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## Particle Swarm Optimization Of a Hybrid Wind/Tidal/PV/Battery Energy System. Application To a Remote Area In Bretagne, France

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### Abstract

A new method proposed in this work to optimize the power generated by a hybrid renewable energy system which consists of Wind turbine/Tidal turbine/PV module/Batteries. This system has been designed to satisfy a stand-alone area in Brittany, France, as an example of load demand. The Particle Swarm Optimization technique (PSO) was proposed and developed to minimize the cost of energy. Where the ability of this algorithm was developed to reach the best results in double speeds, at a time rate better than 80% of conventional technology time and less than 20 repetitions only. The problem is defined as an economic problem, taking into consideration the optimal sizing of the system, high reliability, planning expansion for future development, the state of charge of the battery. The total net present cost (TNPSC) is introduced as the objective function, taking into consideration the minimum fitness values in the particle swarm process. The (PSO) algorithm developed has several characteristics and advantages over other traditional techniques and algorithms. In fact, it allows to achieve the optimal solution and to reduce the overall cost with high speed and accuracy. The PSO algorithm program was developed using MATLAB software.

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**Keywords:** Hybrid energy system, Particle Swarm Optimization (PSO), energy management, optimization, economical cost.

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Nomenclature			
$A_m$	Total area of the solar module	$i$	Annual real interest rate
$B_{rc}$	Battery capacity required	$N_{con}$	Numbers of converters
$C_{acap, fix}$	Annualized fixed cost in (\$/year)	$N_{pv}$	Numbers of PV panels
$C_{acap}$	Annualized capital cost in (\$/year)	$N_{tid}$	Numbers of tidal turbine
$C_{ann, bat}$	Annualized total cost of the batteries in (\$)	$N_w$	Numbers of wind turbine
$C_{ann, con}$	Annualized total cost of the converters in (\$)	$N_{bat}$	Numbers of batteries
$C_{ann, pv}$	Annualized total cost of the PV panels in (\$)	$S$	Salvage value
$C_{ann, tid}$	Annualized total cost of tidal turbine in (\$)	$SFF$	Sinking fund factor
$C_{ann, comp}$	Annualized total cost of a component in (\$)	$r_1$ & $r_2$	Random real numbers
$C_{ann, w}$	Annualized cost of the wind turbine in (\$)	$T_a$	Ambient temperature (°C)
$C_{aopm}$	Annualized O&M cost in (\$/year)	$max, min$	Maximum, Minimum values
$C_{cap}$	Capital cost in (\$)	$NOCT$	Normal operating PV temperature (°C)
$C_{opm}$	O & M cost of the components in (\$)	$Y_{comp}, Y_{proj}$	Component, Project lifetime years
$CRF$	Capital recovery factor	$Y_{rem}, Y_{rep}$	Remaining, Replacement years
$DOD_{max}$	Maximum battery depth of discharge	$P_{best}$	Best fitness value
$D_s$	Battery autonomy days	$\eta$	Efficiency
$f_{rep}$	Factor arising replacement	$\beta$	Temperature coefficient
$G_t$	Global irradiance incident (W/m <sup>2</sup> )	$\chi$	Constriction factor
$G_{best}$	Best value is a global solution	$c_1$ and $c_2$	Acceleration constants

