International Journal on Emerging Technologies (Special Issue on NCRIET-2015) **6**(2): 10-16(2015)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Wind/Solar Generation System with Hybrid Energy Storage Station-by Optimization of Battery–Super capacitor

G.B. Hangaragi
Associate Professor, Department of Electronics & Communication, Engineering,
Bheemanna Khandre Institute of Technology Bhalki, Karnataka, INDIA

(Corresponding author: G.B. Hangaragi)

(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: **In this paper presents, the capacity of optimization of hybrid energy storage station in wind/solar generation system, how can to make full use of wind and solar energy by successfully reducing the first time investment and operation costs based on the power demand through allocating suitable capacity of system is an optimization problem. The optimization goal is to minimize one-time investment and operation costs in the whole life cycle, the constraints are utilization rate, and reliability of power supply. In this paper metrical models of wind/solar generation systems, battery and super capacitor are built, the goal of optimization function of system is proposed, and various factors are considered. To solve the optimization problem, to improved simulated annealing particle swarm optimization algorithm is proposed by introducing the simulated annealing idea into particle mass. The new system the ability to escape from local optimum and improve the variety of particle swarm, then help to avoid prematurity and enhance the global searching ability of the modal. With the example system, the optimization results show that the meeting of new system is faster than the conventional particle group optimization system and its cost optimization is better, which established the rightness and validity of the proposed models and systems. This method can provide a reference for the capacity optimization of hybrid energy storage station (HESS) in wind/solar generation system.**

Index Terms: Battery, capacity optimization, hybrid energy storage station, simulated annealing particle group optimization system, supercapacitor (SC), wind/solar generating system.

I. INTRODUCTION

A guaranteed capacity of the energy storage device needs to be configured in the wind/solar generation system, It is wholly affected by the climate and environment, to ensure the continuity and reliability of the electricity load because of it sunshine available and random output power [1]. Now present days batteries a one of energy storage device, is generally used in the wind/solar generation system, particularly in small and medium scaled generation system, there are some disadvantages in the battery, such as shorter life period, charge and discharge current limits, and environmental problems, In the large scale development of the wind/solar generation system as a super capacitor (SC), as a new type of power storage in the modern days, is receiving more and more concentration due to higher power density, longer period, higher charge–discharge efficiencies, and free maintenance. Therefore, the economic and technical purposes of the energy storage system will be greatly enhanced by combining the battery with the SC [4].

Now, the prices of various energy storage devices are somewhat expensive, i.e 20%–25% of total cost [5]. Therefore, the best combinations of load, solar cells, wind turbines, and storage system should be achieved in the design of wind/solar generation system, to solve the supply reliability of wind/ solar generation system is more economic conditions [6] presently, the study of different hybrid energy storage stations (HESSs) in the wind/solar generation system is still less the wind/solar generation system. A battery capacity optimization system of the solar electric vehicle based on combinatorial optimization based on neural network is proposed in [7]. A hybrid system is designed by combining has strong global search ability with other optimization system that has a good local search ability [9]. The most important characteristics of the simulated annealing method are to step out local optimal area and find the global or approximate optimal, which has nothing to do with the choice of the initial point [10].

Therefore, simulated annealing particle swarm optimization system is presented to enhance the global search ability and escape from local optimal ability. In this paper, to minimize one-time investment and operation costs in the whole life period as an optimization goal, the utilization rate and the reliability of power supply as constraints, the capacity of HESS is optimized to improve the utilizing efficiency of renewable energy.

II. MATHEMATICAL MODEL OF WIND/SOLAR *GENERATION SYSTEM*

A. Wind Turbine Power Generation Unit

Wind speed is one of the most important factors. Wind speed always changes with time because there are many factors such as weather, seasons and causes the changes of wind power generation. To solve this problem, probability distribution function is adopted. There are many kinds of probability distribution functions are available, among them , Two-parameter Weibull distribution is adopted in this paper, and its probability density function is

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} \qquad (1)$$

Where k is the scale parameter, c is the shape parameter, and v is the wind speed. If the average wind speed v and wind speed variance are known,

$$k = \left(\frac{\sigma}{\overline{v}}\right)^{-1.086} \qquad (2)$$

$$c = \frac{\overline{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \qquad (3)$$

