Bibliographic Review and Comparison of Optimal Sizing Methods for Hybrid Renewable Energy Systems

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Renewable energy systems will be widespread power sources in future years due to their sustainability and clean nature. Due to intermittent nature of many renewable energy resources (such as wind, photovoltaic and etc.), their hybrid usage are preferred. One of the most important subjects related to hybrid renewable energy systems is finding the optimal size of their parts to utilize them efficiently and economically. There are various techniques for optimal sizing of hybrid renewable energy systems, reported in many articles, containing their own merits and demerits. The current paper reviewed such methodologies and compared them using some appropriate indicators. This paper helps the system designers to select the appropriate sizing method for their hybrid renewable energy systems.

keywords: *Renewable energy, Hybrid system, Sizing methodologies, Hybrid methods*

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1. INTRODUCTION

Nowadays electrical energy is one of the most necessary requirements of mankind and is a essential factor for social and economic developments [1–3]. Due to increase in population, fast urbanization, rapid industrialization and increased energy consumption, the demand for electricity is increasing [4,5]. A significant portion of energy demand is supplied using fossil fuels which cause problems such as great volatility in costs, limited and inadequately distribution on the earth's crust, harmful emissions and etc. [6,7]. To solve the problems raised, renewable energy resources such as photovoltaic (PV), wind, micro hydro and etc., are the best solution. According to the intermittent nature of many renewable energy sources, hybridization of two or more of them can improve system performance [2,8,9]. Hybrid renewable energy systems (HRES) can work in stand alone (SA) or grid connected (GC) modes. HRES have important advantages in comparison to single-source systems. Some of these benefits are shown in Fig.1. An overview of common primary sources for electricity generation is represented in Fig.2.

Efficient and economical utilization of renewable energy resources depends on optimal sizing of HRES. To achieve this purpose there are different sizing methods. Selection of optimal sizing method can help system designers to reach this purpose efficiently.

In this paper, in addition to a comprehensive review of optimal sizing methods for HRES, they are compared using some indicators. In Section 2, different optimal sizing methods, along with an overview of numerous papers that have already been worked out, are examined separately. Section 3, presents some indicators to compare the appropriate sizing methods of HRES. This is done by the authors after a comprehensive study of the various sizing methods in section 2. A number of challenges in relation to HRES are addressed in Section 4. At the end, Section 5 presents the conclusion of the work.