## 1. Introduction

Nowadays, around the world, the main important problems are growing in consumption of electric power, raising the cost of electricity, increasing the consumption of non-renewable energy, the limits of conventional energy for generating electricity, climate variation, global warming and the linked to the environmental problems. All that caused the emergence of a severe political and economic crisis in the world. Therefore, all states in the world make efforts for the elaboration of clean energy production. Renewable energy production can support countries match their sustainable elaboration goals through the precaution of access to secure, affordable, clean, safe energy [1, 2, 3, 4]. In spite of the great advantages of renewable energies opposed to conventional energies, but they share common weaknesses, like the great suffering to the weather, the poor stability, and the heavy randomness, which leads to the poor reliability of generation and low efficiency. Therefore, the hybrid renewable energy system can take care of the main problems and limitations in terms of the efficiency, reliability, and the economics, which can possibly be considered an important solution to fulfil load demands, support and improve the system [5, 6, 7, 8]. Most of the researchers have been optimized the size, design, control and economic analysis for hybrid renewable systems, which implemented different of renewable sources as a wind turbine or/and solar module or/and tidal turbine with or without energy storage systems [9, 10, 11, 12]. To overcome the problems of hybrid systems and achieve the objectives of its establishment, it has been applied to various methods, such as optimization techniques, software packages and analytical techniques. In [13, 14], the authors presented a model based on the probability using a statistical technique in certain solution depending on the convolution approach to integrate the fluctuating of the renewable generation energy from hybrid systems and the electrical load. Tina and *al.* were introduced a process for the probabilistic handling of data renewable energy sources as a technique of estimating the electric power produced by each resource of the energy conversion systems [15]. However, these methods have a restricted effect power and they are statistically intensive. Various commercial software packages and simulation tools are employed in evaluating the performance of hybrid power systems, as HOMER, RETScreen, Hybrid2, TRNSYS, RAPSIM, INSEL. One of the most Software is (HOMER) the hybrid optimization model for electric renewable, which has been produced by the National Renewable Energy Laboratory [16, 17, 18]. Beck and *al.* In [19], used the simulated by HOMER software to achieve the optimal renewable system resources configuration (wind turbines, photovoltaic panels, converters, and batteries). Anand and *al.* are intended an optimization and simulation technique of an independent hybrid energy system contain a Biomass gasifier generator set, Fuel cell and PV with battery storage system, this model produces to fulfill electric load requirement of energy center in MANIT Bhopal (India), which have been performed using HOMER pro software [20]. This program

is based on linear equations so that does not represent exactly the renewable energy source properties. Many researchers have used different optimization techniques for the hybrid renewable system to reduce the total cost of energy production and improve the efficiency of the hybrid system. As an example, several of these researches harnessed the Evolutionary Algorithm (EA) to considers multi-objective in the optimization issue of a hybrid system [21, 22]. Authors in [23] designed optimum sizing of hybrid Wind turbines/Solar panels with the storage system by employing Fuzzy adaptive with GA which resolves the optimum number of these components, in addition, GA is chosen to achieve the optimal power arrangement of a stand-alone hybrid renewable system. In [24], the authors handle the optimal capacity combination of an autonomous hybrid power system consisted of solar panels and wind turbines. The way out of these non-linear problems is a typical intelligent optimization algorithm. Consequently, the PSO algorithm has been applied and improved to solve this objective, the result achieved proves its effectiveness and performance. Similarly, for Pourmousavi and *al.* [25], which the PSO optimization was presented to fulfill multiple goals in real-time energy management for a hybrid independent system consists of the wind micro-turbine energy system.

From all papers mentioned above, it can be argued that the use of hybrid resources makes the optimization an intricate problem, and it becomes difficult to obtain the global optimum solution. To overcome this problem, various artificial intelligence algorithms can apply and develop. Genetic Algorithms and PSO are among the most famous intelligent algorithms, they have a good ability in dealing with nonlinear problems and avoid the local minimum solution [26, 27, 28, 29, 16], but the main problem with the genetic algorithm rather than it's complex, it takes a lot of time to achieve the optimal solution [30, 31]. To surmount these obstacles, in this article, the Particle Swarm Optimization technique (PSO) was proposed and developed for optimal performance, the ability of this algorithm was developed to reach the best results by making the particles of the algorithm not only follow the traditional formula of the algorithm, in which the particles search and follow the nearest and best particle, but it was developed to review all particles and look at the best particle in the group and follow it, the optimal solution was achieved by double speed, where it reached the optimal solution at a time rate better than 80% of conventional technology time and less than 20 repetitions only. In addition, this algorithm has been harnessed to achieve multiple objective functions. The standalone hybrid renewable energy system depends on solar panels, tidal turbines, wind turbines and with battery bank in order to fulfill an electric load located in the far west of France in Brittany, the results showed the good ability of the PSO developer to solve hybrid system optimization problems such as optimal size, optimal the total cost of energy (COE) and optimal energy management with superior speed and accuracy taking into consideration the several constraints as the State Of Charge (SOC) of the energy storage system, high reliability, and planning expansion for the future development. A variety of different scenarios have been studied to meet the electric load demand. PSO algorithm program was developed using MATLAB software and the total net present cost (TNPC) is proposed as an objective function.

## 2. Hybrid system description

The hybrid renewable energy system model it was built in this paper depending on solar panels, wind turbines, tidal turbines, batteries, converters, controller, and other devices were proposed to fulfill a load demand 16MWh/day peak 2MW in Brittany, France. While, the suggested approach using PSO technique to get the optimization and predict the hybrid system performance, several components must be modeled first as in following.

