to measure the pollutant emission is the (kg of CO_2, SO_2, and NO_x). It represents the large percentage of the emission of fuel combustion. Further, CO_2 represents the main cause of the greenhouse effect. So we evaluate the amount of the CO_2 produced by the use of diesel generator in the PV/WT/diesel/battery system during one year of the operation of the system.

Optimal sizing of hybrid systems is a very difficult task which necessities the improvement of mathematical models for the components and using optimization techniques. In this paper, for cost analysis, a mathematical model is introduced for each system's component and then, an improved particle swarm optimization (IPSO)-based optimization technique is used to optimally size the system components (number of wind turbines, PV panels and batteries) in order to satisfy the load in the most cost-effective way.

1. Unit sizing

The schematic drawing of a typical stand-alone (photovoltaic-wind-battery-diesel) hybrid system is shown in Fig.1. The system consists of PV panels and WTs as renewable power sources, a diesel generator for backup power and batteries to store excess energy and improve the system reliability. As can be seen, an inverter is used before the load, since most of electric appliances are supplied with AC power. In such system, when the power produced by the renewable sources (Pre) at time t is not enough to supply the load power (Pl), the storage system (battery bank) is used. If the load demand is high and the storage system energy is not enough to meet the total energy, the diesel generator works to satisfy the remaining load.

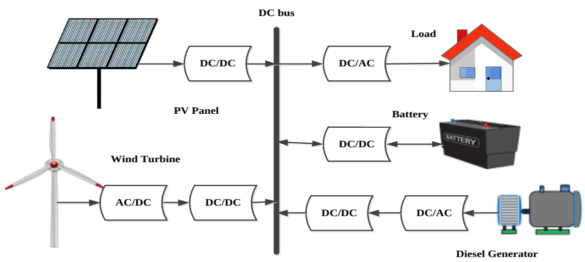

Fig. 1. Schematic of the PV/WT/diesel/battery-based hybrid system.

A. *Resource and load data*

The hourly wind speed data and solar insolation data during a one-year period, which was collected in a remote area in the Iran's Southern (Rafsanjan, Kerman province), regions, are shown in Fig. 2 and Fig. 3, respectively. The hourly load profile during a year of ten typical residential building located in Iran is shown in Fig.4. These sets of data are used in the calculations of the present study.

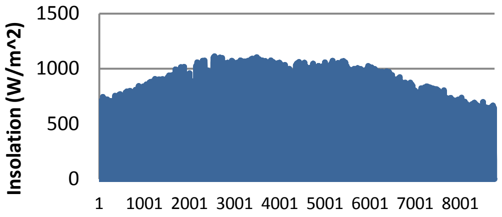

Fig. 2. Hourly profile of insolation during a year.

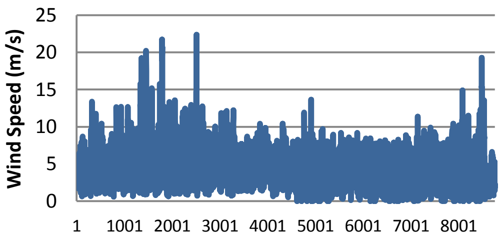

Fig. 3. Hourly wind speed during a year (at height of 10 m).

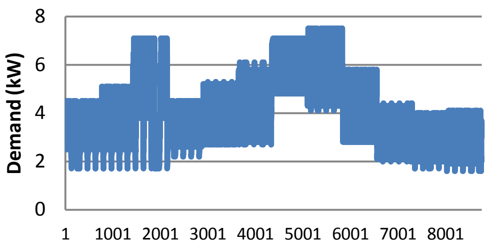

Fig. 4. Hourly load demand during a year.

B. *Wind Turbine (WT)*

For a WT, if the wind speed exceeds the cut-in value, the wind turbine generator starts generating. If the wind speed exceeds the rated speed of the WT, it generates constant output power, and if the wind speed exceeds the cut-out value, the wind turbine generator stops running to protect the generator. The power of the WT is described in terms of the wind speed by Eq. (1) [14, 15]. The specifications of a typical WT used in the present work are shown in table 1.

$$P^{t}_{Wind-Each}=\begin{cases}0 & if \quad v\le V_i \ \ or\ \ v\ge V_o\\ P_r\dfrac{v-V_i}{V_r-V_i} & if \quad V_i<v<V\\ P_r & if \quad V_r\le v<V_o\end{cases} \tag{1}$$

where $P^{t}_{Wind-Each}$ is the power generated by each WT; v is the wind speed; V_i, V_o, V_r, are cut-in, cut-out, rated, or nominal speed of the WT, respectively; and P_r is the WT rated power.