In this paper, since the power output of wind turbine is relate to its rated power [12], the power output of small wind turbine can be calculated using

$$P_w(v) = \begin{cases} P_r \frac{v^k - v_c^k}{v_r^k - v_c^k}, & (v_c \le v \le v_r) \\ P_r, & (v_r \le v \le v_f) \\ 0, & (v < v_c \text{ or } v > v_f) \end{cases} \qquad (4)$$

Where Pr is the rated power of the wind turbine, vc is the cut-in speed, v_r is the rated speed, v_f is the cut-out speed, and *k* is the shape parameter of Weibull distribution. The probability that wind speed is greater than or equal to a specified value can be calculated by using

$$P(V \ge u) = e^{-\left(\frac{u}{c}\right)^k}. \qquad (5)$$

The monthly power generation of wind turbine may be calculated by (4) and (5).

B. Photovoltaic Array Power Generation Unit

The output power of photovoltaic (PV) array is changes due to affected by the environmental factors, i.e environmental random changes, to constantly changing of output power of PV arrays [11]. There are many factors in the PV power generation, such as solar radiation, temperature, shadow, and module efficiency, etc.,

$$\begin{cases} I = I_{SC}\left[1 - C_1\left(e^{\frac{V}{C_2 V_{oc}}} - 1\right)\right] \\ C_1 = \left(1 - \frac{I_m}{I_{SC}}\right) e^{\frac{V_m}{C_2 V_{oc}}} \\ C_2 = \left(\frac{V_m}{V_{oc}} - 1\right) \Big/ \ln\left(1 - \frac{I_m}{I_{SC}}\right). \end{cases} \qquad (6)$$

Considering that the amount of solar radiation and temperature is constantly changing, then the mathematical model for PV array in the condition of random radiation density and temperature (40 oC) is

$$\begin{cases} I(S,T) = I + \Delta I(S,T) \\ V(S,T) = V + \Delta V(S,T) \\ \Delta I(S,T) = \alpha\left(T + \frac{S}{S_{STC}}(T_{NOR} - T_{STC}) - T_{STC}\right) \\ \qquad + I\left(\frac{S}{1000} - 1\right) \\ \Delta V(S,T) = -\beta \times \left(T + \frac{S}{S_{STC}}(T_{NOR} - T_{STC}) - T_{STC}\right) \\ \qquad - R_S \times \Delta I(S,T) \end{cases} \qquad (7)$$

Where Rs is the series resistance of PV array equivalent circuit, and β are the temperature coefficients of short circuit and open circuit, respectively, and TNOR is the normal working temperature of PV array (40 oC). In general, whether or not there is a cloud has a great influence on the solar radiation. For cloudy weather the conditions that the ground receive the solar radiation is more complex. The solar radiation is modified for cloudy weather by using a quadratic curve function relating to the cloud cover in this paper

$$\begin{cases} I_{\text{real}} = I(S,T) \times (1 - T_C) \\ T_C = a \cdot N^2 - b \cdot N + c \end{cases} \qquad (8)$$

Where TC is the weakening coefficient, N is the cloud cover whose value is 0–8,

C. Battery Model

Suppose the charging and discharging currents of battery are both rated charging current and the reference voltage of battery is selected as 24 V.

D. SC Model

It is general that the use of SC needs to be expanded through series or parallel connection because single SC only stores limited energy and cannot used great high voltage [12].

Suppose SCs are connected in series and in parallel with group, then the equivalent capacitance of SC groups is are the maximum and minimum voltages of SC groups, respectively, then the storage energy the maximum and minimum voltages of single SC.

III. CAPACITY OPTIMIZATION MODEL OF HYBRID ENERGY STORAGE SYSTEM

A. GOAL OPTIMIZATION FUNCTION

One-time investment and operation costs in the whole life period, as an optimization aim of the system, should be minimum on the premise of satisfying all the performance parameters of wind/solar generation system.