### 2.1. Wind turbine

Selecting a convenient model is extremely significant for wind turbine power simulation. There are various models for the computation of wind turbine power, like the model built upon Weibull parameters [32], the linear model [14, 33], and the quadratic model. Within this model, the output power of the wind turbine generator and wind speed is estimated by a quadratic model [34]. ENERCON wind power's E-70 is used with rated power capacity 2,300Kw, some parameters of this wind turbine ENERCON E-70 are described in Table 1(a) [35, 36, 37]. In this paper, the wind speed data is acquired from the daily wind speed within one year under field study [38, 39].

## 2.2. Solar panel

The output of solar panels is highly affected by the climate, especially the solar irradiance, ambient temperature, season of the year, the tiled surfaces. In this research, a simplified simulation model is used to determine the Solar panel module performance and to evaluate of output power generator, the manufacturer's data for the Solar module, the solar radiation that reaches the surfaces panels and the ambient temperature are used as model inputs for the solar radiation every hour at the site under study. The computation method and the power generation by the Solar panels is  $P_{PV}$  is given by the equation given as [40, 41]:

$$P_{PV} = N_{PV} \times \eta_{PV} \times A_m \times G_t \quad (1)$$

The efficiency of solar panel power generator is given by the equation [42]:

$$\eta_{PV} = \eta_{ref} \times \eta_{pc} [1 - \beta(T_c - T_{cref})] \quad (2)$$

$T_c$  can be calculated from equation [43]:

$$T_c = T_a + \left( \frac{NOCT - 20}{800} \right) \times G_t \quad (3)$$

Where  $T_{a,NOCT} = 20$  °C and  $G_{t,NOCT} = 800$ W/m<sup>2</sup> for wind speed of 1m/s. The rated power and some parameters of the solar array are tabulated in Table 1(c).

## 2.3. Tidal turbine

Moving water has a kinetic energy similar to wind speed, Marine energy is divided into four types: tidal energy, ocean thermal energy, wave energy and energy from salinity gradients. Tidal current energy is very foreseeable and not much effect on the climate situation as the rainfall, clouds, etc., but it is impacted by tides, thermal and density of water and its location on the ground. The strength of the tidal current's variations, based on the distance of the earth from the moon and the sun, the range of the tide-generating pressure caused by their corresponding masses and distance from the earth is about (32%) from the sun and (68%) from the moon [44]. However, two techniques can be used, for the generating electrical power from tidal energy, the first one is by constructing a tidal barrage throughout tidewater or the Gulf waters at high tides, the second is by taking out energy from free in motion water. Typically, tidal barrages are not utilized because of its impact on the environmental conditions. In this paper, the hourly tidal speed at the site study is used for generating the electricity from tidal turbine which has rated power capacity 500 kW, it has commonly been assumed its lifetime to be about 25 years. Other parameters of this tidal turbine model were shown in Table 1(b).

## 2.4. Storage batteries (SB) and Converter

The storage energy system is used to save the excess energy production through the hybrid system, this system will generate the energy to meet the load demand during the shortfall period. The battery sizing fundamentally depends on different factors such as temperature correction, rated energy capacity, the lifetime of the battery, depth of discharge etc. The required battery capacity in ampere hour is calculated by this equation [45]:

$$B_{rc} = \frac{E_c \times D_s}{DOD_{max} \times \eta_t} \quad (4)$$

In this paper the maximum DOD was considered about 80%,  $D_s$  is the battery autonomy days,  $E_c$  is the electrical load in ampere hour (Ah),  $\eta_t$  is the temperature correction factor. When the output energy of hybrid system is higher than the energy load demand, the battery will be charging by the hybrid system or else in discharging state. The maintenance requirements and the floating charge voltage which are the most important characteristics of the battery, to achieve the optimization for the hybrid renewable energy system, all these characteristics must be taken into consideration. On the other hand, because of difficulty and complexity in combining all in optimization tools, the floating charge voltage and the state of charge were taken into consideration during optimization. In Table 1(d), characterize some parameters of the mentioned battery bank which are used in this paper. The converter used as an inverter from DC to AC conversion, it's efficiency is considered 90%, lifetime about 15 years, the operating &

maintenance cost, initial capital cost and replacement cost are being considered 50(\$/Unit-year), 310(\$/2kW), 310(\$/2kW) respectively [46].