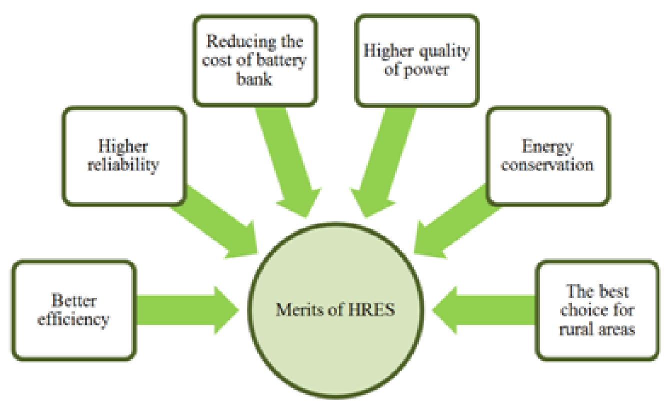

Fig. 1. Main advantages of HRES in comparison to single-source systems

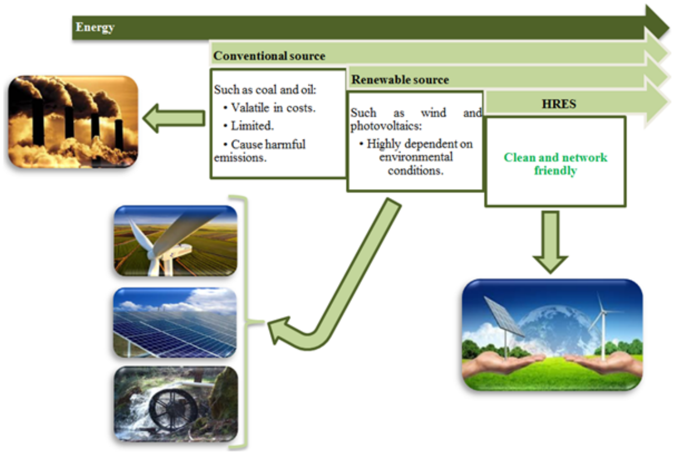

Fig. 2. Overview of common primary sources for electricity generation

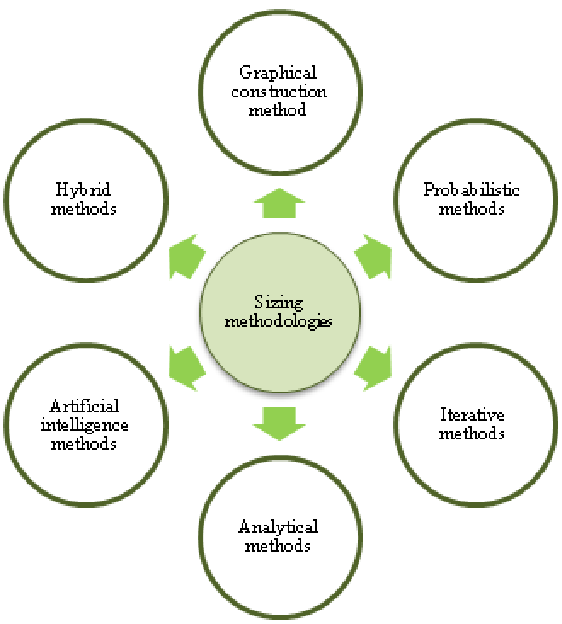

Fig. 3. Sizing methodologies of HRES

2. OPTIMAL SIZING METHODOLOGIES

In this section, each of the different methods for optimal sizing of HRES is studied bibliographically. Optimal sizing methods of HRES is shown in Fig.3.

A. Graphical construction method

Graphical construction method is based on satisfication of average value of demand by average values of photovoltaic and wind power generation for PV generators and wind turbines. In graphical construction method merely two decision variables are considered in optimization process. In other words, PV-wind or PV-battery considered in this method [10–12]. In [13], the authors developed an approach to calculate optimal sizing of a HRES including PV and battery systems for SA mode. In [14], the authors proposed a technique to find the optimal combination of wind-PV system using the existing meteorological data, based on the solution of supply-demand energy balance. A number of examples of the graphical approaches used in papers are given in Table 1.

B. Probabilistic methods

One of the easiest methods to find of optimal sizing of HRES are probabilistic methods. These methods incapable to represent the dynamic performance of HRES, so the results of probabilistic methods are not the best solution [11,12]. In [22], to help system designers on selection of energy types, size of them, operating policies and etc. a simulation method is proposed, when utilizing wind energy and PV systems in small isolated systems. For sizing of PV modules and battery storage, a new method is presented for a SA hybrid system including PV and wind systems in [23]. To reduce the computational effort, the probabilistic method is considered to generate an input-output dataset of various samples that were later used to train the artificial neural networks in [24]. A summary of probabilistic approaches for sizing of HRES is listed in Table 2.

C. Iterative methods

In iterative methods, the design of HRES is done by means of a recursive process which stops when the optimal system design is attained [12]. In [34], performance of a hybrid energy system including PV and wind systems, PV-alone system and wind-alone system, for utilization as SA systems, for use at the residential customer level has been evaluated. In [36], a general model to find an optimal sizing of a HRES including PV, wind, micro hydro, DG and battery for a rural community is developed. In [37], a new optimum sizing method for HRES including PV, wind and battery storage systems in SA mode, based on the LPSP and ACS, is presented. In [38], under different loads and unit cost of auxiliary energy systems, optimal sizing of a HRES including PV, wind and battery storage systems, is presented. A number of examples of the iterative methods used in papers are given in Table 3.

D. Analytical methods

In these methods, ingredients of HRES are characterized by computational models to find techno-economic feasibility of the system and allow the system designers to simulate the efficiency of various HRES configurations.

Nowadays, various computer tools have been proposed. in order to sizing of HRES. The function of most computer tools is based on an analytical method [1]. One of the most famous sizing programs for HRES is hybrid optimization model for electric renewables (HOMER). HOMER has been developed by National Renewable Energy Laboratory (NREL) for both SA and GC systems in 1993. From the date of release, this software has been downloaded by over 80000 people in 193 countries [2,39]. Fig.4 gives a schematic representation of HOMER.

To find the optimal sizing of HRES using HOMER, there are many papers have been published [40–50]. In [57], different designs of HRES including of PV and wind systems in GC mode along with intermittent production of hydrogen, to maximise the net present value of the system has been evaluated. In [59], for peak shaving and power arbitrage, the problem of determining the battery size for GC PV systems has been evaluated. In [60], a novel approach for optimally allocating various types of renewable energy sources in the hybrid energy systems, to minimize annual energy loss is presented. In [61], with using linear programming methods in GAMS software, optimal sizing of a HRES including PV, wind, storage systems and DG, in SA mode has been evaluated. A number of examples of the analytical methods used in papers are given in Table 4.