B. CONSTRAINT CONDITIONS

The following constraints must be measured when optimizing the capacity of battery and SC hybrid energy storage:

1) Charging and Discharging Current Constraints of SC: Due to lower energy density, SC is mainly responsible for the instantaneous maximum power of load fluctuation in hybrid energy storage station

2) Surplus of Power is maximum Process: In order to fully absorb the excess energy and improve the utilization of wind/solar and strong system

3) Maximum Power Loss Process: In order to provide a continuous power supply for important load and ensure the reliability of power supply systems when the system does not work normally during the long rainy and windless days, the load must be a satisfied demand.

C. Handling Constraint Violation

In the process of solving the optimization problem, handling the constraint violation is an important problem. By considering more constraints in the model, the handling method based on feasibility rule is adopted.rules:

1) Feasible solution is superior than to infeasible solution;

2) If the two solutions are feasible, then the solution with better target value is superior;

3) If the two solutions are not feasible, then the solution with little constraints violation is superior.

IV. SAPSO ALGORITHM

A. PSO ALGORITHM

PSO algorithm is using search model of speed position [13]. In this algorithm, a group consists of particles. each particle performance depends on the fitness value of objective function which will be optimized by the current optimum particle, the particles search in the solution space.

The PSO is initialized to a swarm of random particles, which find the optimal solution by iteration [19].Suppose a particle swarm consisting of particles search in the -dimensional target space, the position of the the particle in the dimensional space is expressed as vector, and flying velocity is expressed as vector. Each particle has a fitness value that is decided by the optimized function;

B. SIMULATED ANNEALING SYSTEM

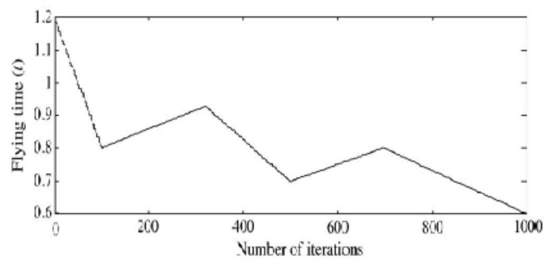

Fig. 1. Changed trend of particle flying time.

The solid is first heated to a sufficiently high temperature, and then it is slowly cooled. While heating, the particles in the solid state become disorder with the rise of temperature, and internal energy of the particles increases; instead, the particles can become gradually order when slowly cooling and reached an equilibrium at each temperature, and finally reaching the fundamental state at normal temperature. Simulated annealing system, simulating a physical process of the object in the molten state from gradually cooling to ultimately achieving a crystalline state, is used to solve the optimization problems by using the similarity between the solution procedure of the problems and annealing the process

of melting objects, namely the values of parameters are not adjusted at the end under the action of control parameters until selected parameters make the energy function eventually reach the global minimum value *C. Improved Algorithm*

1) Improved PSO Algorithm: By analyzing (24), we find that each flying time per bird is fixed in unit time when birds are preying, namely the flying time of particles among the standard PSO algorithm is one, which make the particles miss some good positions during the flight in a sense [15]. Where flying time adopts the changed trend that is shown in Fig. 1, which is equivalent to increase the flying velocity of the particle, thus the global optimization ability of particle can be enhanced and the probability of falling into the local optimum can be reduced.

2) Improved Simulated Annealing Algorithm: Inspired by the inertia weight strategy linear decreasing of PSO algorithm and considering the characteristics of SA algorithm, linear annealing temperature coefficient as well as inertia weight are used in the algorithm, which is shown in (25). The purpose is to accelerate the speed of convergence in the early optimization and to improve the accuracy of local search in the later period of optimization [16]

The method that the current solution increased the random disturbance, as a new position function of particle, is selected in SAPSO algorithm.

D. The Algorithm Flow

For capacity optimization of HESS in the wind/solar generation system, the potential solution of each optimal problem is a "particle" of the search space, where every particle has a fitness value that is determined by the objective function [22]. The voltage of the selected battery and single SC is 24 and 3 V, respectively, because the charging voltage of the battery should be kept unanimous with the charging voltage of SC, and hence the series number m=8. One-time investment and annual operation costs are defined as optimization objective function, where the rated charging current of battery Ic and the equivalent SC groups C are defined as optimization variables. The specific steps are as follows:

Step 1: Initializing the parameters of particle swarm and simulated annealing algorithm. Setting the particle number ,m=20 inertia weight wi=0-9-04 with linear decreasing, learning factor C1=1.5and C2=1.5 the maximum number of iterations with initial temperature and the sampling frequency is 10.