### 2.5. The load demand model and Case study location

In this study, a practical electrical consumption was taken from the site of the electricity transmission network (RTE) website [47]. In this case, hourly data from 2014 in metropolitan France was used and scaled to achieve an electric load for the purposes of representing a typical electric load size for this hybrid system. Adjusting the data down is illustrative of a typical load as the hourly, daily and seasonal trends are maintained. In this simulation, it had a scaled annual average daily load is 16MWh/day and the peak load was 2MW. Measured data were used for calculations in HOMER [48]. The hybrid system has been verified studies using a real weather data, such as the wind speed, the tidal current speed, the solar radiation and clearness index recorded monthly by NASA for the pilot area for an Eastern French remote site in Brittany, Brest city which its location at (48, 45° N latitude, −4, 42° E longitude).

## 3. Energy management and operation strategy

In this research, the energy management process in the hybrid system can be represented in three main cases: The first case if the total energy production by the hybrid system exceeds the electrical load, the surplus energy will be charging the batteries. The second case if the electrical load is greater than hybrid energy production, the batteries will discharge at the load to satisfy the deficit in the system. The third case if the electrical load is equal with the available power production, the batteries will maintain its initial amount of charge without charge or discharge.

## 4. Methodology and constraints

The issue of optimization the hybrid renewable energy system has been resolved by achieving the objective function taking into consideration all constraints, which includes the high reliability, the state of charge, minimum pollution, etc. This paper focuses on the optimization of cost of energy and total net present cost (TNPC) taking into consideration many of constraints as the high reliability, state of charge of the battery (SOC), the optimal sizing of the system and planning expansion for the future development. The COE and (TNPC) are developed as among the most effective economic profitability indicators of system economic analysis, which are considered as an objective function, the COE and TNPC can be calculated as [49]:

$$\min(TNPC) = \min\left(\frac{C_{ann,tot}}{CRF(i,Y_{proj})}\right) \quad (5)$$

$$CRF = \frac{i \cdot (1+i)^{Y_{proj}}}{(1+i)^{Y_{proj}} - 1} \quad (6)$$

$$C_{ann,tot} = \sum C_{ann,w} + C_{ann,pv} + C_{ann,tid} + C_{ann,bat} + C_{ann,con} + C_{acap,fix} \quad (7)$$

$$COE = \frac{C_{ann,tot}}{E_{served}} \quad (8)$$

In this paper, the annual real interest rate was considered 0.06, the system reliability was super reliability (the hybrid system satisfied the load by 100%).

## 5. PSO optimization algorithm

There are many techniques and algorithms that fall under the heading of artificial intelligence algorithms and techniques, Particle swarm Algorithm is one of the most important of these algorithms, it is a modern technique based on stochastic technique was presented in 1995 by Kennedy and Eberhart [50], it was applied with great success in the computational intelligence arena, solving global optimization problems and had exhibited many successful applications in many scientific fields [51]. the PSO is using individual improvement that called particles, these particles are flying during the problem area plus population cooperation and competition by following the current optimum particles, this technique inspired by the social behavior of some animals, like fish schooling, the bird

flocking, and the swarm theory. Each individual in PSO represents a possible solution assumed to have two properties: velocity and position. These two variables are adjusted for each particle according to its own experience and the experience of its neighbors. Each particle wanders through in the solution area and recalls the best objective function value (position), which has already been discovered, the fitness value is saved and known  $P_{best}$ . The PSO optimizer is seeking another best value which is acquired yet by any particle in the population. When a particle captures all the best population as its topological neighbors, the superior value is a global best and it is called  $G_{best}$ . Let the variable ( $x_i$ ) refers to the position of particle ( $i$ ) in the study space and its speed is ( $v_i$ ), so the ( $i_{th}$ ) from the particle can be represented as [52]:  $x_i = [x_{i1}, x_{i2}, x_{i3}, \dots, x_{id}, \dots, x_{iN}]$  (9)