Table 1. Summary of graphical construction methods

Reference	SA, GC or SA-GC mode	Energy sources considered	Objectives	Outcome
[13]	SA	wind, PV and battery	Capital cost	In this paper, the authors developed an approach to calculate optimal sizing of a HRES including PV and battery systems for SA mode.
[14]	SA	wind and PV	Power balance	In this paper, the authors proposed a technique to find the optimal combination of wind-PV system using the existing meteorological data, based on the solution of supply-demand energy balance.

Table 2. Summary of probabilistic methods

Reference	SA, GC or SA-GC mode	Energy sources considered	Objectives	Outcome
[15]	SA	PV, wind and battery	loss of power supply probability (LPSP)	In this paper, a HRES including wind turbine, PV modules, and battery is considered, and the optimized combinations of them are obtained for various loss of power supply probability (LPSP).
[16]	SA	Diesel generator, wind and battery	expected energy not supplied (EENS)	In this paper, a method to model and simulatethe operation of a wind-Diesel energy conversion system is considered.
[17]	SA-GC	PV- wind	Annual total cost	In this paper, the results can be used to calculate the energy index of reliability and to document many other relationships between various system parameters of interest.
[18]	SA	PV, wind and battery	Expected energy supplied (EES)	In this paper, the proposed method may be associated with a production costing program to determine, using a probabilistic method, the effect of renewable resources on existing or planned thermal systems.
[19]	SA	PV-wind	EIR which is directly related to EENS and the internal rate of return	In this paper, the effect of using tracking system on the energy performance of a hybrid system including wind and PV, with a probabilistic approach, is studied.
[20]	SA	wind generator	Wind power imbalance	In this paper, the authors use a probabilistic method to appraisement reserve requirements and establish a methodology that makes it possible to distinguish amongst various categories of reserves based on the imbalance drivers of wind energy.
[21]	GC-SA	wind-PV	Annual total cost	In this paper, a method for the probabilistic approach of wind speed and solar irradiance data is presented for evaluation, at a given place, the electric energy generated by wind system and PV system.
[22]	SA	PV, wind and diesel Generator	Loss of load expectation (LOLE)	In this paper, to help system designers on selection of energy types, size of them, operating policies and etc. a simulation method is proposed, when utilizing wind energy and PV systems in small isolated systems.
[23]	SA	PV, battery	System cost	For sizing of PV modules and battery storage, in this paper a novel approach is presented for a SA hybrid system including PV and wind systems.
[24]	SA	PV, wind, diesel generator, battery	Net present cost (NPC)	In this paper, to reduce the computational effort, the probabilistic method is considered to generate an input-output dataset of various samples that were later used to train the artificial neural networks.
[25]	SA-GC	PV, wind and battery	cost of system	In this paper, a HRES with using "Box-Behnken design" and "RSM", based on an hourly operating cost, is optimized.

Table 3. Summary of iterative methods

Reference	SA, GC or SA-GC mode	Energy sources considered	Objectives	Outcome
[26]	SA	PV, wind and battery	Number of PV panel, total cost analysis	In this paper, the presented solution is favorably compared with all other SA energy alternatives, and it shows the ability of HRES to regulate even in areas where the local renewable energy systems potential is not necessarily of high quality.
[27]	SA	PV, micro-hydro, biogas biomass	limits of battery storage and unit generation	In this paper, an optimum control algorithm written in C++, based on combined dispatch strategy and allowing easy handling of the models and data of HRES ingredients is investigated.
[28]	SA	PV, battery	SOC	In this paper, with using MATLAB simulation, sizing of a SA hybrid system including PV and battery systems, is presented.
[29]	SA	PV, wind and battery	LPSP, levelised cost of energy (LCE)	In this paper, a new optimum sizing method for HRES including wind, PV and battery storage systems, based on the LPSP and LCE, is presented.
[30]	SA	Diesel generator, wind and battery	total cost and fuel consumption	In this paper, an optimal sizing of a HRES including wind and DG in SA mode based on the minimum long term electricity cost, has been evaluated.
[31]	SA	PV, battery and diesel generator	Cost of energy (COE)	According to the results of this paper, the presented sizing search approach can lead to the convergence of the optimal objective solutions with diminution to its computational load.
[32]	SA	PV, battery, fuel cell (FC)	System cost, system efficiency	In this paper, three SA PV systems with using energy storage systems are optimized.
[33]	SA-GC	wind, PV and battery	System cost	According to the results of this paper, a novel optimal sizing approach for a HRES including wind, PV and battery systems, for both SA and GC mode of system working, is presented.
[34]	SA	PV-wind	Total cost	In this paper, performance of a HRES including PV and wind systems, PV-alone system and wind-alone system, for utilization as SA systems, for use at the residential customer level has been evaluated.
[35]	SA	wind, PV and battery	Unutilized energy probability, deficiency of power supply probability, relative excess power generated and life cycle unit cost	In this paper, a new method to find the optimal sizing of a hybrid energy system including PV and wind systems, based on iterative method is presented.
[36]	SA	PV, wind, and micro-hydro	Total capital cost	In this paper, a general model to find an optimal sizing of a HRES including wind, PV, micro hydro, DG and battery for a rural community is developed.
[37]	SA-GC	PV, wind and battery	Annualized system cost	In this paper, a new optimum sizing method for HRES including wind, PV and battery storage systems in SA mode, based on the LPSP and ACS, is presented.
[38]	SA	PV, wind and battery	Hybrid system cost	In this paper, under different loads and unit cost of auxiliary energy systems, optimal sizing of a HRES including wind, PV and battery storage systems, is presented.