Step 2: Determining the required power for load and calculating the PV/wind turbine power generation.

Step 3: Objective optimization function model and constraint function model are constructed.

Step 4: The newborn particles are evaluated. The fitness value of the objective function for every particle

Step 5: A new position is randomly generated for the particle according to (127) and the increments Δ of the fitness between the new position and old position are calculated.

Step 6: If Δ <, entering a new position, the particle executes annealing temperature operation according to (21), otherwise random number rand between 0 and 1 is generated;

if rand < exp(Δ /T(t)) [23], entering a new position, the particle executes annealing temperature operation, otherwise step 3 is executed. Step 7: The constraint conditions are dealt according to(10)–(12), and local optimal value and global optimal value of the particle are updated and recorded in accordance with the processing result.

Step 8: The position and velocity of the particle are updated according to (13) and (15).

Step 9: To determine whether the number of iterations is greater than MAXITER, if it is yes, the optimization is stopped and the optimal solution is output, otherwise, go to Step 2.

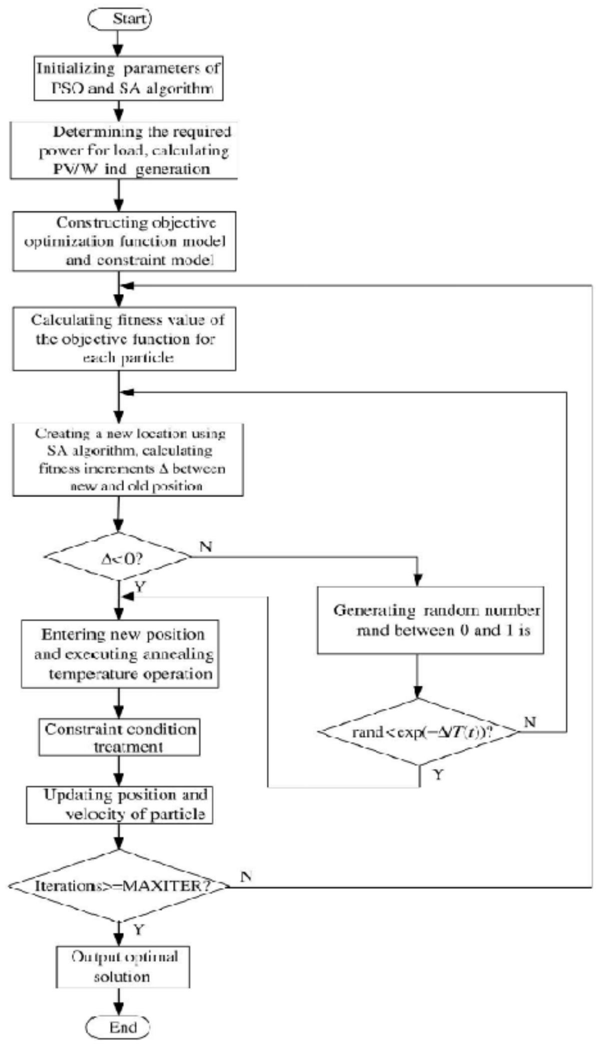

Fig. 2. The flowchart of the improved SAPSO algorithm is shown

V. APPLICATION

A. System Introduction

A wind/solar generation system that is installed power plant working.

1 The wind turbine parameters are as follows:

Rated power is 3 kW, cut-in speed is 3 m/s, rated speed is 9 m/s, and cut-out speed is 18 m/s;

The PV models parameters are as follows:
open-circuit voltage is 21 V, short-circuit current is 7.2 A, voltage is 17 V, and current at Pmax is 6.18 A. The power consumption of the load is 10.84 kWh/days. Annual change of wind speed is shown in Fig. 3. The monthly wind speed may be integral with every month. The minimum time interval of wind speed proper should firstly be determined, in which the wind speed is constant. As minimum time interval, wind speed distribution with points is fitted if this month is 30 days. Average and variance of monthly wind speed can be calculated by analyzing the wind speed data, then the monthly distribution parameters can also be calculated by using (1)–(3)and the results are shown in Table I. The monthly power generation of wind turbine can be calculated using (4) and (5), which is shown in Fig. 4. The average daily global solar radiation shown in Table II, and the monthly power generation of PV array can be calculated according to the data given in Table II and (6)–(9), which is shown in Fig. 5. The annual power generation and load demand and their difference are shown in Table III.