Photovoltaic cells

The output power of each photovoltaic panel, with respect to the solar radiation power, can be calculated by Eq. (2) [15, 16]. The characteristics of PV panels used in the present study are presented in Table 2.

$$P^{t}_{PV-Each}=\begin{cases}P_R\left(\dfrac{r^2}{R_{SRS}R_{CR}}\right) & if \quad 0\le r<R_{CR}\\ P_R\dfrac{r}{R_{SRS}} & if \quad R_{CR}\le r<R_{SRS}\\ P_R & if \quad R_{SRS}\le r\end{cases} \tag{2}$$

where $P^{t}_{PV-Each}$ is the power generated by each PV panel, P_R is the PV rated power, r is the solar radiation factor, R_{CR} is a certain radiation point set usually as 150 (W/m^2), and R_{SRS} is the solar radiation in the standard environment set usually as 1,000 (W/m^2).

Table.1.
Wind turbine parameters.

P_r	1 kW
V_i	3 m/s
V_o	20 m/s
V_r	9 m/s
T_p	\$1443
T_{if}	0.25 × T_p
N^{max}_{Wind}	200
C^{Wind}_{Mnt}	100 \$/year
Life Span	20 years

C. *Diesel generator*

As a backup power system, diesel generator begins to work when the produced power is not enough and the storage system energy is at the lowest level. In this case, diesel begins to work and satisfies the deficit power. The fuel consumption of the diesel generator, $Cons_D$ (*l/h*), depends on the output power and is defined by the following equation:

$$Cons_D=B_D\times P^{D}_{N}+A_D\times P_D \tag{3}$$

where P^{D}_{N} is the rated power, P_D is the output power of the diesel generator, and B_D = 0.0845 (*l*/kWh) and A_D = 0.246 (*l*/kWh) are the coefficients of the consumption curve.

The hourly cost of the fuel consumption can be obtained by Eq. (4).

$$C_f = P_{fuel} \times Cons_D \tag{4}$$

where P_{fuel} is the fuel price. The characteristics of diesel generators used in the present study are presented in Table 3

Table.2.
PV panel parameters.

P_{rs}	260 W
P_p	\$312
P_{if}	$0.5 \times P_p$
C^{PV}_{Mnt}	20 \$/ year
Life Span	20 years
$N^{\max}_{PV}$	200

D. Battery

Battery discharging or charging of the input power can be negative or positive. State of charge (*SOC*) battery, according to the calculations of productivity and time consumption, is obtained thus:

If $P^t_{PV} + P^t_{Wind} = P^t_{Dmd}$, then the battery capacity will not change. When the total output power of the WTs and PV panels is more than the load power, $P^t_{PV} + P^t_{Wind} > P^t_{Dmd}$ than the load power, the battery bank is in charging state, and the charged amount of the battery at time (*t*) is expressed by Eq.(5) [17].

$$E^t_{Batt} = E^{t-1}_{Batt}.(1-\sigma) + \left[\left(P^t_{Wind} \times \eta^2_{Inv} + P^t_{PV} \times \eta_{Inv}\right) - \frac{P^t_L}{\eta_{Inv}}\right] \times \frac{\eta_{BC}}{\eta_{Inv}} \tag{5}$$

In this equation, E^{t-1}_{Batt} and E^t_{Batt} are the charge quantities of battery bank at time *t-1*, and *t*, P^t_L is the energy demand for the particular hour. P^t_{Wind} is the power generated by the WTs, P^t_{PV} is the power generated by the PV panels, η_{Inv} is the efficiency of the inverter, η_{BC} is the charge efficiency of battery bank, and σ is the hourly self-discharge rate.