E. Artificial intelligence methods

Artificial intelligence methods such as genetic algorithms (GA), particle swarm optimization (PSO), artificial bee colony (ABC) and etc. are of widely used methods in hybrid systems [62–66]. In [70], a HRES including wind, PV and FC systems, to supply power demand with consideration the outage probabilities of three main ingredients of system, i.e. PV module, wind system, and power electronic converter, is designed. In [80], an optimal method based on a GA for find the sizing of a SA hybrid energy system including PV and wind systems is presented and according to the results of this paper, the GA converges is very well. In [81], the performance of a HRES including renewable energy systems and energy storage systems, to meet a controllable

Table 4. Summary of analytical methods

Reference	SA, GC or SA-GC mode	Energy sources considered	Objectives	Outcome
[51]	SA	wind, biogas, PV, biomass, battery and small power plant	Energy index ratio (EIR)	In this paper, sizing of HRES components, for four various load profiles is presented and for the selection of optimum solution of year round application, two reliability values are investigated.
[52]	SA	PV, biogas, biomass, battery, small hydro power plant and DG	COE	In this paper, an optimum control algorithm written in C++, based on combined dispatch strategy and allowing easy handling of the models and data of HRES ingredients is investigated.
[53]	SA	wind, PV and battery bank	Production cost	In this paper, an analytical approach for the well-being evaluation of small independent power systems with wind and PV systems, is presented.
[54]	GC	PV, wind and battery	Power balancing	In this paper, a new method for characterizing maximum energy storage prescriptions for a balancing area or interconnections is presented.
[55]	SA	PV, lead-acid battery	Energy payback period	According to the results of this paper, the best energy based sustainable solutions should use mc-Si or CdTe panels, while the size of the optimum energy independent PV-Battery arrangement is remarkably influenced by the local solar energy.
[56]	GC	Hydro power plant, natural gas and coal	COE	In this paper, a mixed integer linear programming model for the optimal planning of a hybrid energy system design for a nation to meet a specified CO2 emission aim is discussed.
[57]	GC	PV, wind and H2	Net present value (NPV)	In this paper, various designs of HRES including of PV and wind systems in GC mode along with intermittent production of hydrogen, to maximise the NPV of the system has been evaluated.
[58]	SA-GC	PV, FC, wind, micro-turbine and battery	Total cost and total Benefit	In this paper, for optimal sizing of an energy storage system in a hybrid energy system, a novel algorithm based on the cost benefit analysis has been raised.
[59]	GC	PV and battery	Net power purchase cost	In this paper, for peak shaving and power arbitrage, the problem of determining the battery size for GC PV systems has been evaluated.
[60]	SA	Wind, PV and battery	Annual energy losses	In this paper, a novel approach for optimally allocating various types of renewable energy sources in the hybrid energy systems, to minimize annual energy loss is presented.
[61]	SA	Wind, PV, DG and battery	COE	In this paper, with using linear programming methods in GAMS software, optimal sizing of a HRES including PV, wind, storage systems and DG, in SA mode has been evaluated.

heating, ventilation, and air conditioning has been evaluated. A number of examples of the artificial intelligence methods used in papers are given in Table 5.