B. Constraint Conditions Process

1) It can be seen from Table III that the max power in April, in which the value is 141.09 kWh, i.e., 4.703 kWh/days. To make sure that the HESS can be filled to full capacity, in this condition that total of rated capacity of battery and SC cannot be more than the maximum power.
2) The load should be ensure and reliably by the power supplied for 2 days during the long rainy and windless days. It can be seen from Table III that the power loss in August is maximum, in which the value is 69.32 kWh, i.e., 2.236 kWh/days and the minimum energy for the storage system, the power supply of the load, it is required that the battery and SC cannot be less than the power loss.

C. Optimized Results

According to the aim function, and relevant program, the capacity of the battery–SC HESS is optimized population is 20.

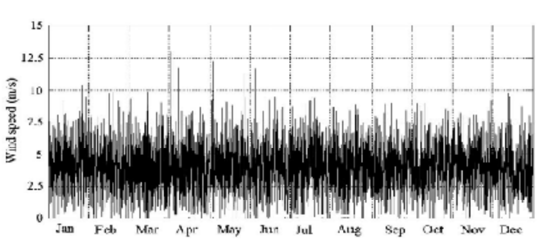

Fig. 3. Annual change of wind speed.

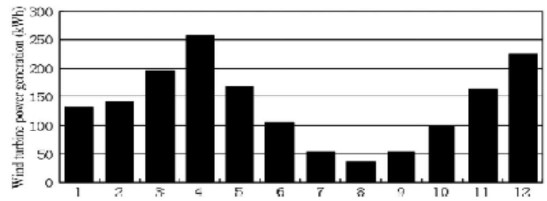

Fig. 4. Power generation of wind generation.

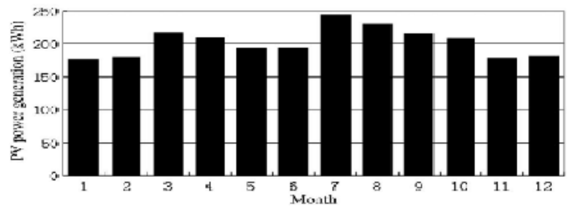

Fig. 5. Power generation of solar generation.

TABLE I
MONTHLY WEIBULL DISTRIBUTION PARAMETERS

Month	Average wind speed (m/s)	Scale parameter k	Shape parameter c (m/s)
1	3.7	2.04	4.20
2	3.8	2.13	4.32
3	4.1	2.30	4.66
4	4.5	2.42	5.11
5	3.9	2.18	4.43
6	3.5	2.01	3.98
7	2.6	1.87	2.95
8	2.5	1.72	2.84
9	2.6	1.89	2.94
10	3.4	1.96	3.85
11	4.0	2.32	4.54
12	4.2	2.41	4.77

TABLE II
AVERAGE DAILY GLOBAL SOLAR RADIATION OF XUZHOU AREA

Month	Average monthly outside temperture (°C)	Average daily global solar radiation of horizontal surface (MJ/m^2·days)	Average daily global solar radiation of inclined surface (MJ/m^2·days)	Monthly sunshine hours (h)
1	1.4	8.376	13.630	175
2	1.1	10.930	15.225	177.3
3	7.6	14.423	16.634	217.7
4	15.6	16.679	16.523	248.8
5	21.8	20.770	18.716	280.3
6	26.3	21.055	18.212	263.1
7	27.4	16.776	14.812	216.9
8	26.2	15.663	14.979	224.3
9	21.7	14.884	16.498	224.4
10	15.8	12.093	16.003	216.4
11	7.9	9.089	14.162	181.2
12	1.1	7.657	13.854	171.9