In the N-dimensional space, each particle continuously registers the best solution that has reached so far during its flight (best fitness value  $P_{best}$ ). The best past position of the  $i_{th}$  particle is saved under the name vector and calculated by:  $P_{besti} = [P_{best1}, P_{best2}, P_{best3}, \dots, P_{bestid}, \dots, P_{bestiN}]$  (10)

where  $i = 1, 2, 3, \dots, N$  is the number of particles in a swarm, the global best  $G_{best}$  refers to the best position which is ever achieved by all the individuals of the population is also tracked by the optimizer. The best particle of all the particles in the swarm is denoted by  $G_{bestd}$ . The velocity of particle  $i$  is represented as:

$$v_i = [v_{i1}, v_{i2}, v_{i3}, \dots, v_{id}, \dots, v_{iN}] \quad (11)$$

The velocity and position of each particle can be continuously adjusted based on the current velocity and the distance from  $P_{bestid}$  to  $G_{bestd}$ :

$$v_i(t+1) = w(t)v_i(t) + c_1 r_1 (P_i(t) - X_i(t)) + c_2 r_2 (G(t) - X(t)) \quad (12)$$

$$X_i(t+1) = X_i(t) + \chi v_i(t+1) \quad (13)$$

In the equations (12, 13) the  $r_1$  and  $r_2$  are random real numbers drawn from [0, 1],  $c_1$  and  $c_2$  are acceleration constants that pull each particle towards  $P_{best}$  and  $G_{best}$  positions which are considered equal 1.0 in all applications. Thus, the particle flies through potential solutions toward  $P_i(t)$  and  $G(t)$  in a navigated way while still exploring new spaces by the random mechanism to escape from local optimum solution. There was no actual mechanism for controlling the velocity of a particle, so it was necessary to impose a maximum value  $V_{max}$ , which controls the maximum travel distance in each iteration to avert this particle flying past good solutions. The  $\chi$  is constriction factor which is used to limit velocity, here is  $\chi = 0.7$ . Also, after updating the positions, it must be checked that no particle violates the boundaries of search space. If a particle has violated the boundaries, it will be set at the boundary of search area [52, 53]. In equation 12, where the inertia coefficient indicates the impact of the previous history of velocities on the current iteration one and is extremely very important to ensure the convergent behaviour. There are various strategies for calculating the inertia weight, these computations depend on the designer and can be supposed fixed or a variable [54]. In this paper, the Particle Swarm Optimization technique (PSO) was developed to reach the best results by making the particles of the algorithm not only follow the traditional formula of the algorithm, in which the particles search and follow the nearest and best particle, but it was developed to review all particles and look at the best particle in the group and follow it, the optimal solution was achieved in double speed, where it reached the optimal solution at a time rate better than 80% of conventional technology time and less than 20 repetitions only. In addition, this algorithm has been harnessed to achieve multiple objective functions. All the parameters of PSO algorithm are tabulated in the Table 1(e), the inertia weight in this research is considered random and calculated by the equation:

$$w(t) = 0.5 + \frac{rand(0)}{2} \quad (14)$$

## 6. Simulation results and discussion

This research focuses on the economic optimization of hybrid renewable systems using Particle Swarm Optimization (PSO), with an objective function based on minimizing the total net present cost (TNPC) and the cost of energy production (COE) of the hybrid renewable system consist of PV panels/wind turbine/tidal turbine/battery, taking into account many of the constraints, like the meet of the electrical demand with high reliability, the State Of Charge (SOC) of the battery, the optimal sizing of the system and planning expansion for the future development. The PSO algorithm program was developed using MATLAB environment. All variables and data concerned the hybrid system and renewable energy sources at its location are inserted, as the solar energy, the wind energy, the temperature, the depth state of charge of the battery, the tidal energy, sizes batteries, the type and size of wind and tidal turbines

available, all prices details as the total cost, maintenance and operating costs, the coordinates of the location, the life of project, the nearness of the national electric grid, the numbers and prices of all components of hybrid power system generation if they already exist before the creation of the project and etc. The particle swarm optimization design in order to get highly accurate solutions with the minimum time, at a time rate better than 80% of conventional technology time and less than 20 repetitions only. One of the most important tasks in the applying of PSO algorithm in solving optimization problem is how to represent the target function and all constraints carefully in each individual particle to achieve the optimal solution. Initially, random values for position and velocity are created for the 10 individual Particle in each swarm with respect the PSO characteristics and all constraints (as the minimum and maximum of hybrid components, the reliability ...et.), the maximum iteration number is considered 100 iterations. And then, the equation 14 and position are carried out with other parameter values as the data in table 1(e), the values of position and velocity will be updating in each time and safeguarding the best values and neglecting their worst. The search will be terminated if the number of iterations reached a final value or if the value of the optimal solution reached to the tolerance value which was considered in this paper equal to (0.0001). The ultimate optimum solution is delegated to the system's designer depending on its desire, development and expansion of a pre-existing system or other variables like the location, the availability of energy sources and so on. Hence, in this paper, the particle swarm algorithm is implemented to achieve the optimal solution in different scenarios taking into consideration various constraints as follows:

- Scenario 1: A stand-alone hybrid renewable system consist of (wind turbines, solar panels, tidal turbines) with stored energy, to achieve the minimum (COE) and lowest (TNPC), high reliability and respect the SOC of the battery. The optimal result is achieved and tabulated in Table2(a). The convergence curve of the PSO algorithm for this scenario is shown in Figure 1(a).
- Scenario 2: A a stand-alone hybrid renewable system consists of two components of renewable energy sources (solar panels and wind turbines, solar panels and tidal turbines and wind turbines) with stored energy, for the optimum economic system, high reliability and respect the SOC of the battery. The optimal result is achieved and tabulated in Table 2(b).
- Scenario 3: A stand-alone hybrid renewable system consist of (solar panels, wind turbines, tidal turbines) with stored energy, to achieve the minimum surplus power, minimum the (COE) and lowest (TNPC), high reliability and respect the SOC of the battery. The optimal result is carried out and tabulated in Table 2(c). The convergence curve of the PSO algorithm for this scenario is shown in Figure 1(b).

From all scenarios, it can be observed the batteries are discharged through the course of any shortage occurs in the energy sources and no load declined was seen, so the electric load is fulfilled by the hybrid energy system in the optimal configuration in all days of the year. Figure 2(a) shown the optimal energy management balance in one day, which obtained from the proposed hybrid system in scenario1. While Figure 2(b) shows the variation in the state of charge of the battery bank during one day in scenario1. To ensure access to the most efficient results in a short time, the program was designed and used by a new technology treating with the size of each component inside any one of the particles. The comparison of final results for the various components of the hybrid system under the same location studied shown, the hybrid wind turbine with the battery is very economical compared with other hybrid systems, as a result of the high percentage of wind standard in this region, concurrently, the high cost of a hybrid system that relies on solar cells and battery can be justified because of the low temperatures and the weak solar radiation in this region, these results are not suitable for other areas that have different characteristics such as the location of the site, the solar radiation, the wind energy, tidal power with other variables or restrictions.

## 7. Conclusion

This paper proposes a universal solution of the problems of the optimal sizing, economic, energy management and planning expansion for any independent hybrid energy system at anywhere in the world, where the solar radiation, ambient temperature, tidal speed, wind speed, location, electrical load and other constraints are used for theoretical simulation. The lifetime of the project was considered 25 years. The advantages of the PSO algorithm have been developed to achieve the optimal solution in double speed, where it reached the optimal solution at a time rate better than 80% of conventional technology time and less than 20 repetitions only. In addition, this algorithm has been harnessed to achieve multiple objective functions and giving flexibility in the selecting of system components. The

economic problem was represented by several scenarios to minimize the (COE) and (TNPC) of a stand-alone hybrid renewable energy system with considered many of constraints like the high reliability, high efficiency, SOC battery etc. The results demonstrate that the best results in the area under study is a wind turbine with the batteries, and the solution depends on a lot of variables such as weather data, electric load demand, and other restrictions, Meanwhile, The results showed the improved PSO algorithm has a good capability and several parameters to solve the objective function for any complex and nonlinear problems and find the global solution.

Table 1. Input parameters.

(a) Wind turbine.		(b) Tidal turbine.		(c) Photovoltaic	
Parameters	Values	Parameters	Values	Parameters	Values
Cut-in, cut-out wind speed	5 (m/s), 25 (m/s)	The rated power	500kW	Capital Cost	450(\$/Unit)
Rated Speed, $v$	15 (m/s)	Cut-in & Cut-out tidal speed	< 1 (m/s), > 5 (m/s)	Rep. Cost	450(\$/Unit)
Hub height	57 m	Rated tidal speed	2.25 (m/s)	The lifetime	25 years
Rotor diameter	71 m	Power coefficient, $C_p$	0.44	Operation	5(\$/Unit-y)
The maximum power	2,300 kW	Capital & Rep. Cost	1250000(\$/Unit)	The rated power	285W
Capital & Rep. cost	1200000 (\$/Unit)	Operation & M Cost	1000(\$/Unit-y)	Maintenance Cost	5 (\$/Unit-y)
Operation & M Cost	200 (\$/Unit-y)	efficiency $\eta$	90%	efficiency $\eta$	90%