F. Hybrid methods

Combining two or more different methods for optimal sizing of HRES can be called as hybrid method. This method is the best suitable approach to solve multi-objective design. For multi-objective problems, there are two general methods, one is to elide the individual objective functions into a single compound and the second general method an entire Pareto optimal solution set is to be determined. "Obtained solution is expressed to be Pareto optimal if it is dominant amongst several solutions in the solution space" [3, 11, 82]. Fig.5, shows Pareto front of a multi-objective evolutionary algorithms (MOEA). In [85], a hybrid of renewable energy sources and maximize its contribution to the peak load is optimized. Also in this paper demand

Table 5. Summary of artificial intelligence methods

Reference	SA, GC or SA-GC mode	Energy sources considered	Objectives	Outcome
[67]	SA	PV, batteries banks	PV generator area	In this paper, to find an appropriate model for sizing stand alone PV systems, the possibility of using an adaptive artificial neural network is discussed.
[68]	SA	Wind- FC	NPC	In this paper, the optimal sizing of a HRES including wind turbines, FC, an electrolyzer, hydrogen tanks, a reformer and converters, are considered.
[69]	SA	PV, wind and battery	COE	According to the results of this paper, cost of system in a hybrid system including PV and wind systems, is lower compared to using either PV system alone or wind system alone.
[70]	SA	Wind, PV and FC	Annualized cost	In this paper, a HRES including PV, wind and FC systems, to supply power demand with consideration the outage probabilities of three main ingredients of system, i.e. PV module, wind system, and power electronic converter, is designed.
[71]	SA	Wind, microturbine and battery	Total operating cost	According to the results of this paper, the opportuneness and potential merits of the presented PSO based energy management method for the HRES.
[72]	SA	Wind, PV and battery	ACS	In this paper, to optimize the sizing of a HRES including PV, wind and battery systems, an optimal approach based on a GA, is presented.
[73]	SA	Wind, PV and battery	Total system cost	In this paper, to optimize the sizing of a HRES including PV, wind and battery systems, an optimal method based on a simulated annealing algorithm, is presented.
[74]	SA	Wind, PV and battery	NPV, COE	According to the results of this paper, a HRES in SA mode can deliver energy at an acceptable cost.
[75]	SA	PV, small and large wind, DG and battery	System penetration and LEC	In this paper, the possible for achieving very high renewable energy source penetration levels with the introduction of battery energy storage systems in an existing small island system is discussed.
[76]	SA	Wind, PV and DG	NPV	In this paper, a HRES including wind, PV, battery storage and DG systems, was optimised with using GA.
[77]	SA-GC	Wind, PV, DG and battery	LCE	In this paper, a developed formulation for determination of optimal resource sizing for planning of autonomous hybrid energy system is presented.
[78]	SA	Wind, PV, micro hydro plant and Battery	Total cost of the system	In this paper, to find the optimal sizing of a hybrid energy system, a biogeography based optimization approach has been raised.
[79]	SA-GC	PV, wind and battery	Total annual cost	In this paper, to find the optimal sizing of a HRES including wind and PV systems, a discrete simulated annealing algorithm is presented.
[80]	SA	Wind, PV and battery	Total capital cost	In this paper, an optimal method based on a GA for find the sizing of a SA HRES including PV and wind systems is presented and according to the results of this paper, the GA converges is very well.
[81]	SA	Wind, PV and battery	Cost, efficiency	In this paper, the performance of a HRES including renewable energy systems and energy storage systems, to meet a controllable heating, ventilation, and air conditioning has been evaluated.

response technologies and demand side management are considered. In [93], a multi-objective linear programming model that can be used to determine the optimal size of HRES and existing fossil fuel facilities on a regional basis is presented. In [94], the sizing and techno-economical optimization of a SA hybrid system including PV and wind systems for three sites located at Corsica island are presented. According to the results of [99], via more efficient control and harmony of storage systems, the wind power plant output can be buffered to ensure that it produces the prognosis amount of power within a tight tolerance. A number of examples of the hybrid methods used in papers are given in Tables 6 and 7.