TABLE III
ANNUAL POWER GENERATION AND LOAD DEMAND

Month	Total power generation (kWh)	Power consumption (kWh)	Difference (kWh)
1	308.73	336.04	−27.31
2	319.13	303.52	15.61
3	412.52	336.04	76.48
4	466.29	325.2	141.09
5	360.85	336.04	24.81
6	301.51	325.2	−23.69
7	297.49	336.04	−38.55
8	266.72	336.04	−69.32
9	269.68	325.2	−55.52
10	308.73	336.04	−27.31
11	341.02	325.2	15.82
12	407.22	336.04	71.18

TABLE V
COMPARISON OF COST AND COMPUTATION TIMES OF TWO METHODS

Method	Cost/US$	Computation time/s
Standard PSO	6592.46	8.41
SAPSO	6105.30	7.34

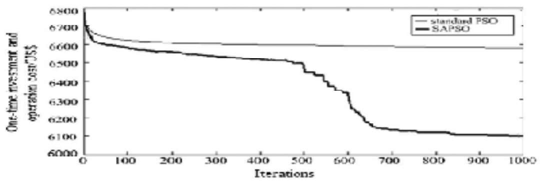

Fig. 6. Different algorithms optimizing curve.

The system is run independently 24 times every optimization. For the optimization results, one minimum and maximum are deserted. The remaining part of the average value is calculated and the results are reserved to two decimal places. The results are shown in Table IV. The comparison of cost and computation times between the standard and the computation times are less for SAPSO system as compared to standard PSO system As shown in Fig. 6, in the premise of ensuring that the result is convergence, the optimization performance of SAPSO system is more obviously improved than the standard PSO system and thus verifying the effectiveness and practicality of the algorithm.

VI. CONCLUSION

Combining PSO system which has strong global search ability, with other optimization system which have good local search ability, the SAPSO system has been proposed using the new position generating function, which is applied to battery–SC HESS. The effectiveness and practicality of the system are verified by the calculation of an example system. By optimizing the capacity of HESS in the wind/solar generation system, the investment and the operation costs may be greatly reduced on the basis of maximizing the renewable energy and satisfying the load demand.

REFERENCES

[1] M. S. Lu, C. L. Chang, W. J. Lee, and L. Wang, "Combining the wind power generation system with energy storage equipment," *IEEE Trans. Ind. Appl*.vol. **45**, no. 6, pp. 2109–2115, Nov. 2009.

[2] X. J. Li, D. Hui, and X. K. Lai, "Battery energy storage station (BESS)- based smoothing control of photovoltaic (PV) and wind power generation fluctuations," *IEEE Trans. Sustain. Energy*, vol. **4**, no. 2, pp. 464–473, Apr. 2013.

[3] Y. Riffonneau, S. Bacha, F. Barruel, and S. Ploix, "Optimal power flow management for grid connected PV systems with batteries," IEEE Trans. Sustain. *Energy*, vol. **2**, no. 3, pp. 309–420, Jul. 2011.

[4] P. Z. Huang, J. N. Wu, and X. M. Liu, "Multi-objective sizing optimization of standalone photovoltaic system," in Proc. First ICSPGS 2009, China,pp. 2–6.

[5] X. S. Tang, X. Wu, and Z. P. Qi, "Study on a standalone PV system with battery–ultracapacitor hybrid energy storage," *Acta Energ. Solar. Sin*., vol. **28**, no. 2, pp. 178–183, Feb. 2007.

[6] Q. Yang, J. H. Zhang, and Z. F. Liu, "Multi-objective optimization of hybrid PV/wind power supply system," *Autom. Electr. Power Syst.*, vol. **33**, no. 17, pp. 86–90, Aug. 2009.

[7] S. Q. Zhou, L. Y. Kang, and B. G. Cao, "Optimization of energy storage system in solar energy electric vehicle," *Acta Energ. Solar. Sin*., vol. **29**, no. 10, pp. 1278–1282, Oct. 2008.

[8] W. F. Gao and S. Y. Liu, "An efficient particle swarm optimization," *Control Decis.*, vol. **26**, no. 8, pp. 1158–1162, Aug. 2011.

[9] A. Arabali, M. Ghofrani, M. Etezadi-Amoli, M. S. Fadali, and Y. Baghzouz,"Genetic-algorithm-based optimization approach for energy management," IEEE Trans. Power Del., vol. **28**, no. 1, pp. 162–170, Jul. 2013.