When $P^t_{PV} + P^t_{Wind} < P^t_{Dmd}$, the total output powers of the WTs and PV panels are less than the load power, the battery is in the state of discharge, and the charged quantity of the battery at time (*t*) is expressed by Eq. (6). The battery bank with the nominal capacity is only allowed to be discharged to a limited extent. [17]

$$E^t_{Batt} = E^{t-1}_{Batt}.(1-\sigma) - \left[\frac{P^t_L}{\eta_{Inv}} - \left(P^t_{Wind} \times \eta^2_{Inv} + P^t_{PV} \times \eta_{Inv}\right)\right] / \eta_{BF} \times \eta_{Inv} \tag{6}$$

where η_{BF} is the discharging efficiency of battery bank. The profile battery banks used are shown in Table 3.

Table.3.
Component parameters.

j	6 %
n	20 years
Battery	
S_{Batt}	2.1 kWh
η_{BC}	95 %
η_{BF}	100 %
C_{Batt}	170 \$
Life Span	5 years
DOD	0.8
σ	0.0002
$N^{\max}_{Batt}$	200
Voltage	12 V
Diesel generator	
P^D_N	9.875 kW
Continous Output	8.750 kW
C_{Diesel}	6975 \$
C^{Diesel}_{Mnt}	0.33 \$/h
Life Span	8760 h
C_{fuel}	1.2 \$/L
Inverter	
Rated power	2 kW
η_{Inv}	80 %
Voltage	24 V
C_{Inv}	751.24 \$
Life Span	10 years

2. Formulation of the optimum design problem

A. Objective function

In this section, the objective function of the optimum design problem is the minimization of the total annual cost (CTot). The total annual cost consists of the annual capital cost (CCap), the annual maintenance cost (CMan), and the total annual cost of fuel consumption of the diesel generator (CFuel). To optimally design the hybrid generation system, the optimization problem defined by Eq. (7), should be solved using an optimization method,

$$Minimize \quad C_{Tot} = C_{Cap} + C_{Man} + C_{Fuel} \tag{7}$$

Capital cost occurs at the beginning of a project while maintenance cost occurs during the project life.

In order to convert the initial capital cost (P) to the annual capital cost (A), capital recovery factor (CRF), defined by Eq. (8), is used.

$$CRF = \frac{A}{P} = \frac{j\left(1+j\right)^{n}}{\left(1+j\right)^{n}-1} \tag{8}$$

In this equation, n denotes the life span and j is the interest rate of the system.

Some components of PV/WT/diesel/battery system need to be replaced several times over the project's lifetime. In this paper, the lifetime of PV/WT/diesel/battery is assumed to be 5 years. By using the single payment present worth factor, we have

$$C_{Batt} = P_{Batt} \times \left(1+\frac{1}{\left(1+i\right)^{5}}+\frac{1}{\left(1+i\right)^{10}}+\frac{1}{\left(1+i\right)^{15}}\right) \tag{9}$$

where C_{Batt} is the present worth of battery, and P_{Batt} is the battery price.

In the same way, the lifetime of converter/inverter is assumed to be 10 years. By using the single payment present worth factor, we have

$$C_{Conv/Inv} = P_{Conv/Inv} \times \left(1+\frac{1}{\left(1+i\right)^{10}}\right) \tag{10}$$

where $C_{Conv/Inv}$ is the present worth of converter/inverter components, and $P_{Conv/Inv}$ is the converter/inverter price.

By breaking up the capital cost into the annual costs of the WT, PV panels, converter/inverter, battery, and diesel generator, Eq. (11) is obtained.

$$C_{Cpt} = CRF \times \begin{bmatrix} N_{Wind} \times C_{Wind} + N_{PV} \times C_{PV} + N_{Batt} \times C_{Batt} \\ +N_{Conv/Inv} \times C_{Conv/Inv} + N_{Diesel} \times C_{Diesel} \end{bmatrix} \tag{11}$$

In this equation, N_{Wind} is the number of WTs; C_{Wind} is the unit cost of WT, which is defined as the sum of turbine price (T_{pr}) and turbine installation fee (T_{inf}); NPV is the number of PV panels; C_{PV} is the unit cost of PV panels, which is defined as the sum of panel price (P_{pr}) and panel installation fee (P_{inf}); N_{Batt} is the number of batteries; $N_{Conv/\mathrm{Inv}}$ is the number of converter/inverter systems; N_{Diesel} is the number of diesel generator; and C_{Diesel} is unit cost of the diesel generator.