(d) Batteries bank.		(e) Some of PSO parameters.	
Parameters	Values	Parameters	Values
Nominal voltage	100v	$c1$ & $c2$	1
Rated energy	50kWh	$r1$ & $r2$	Randomly
Capital Cost & Replacement Cost	2500(\$/Unit)	$w$	Randomly equation 14
Operation & Maintenance Cost	20(\$/Unit - y)	No. of iteration	100
Efficiency $\eta$	71%	No. of population	10

Table 2. Optimal hybrid combination system

	(a) scenario 1.	(b) scenario 2.			(c) scenario 3.
System	Case 1	Case 1	Case 2	Case 3	Case 1
No. of PV module	0	11	0	1	1313
No. of Tidal turbine	0	0	1	6	0
No. of Wind turbine	2	1	1	0	1
Size of Battery (Wh)	59739	10986772	7577958	8941885	10172692
COE (\$/kWh)	0.0942	0.1003	0.1221	0.2647	0.1154
TNPC (\$)	3488082	3711676	4522475	9802707	4274204

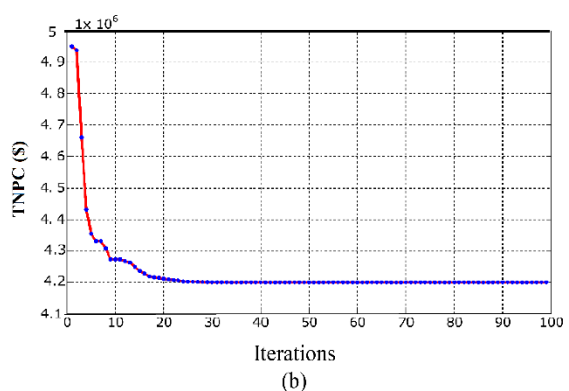
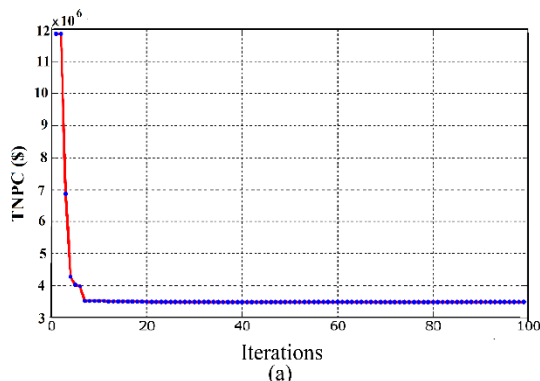


Fig. 1 Convergence of PSO algorithm (a) scenario 1, (b) scenario 3



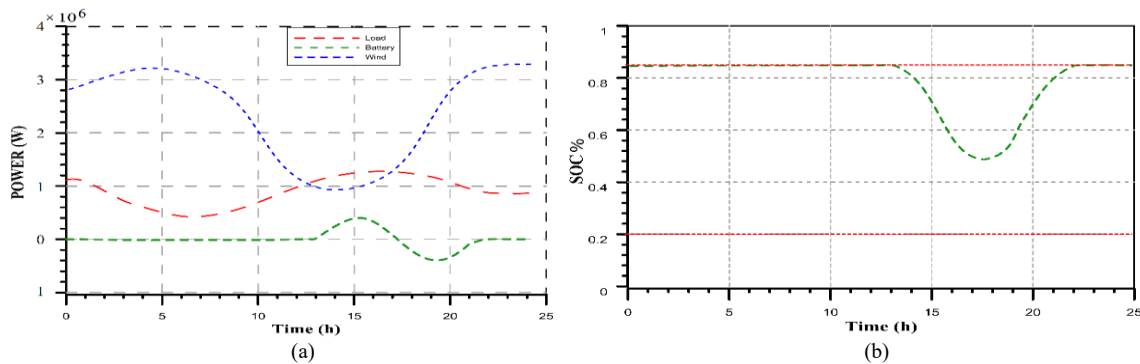


Fig. 2 Optimal results scenario 1 (a) Variation in power generation, load, and battery energy (b) Variation in battery SOC

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