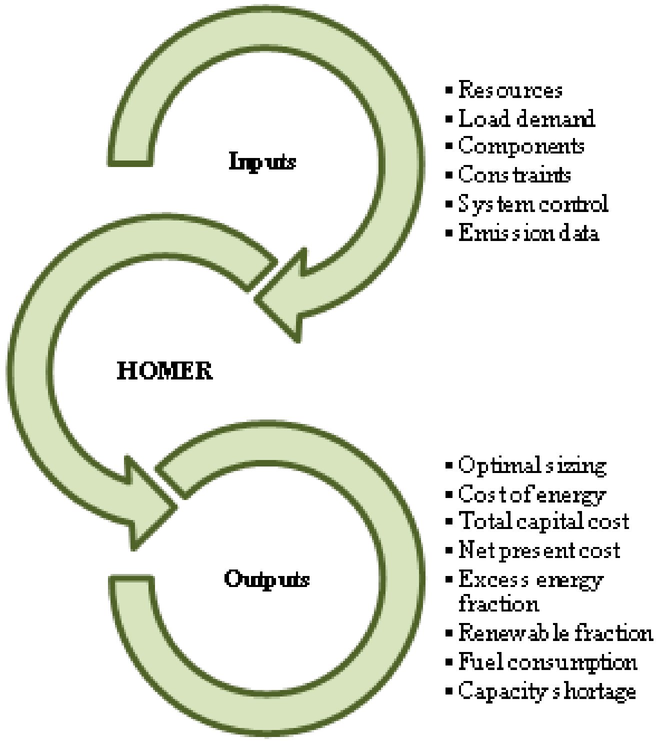

Fig. 4. Schematic representation of HOMER

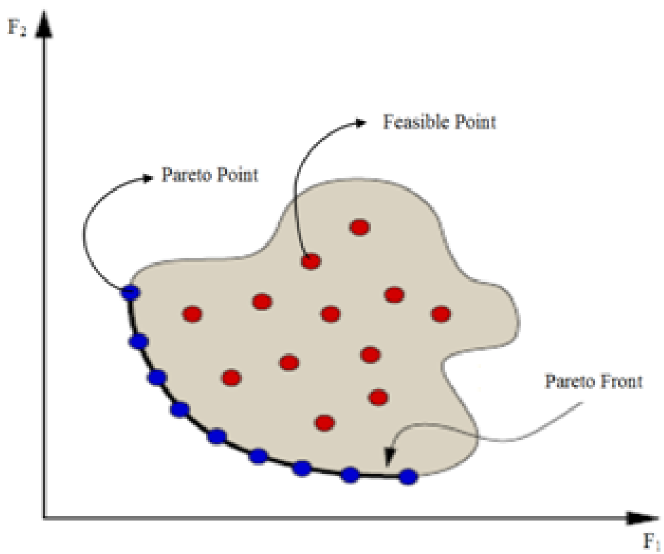

Fig. 5. Pareto front of a MOEA

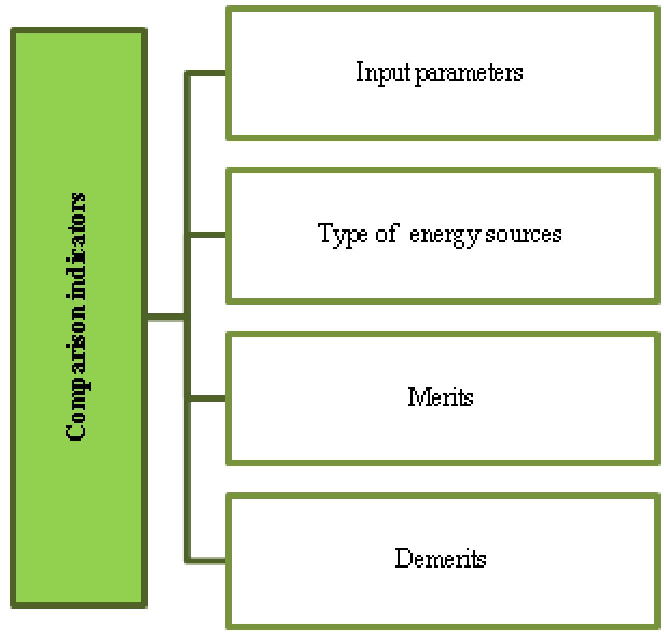

Fig. 6. Comparison indicators for HRES sizing methodologies

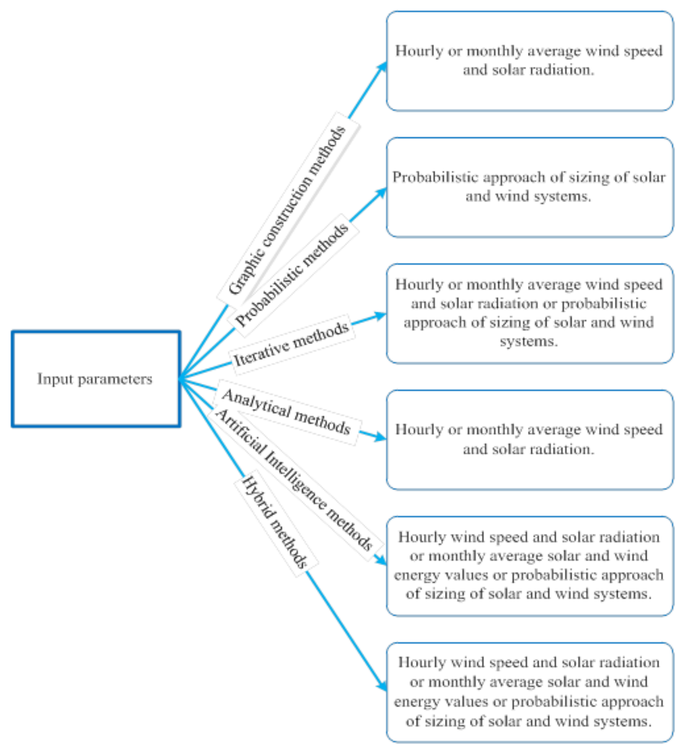

Fig. 7. Input parameters in sizing methodologies of HRES

3. COMPARISON INDICATORS FOR SIZING METHODOLOGIES

Selection of an appropriate method for HRES sizing requires using some proper indices. This section presents some indicators to compare the appropriate sizing methods of HRES, as illustrated in Fig.6.