[10] D. Lu, C. M. Tong, and W. J. Zhong, "Study on hybrid algorithm based on particle swarm optimization and simulated annealing algorithm," *Comput. Eng. Des.*, vol. **32**, no. 2, pp. 663–666, Feb. 2011.

[11] B. Y. Tan, J. H. Yang, and K. D. Li, "Novel method for optimizing design of hybrid wind/photovoltaic generation system," *East China Electr. Power*, vol. **33**, no. 12, pp. 893–897, Dec. 2005.

[12] R. Carter, A. Cruden, and P. J. Hall, "Optimizing for efficiency or battery life in a battery/supercapacitor electric vehicle," *IEEE Trans. Veh. Technol*., vol. **61**, no. 4, pp. 1526–1533, Sep. 2012.

[13] F. Ongaro, S. Saggini, and P. Mattavelli, "Li-ion battery–super capacitor hybrid storage system for a long lifetime, photovoltaic-based wireless sensor network," *IEEE Trans. Power Electron*., vol. **27**, no. 9, pp. 3944–3952, Sep. 2011.

[14] R. Karki, P. Hu, and R. Billinton, "A simplified wind power generation model for reliability evaluation," IEEE Trans. *Energy Convers*., vol. **21**, no. 2, pp. 533–540, Apr. 2006.

[15] W. Li and G. Joos, "A power electronic interface for a battery supercapacitors hybrid energy storage system for wind applications," in *Proc. IEEE Annu. Power Electron. Specialists Conf. (PESC), Rhodes*, Greece, 2008, pp. 1762–1768.

[16] D. M. Xu, L. Y. Kang, and B. G. Cao, "Optimal design of standalone hybrid wind/PV power systems," *Acta Energ. Solar. Sin.,* vol. **27**, no. 9, pp. 919–922, Sep. 2006.

[17] H. L. Song, J. Y. Wu, and L. Y. Ji, "Multi-objective optimal sizing of standalone hybrid wind/PV system," Trans. *China Electrotechn. Soc*., vol. **26**, no. 7, pp. 104–111, Jul. 2011.

[18] M. Clerc, Particle Swarm Optimization, Hoboken, NJ, USA: Wiley, 2008.

[19] W. Lingfeng and C. Singh, "Multicriteria design of hybrid power generation systems based on a modified particle swarm optimization algorithm," *IEEE Trans. Energy Convers.*, vol. **24**, no. 1, pp. 163–172, Mar. 2009.

[20] X. B. Li and Q. J. Zhu, "Application of improved particle swarm optimization algorithm to multi-objective reactive power optimization," *Trans. China Electrotechn. Soc.,* vol. **25**, no. 7, pp. 102–109, Jul. 2010.

[21] F. J. Rodriguez, C. Garcia-Martinez, and M. Lozano, "Hybrid metaheuristics based on evolutionary algorithms and simulated annealing: Taxonomy, comparison, and synergy test," *IEEE Trans. Evol. Comput*., vol. **16**, no. 6, pp. 787–800, Nov. 2012.

[22] S. Ali Pourmousavi, M. Hashem Nehrir, C. M. Colson, and C. Wang, "Real-time energy management of a stand-alone hybrid wind-microturbine energy system using particle swarm optimization," *IEEE Trans. Sustain.*

[22] T. S. Huang, W. H. Gui, Y. L. Wang, and C. H. Yang, "Time-sharing power supply optimal decision for lectrolytic deposition process of zinc based on simulated annealing algorithm," *J. Syst. Eng. Electron.*, vol. **11**, no. 4, pp. 43–50, Jul. 2000.

[23] J. H. Yang, J. J. Mao, and Z. H. Chen, "Calculation of solar radiation on variously oriented tilted surface and optimum tilt angle," *J. Shanghai Jiaotong Univ.*, vol. **36**, no. 7, pp. 1031–1036, Jul. 2002.

[24] K. W. Wee, S. S. Choi, and D. M. Vilathgamuwa, "Design of a least-cost battery–supercapacitor energy storage system for realizing dispatchable wind power," *IEEE Trans. Sustain. Energy*, vol. **4**, no. 2, pp. 786–796, Apr. 2013.