For the annual maintenance cost, Eq. (12) is obtained.

$$C_{Mnt} = N_{Wind} \times C_{Mnt}^{Wind} + N_{PV} \times C_{Mnt}^{PV} + C_{Mtn}^{Diesel} \tag{12}$$

In this equation, C_{Mnt}^{Wind} is the annual maintenance cost of wind turbine, C_{Mnt}^{PV} is the annual maintenance cost of PV panel, and C_{Mnt}^{Diesel} is the hourly maintenance cost of the diesel generator. The maintenance costs of inverter and battery bank are ignored.

B. Constraints

Equations (1)-(12) show the description of the objective function in detail. In addition to these equations, some restrictions need to be regarded during the optimization process. Eqs. (13)- (16) show these restrictions

$$N_{PV} = Integer, \quad 0 \le N_{PV} \le N_{PV}^{\max} \tag{13}$$

$$N_{Wind} = Integer, \quad 0 \le N_{Wind} \le N_{Wind}^{\max} \tag{14}$$

$$N_{Batt} = Integer, \quad 0 \le N_{Batt} \le N_{Batt}^{\max} \tag{15}$$

Where $N_{PV}^{\max}$, $N_{Wind}^{\max}$, and $N_{Batt}^{\max}$ are the maximum available number of PV panels, WTs, and batteries, respectively.

At any time, the charge quantity of battery bank should satisfy the constraint of $E_{Batt}^{\min} \le E_{Batt}^{t} \le E_{Batt}^{\max}$

$$E_{Batt}^{\min} = (1-DOD) \times S_{Batt} \tag{16}$$

where $E_{Batt}^{\max}$ is the maximum charge quantity of battery bank, $E_{Batt}^{\min}$ is the minimum charge quantity of the battery bank, DOD is the obtained by maximum depth of discharge battery bank, and S_{Batt} is the value of nominal capacity of battery bank. For the diesel generator, the minimum output power recommended by the manufacturer is 30% of the rated power. Moreover, during the continuous output power, the maximum output power recommended by the manufacturer is 90% of the rated power for the diesel generator.

3. Methodology

A. improved particle swarm optimization algorithm (IPSO)

Particle swarm optimization originally invented by Kennedy and Eberhart in 1995, PSO is a population-based metaheuristic algorithm attempting to discover the global solution of an optimization problem by simulating the animals' social behaviour such as fish schooling, bird flocking, etc. In PSO algorithm, each feasible solution of the problem is called a particle which is specified by a vector containing the problem variables. Particles have memory and thus retain part of their previous state. There is no restriction for particles to share the same point in belief space, but anyway, their individuality is protected. Each particle's movement is the composition of two randomly weighted influences and an initial random velocity: sociality, the tendency to move towards the neighbourhood's best previous position and individuality, the tendency to return to the particle's best previous location.

The standard PSO algorithm utilizes a real-valued multidimensional space as belief space, and evolves. The particles fly through the n dimensional domain space of the function to be optimized (in this paper, minimization is assumed). The state of each particle is represented by its position $X_i = (X_{i1}, X_{i2}, \ldots, X_{in})$ and velocity $V_i = (V_{i1}, V_{i2}, \ldots, V_{in})$. The states of the particles are updated. The three key parameters to particle swarm optimization algorithm are in the velocity update equation. First is the momentum component, which is the cognitive component. Here the acceleration constant c_1 controls how much the particle heads toward its personal best position. The second component is the inertial constant w, which controls how much the particle remembers its previous velocity [18]. The third component, referred to as the social component, draws the particle toward swarm's best ever position; the acceleration constant c_2 controls this tendency. At the beginning of the algorithm, a group of particles is randomly initialized in the search space. Each particle makes use of its memory and flies through the search space for obtaining a better position than its current one. In its memory a particle memorizes the best experience found by itself (p_{best}) as well as the group's best experience (g_{best}). The position of each particle in that space is achieved using the following equations:

$$v_i^{k+1} = w^k v_i^k + c_1.r_1.\left(p_{best}^k - x_i^k\right) + c_2.r_2.\left(g_{best}^k - x_i^k\right) \tag{17}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{18}$$

where v_i^k is the component in dimension d of the ith particle velocity in iteration k, x_i^k is the component in dimension d of the ith particle position in iteration k, c1 and c2 are constant weight factors, pbest is the best position achieved so far by particle i, gbest is the best position found by the neighbours of particle i, r1 and r2 are random factors in the between 0 and 1 interval, and w is inertia weight which is started from a positive initial value (w0) and is decreased during the iterations by $w\,(iter+1) = \beta \times w\,(iter)$.

4. Results and cost analysis

The experimental data used here for wind speed and solar insolation is obtained from Rafsanjan, Iran (latitude: 30.40 º). Figs. 2 and 3 show the hourly insolation and wind speed (at height of 10 m) profiles of during a year. Table 1 and Table 2 list the WT and PV panel parameters, respectively. The parameters related to the other components have been given in Table 3. Fig. 4 shows the hourly load profile during a year.

MATLAB environment is used to implement the proposed methodology. Parameter setting of the IPSO is as follows: Np = 10; c1 = 2; c2 = 2, β = 0.99; w0 =1; itermax = 100. IPSO try to find the optimum number of each component. The minimum and maximum bounds of the decision variables are set to 0 and 200, respectively. At initial moment, it is assumed that the charge of each battery is 30 % of its nominal capacity.

In Iran, the cost of fuel is highly subsidized. According to the radiation data and wind speed if Iran removes the fuel subsidy, the cost of diesel fuel would increase and the PV panels, WTs or hybrid PV/WT/diesel/battery systems would become more attractive. Hybrid PV/WT/diesel/battery systems which use PV and WT energy, combined with diesel generation power and battery bank storage are an excellent solution to decrease diesel generator costs, pollution, and electrification of remote rural areas.

Table 4 summarize in detail the results of optimum sizing for different hybrid systems: PV/WT/diesel/battery, PV/diesel/battery, WT/diesel/battery, and diesel generator alone.

Table 5 shows the optimum number and cost of each component as well as the total annual cost. This table shows the best performance of IPSO during 30 runs. It is clear that economically the PV/diesel/battery-based hybrid system is a better choice for providing power. The total annual costs for PV/WT/diesel/battery, PV/diesel/battery, WT/diesel/battery, and diesel generator alone systems are found 24008.57 $, 24008.57 $, 28820.82 $, and 31036.47$, respectively. For the PV/diesel/battery system, it is found that the optimum number of PV panels, batteries and diesel generator are 91, 37, and 1, respectively. Also economically the PV/diesel/battery, PV/WT/diesel/battery and WT/diesel/battery-based hybrid systems are a better choice of a diesel generator alone. Also this table shows that an emissions for PV/diesel/battery-based hybrid system is a better choice for providing less pollution emissions. The total annual pollution emissions, CO2 for PV/WT/diesel/battery, PV/diesel/battery, WT/diesel/battery, and diesel generators alone systems are found 21807.63 Kg, 21807.63 Kg, 29933.88 Kg, and 54239.41 Kg respectively, which are WT/diesel/battery-based hybrid system pollution emissions greater than of the other hybrid systems. The pollution emissions, SO2, NOx, and total fuel in a year for WT/diesel/battery-based hybrid system are found 380.11 Kg, 570.2 Kg, and 9502.82 L, respectively.

Fig. 5 illustrates the load curve and the produced power of the PVs, diesel generator and the storage level of the battery bank for the optimized hybrid (PV/diesel/battery) systems, it is seen that the diesel generator more works in the during peak hours load and is lower the storage level of the battery bank for the peak hours. Fig. 6 shows the convergence process of the IPSO algorithm for finding the optimal size of the systems. In this figure, the minimum of total annual cost (corresponding to the best performance) during the iterations has been shown. As the figure shows, during the iterations, the total cost of the system decreases. This means that the optimization technique decreases the total cost by moving toward the optimum size. For such systems, there is no information about the optimum size, so any reduction of the cost function is significant, because it leads to having more knowledge about the optimal sizing.