A. Input parameters

One of indicators used to compare sizing methods is their input parameters. Input parameters reported in references for all of the sizing methodologies are shown in Fig.7.

B. Type of energy sources

The second indicator is type of energy resources used in each of the optimal sizing methodologies. Energy sources for all of the sizing methodologies are shown in Fig.8.

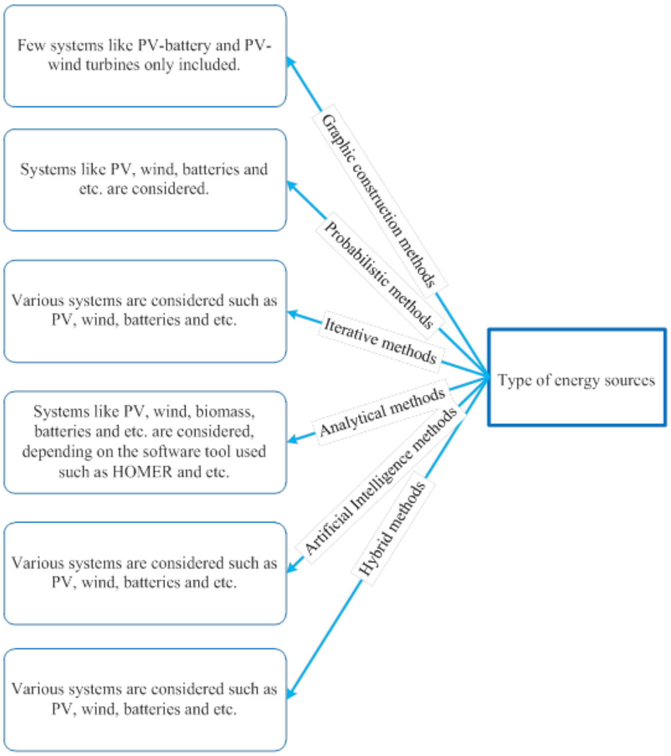

Fig. 8. Type of energy sources in sizing methodologies of HRES

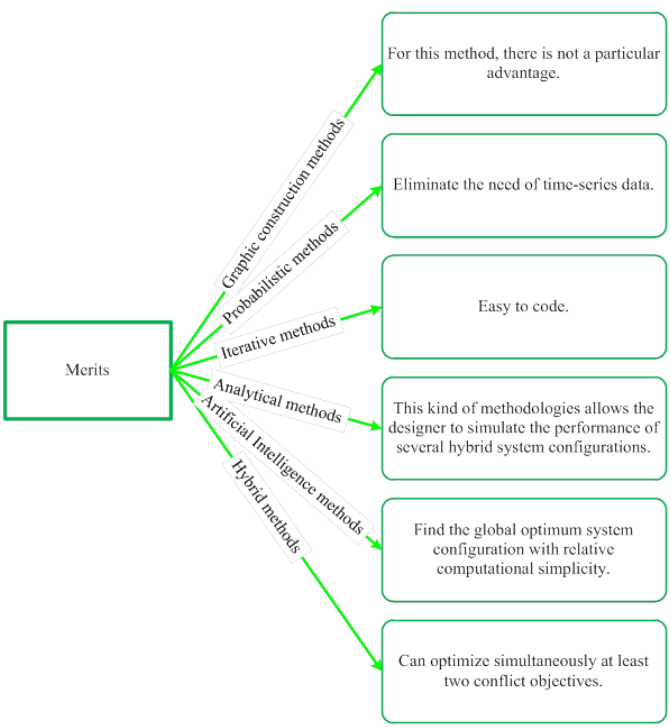

Fig. 9. Merits in sizing methodologies of HRES.