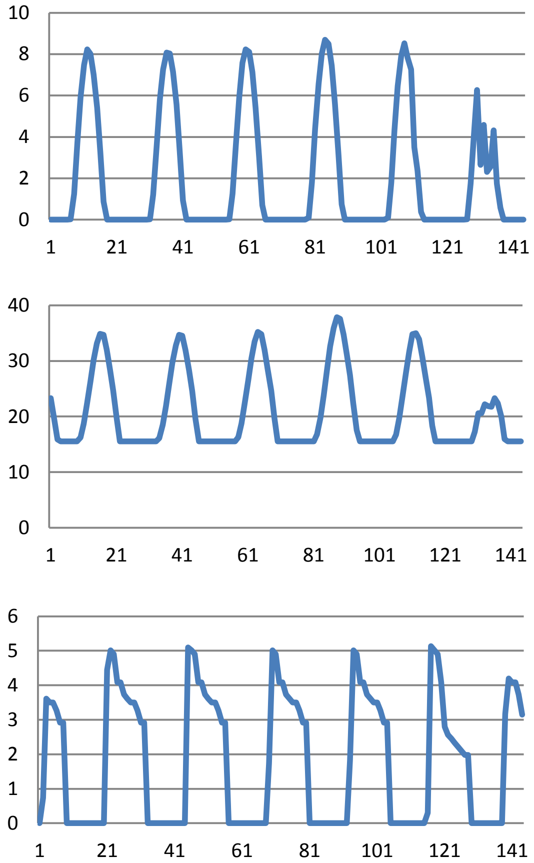

Fig. 5. The change of power during a year for PV/diesel/battery system. (a) PVs produced power; (b) Storage level of the batteries; (c) Diesel generators produced power.

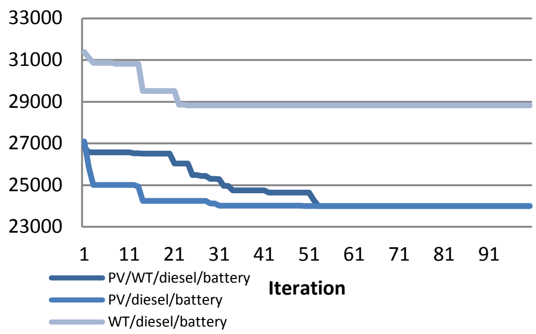

Fig. 6. Convergence process of the algorithms for finding the optimum size of the hybrid systems.

5. Conclusion

This paper presents modeling and optimization of a PV/WT/diesel/battery-based hybrid system for electrification to an off-grid remote area located in Rafsanjan, Iran. The optimal sizing of the system is found by a improved particle swarm optimization algorithm (IPSO). IPSO is a heuristic technique that uses stochastic techniques instead of differential relations to find the global solution. For this location, different generation systems (PV/WT/diesel/battery, PV/diesel/battery, WT/diesel/battery, and diesel alone) are studied and compared in terms of cost. Simulation results indicate that, elimination of the present diesel fuel price subsidies by Iran, decreases the role of the diesel generator in hybrid PV/WT/diesel/battery systems. Nevertheless, with the increase in fuel prices diesel generators and using PV/WT/diesel/battery energy source, in the near future PV/diesel/battery systems will be a more desirable economical alternative and leads to a less-polluting reliable energy source to electrification of the remote regions in Iran.

Table.4.
Summary of the results for the hybrid systems obtained by IPSO algorithm.

hybrid systems	**PV/WT/diesel/battery**	**PV/diesel/battery**	**WT/diesel/battery**	**Diesel alone**
N_{PV}	91	91	-	-
N_{Wind}	0	-	10	-
N_{Batt}	37	37	143	-
N_{Diesel}	1	1	1	1
Total annual cost (*$*)	24008.57	24008.57	28820.82	31036.47
Total fuel in a year (*L*)	6923.06	6923.06	9502.82	17218.86
CO_2 (*Kg*)	21807.63	21807.63	29933.88	54239.41
SO_2 (*Kg*)	276.92	276.92	380.11	688.75
NO_x (*Kg*)	415.38	415.38	570.2	1033.13

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