C. Merits

ch of optimal sizing methodologies, has its own advantages. Merits for all of the sizing methodologies are shown in Fig.9.

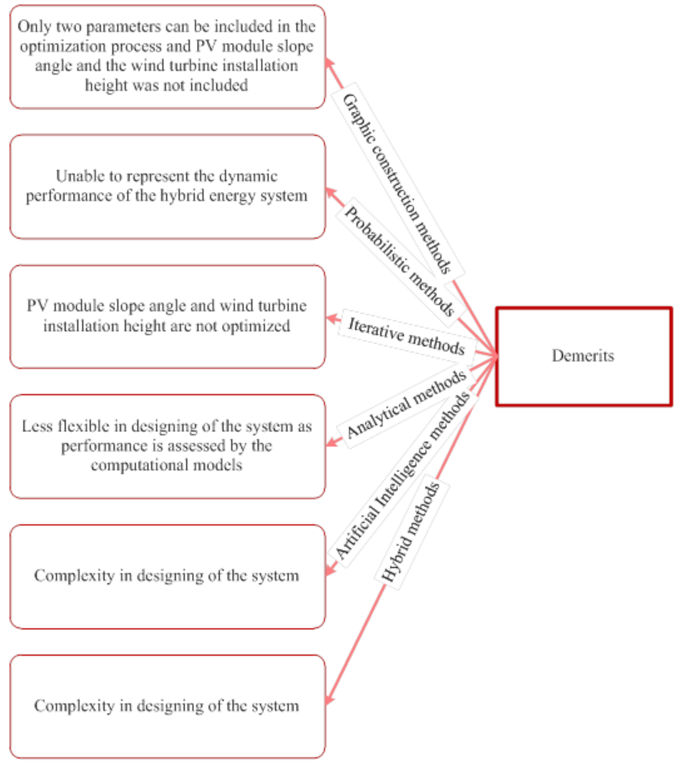

Fig. 10. Demerits in sizing methodologies of HRES.

D. Demerits

To use each of the optimal sizing methodologies, there are some limitations. For example, in graphical construction approach, just two parameters can be contained in optimization process. Parameters such as wind turbine installation height or PV tilt angle was not included. Probabilistic approaches incapable to represent the dynamic performance of HRES.

Demerits for all of the sizing methodologies are shown in Fig.10.

Each of the indicators presented, for any of the sizing methods were evaluated and thus, the possibility of comparing the optimal sizing methodologies of HRES to suit each specific system and selection of an appropriate sizing for system designers is provided. According to studies, each of the sizing methodologies, has its specific features but using hybrid methods can cause a decrement in the operation time, while producing the best suitable result simultaneously, due to the hybrid methods or in other words, the multi objective methods can resolve the constraints of a particular approach by adding some good features of other appropriate approaches, so the multi objective methods are the most versatile [103].

Table 6. Summary of hybrid methods

Reference	SA, GC or SA-GC mode	Energy sources considered	Objectives	Outcome
[83]	SA-GC	PV, wind, diesel	NPC, pollutant emissions	In this paper, with using strength pareto evolutionary algorithm, multi-objective design in the HRES design, is considered.
[84]	GC	wind, nuclear, coal-steam, hydro, Oil-steam	fuel consumption, Total costs, CO2 emission, minimization of outage cost and energy price risk	In this paper, multi-objective generation expansion planning model of power electric system including RESs is evaluated.
[85]	SA-GC	PV, wind and hydro	HRES share to the peak load	In this paper, a hybrid of renewable energy sources and maximize its contribution to the peak load is optimized. Also in this paper demand response technologies and demand side management are considered
[86]	SA	PV, wind, diesel, biodiesel, FC and battery	Cost of energy	According to the results of this paper, compared to the solutions provided by individual tabu search or individual simulated annealing methods, combining these two methods, ameliorates the obtained solutions, in terms of convergence and quality.
[87]	SA	PV, wind and battery	Life cycle cost (LCC), system embodied energy, LPSP	In this paper, for the Multi-Objective design of a HRES including PV, wind and battery, a controlled elitist genetic algorithm is presented.
[88]	SA	PV, wind and FC	Voltage stability, COE, emissions and power loss minimization	In this paper, to solve the distribution system reconfiguration and sizing of HRES including PV, wind, FC, a new multi objective ABC algorithm has been raised.
[89]	GC	PV and battery	ACS, peak power decrement and voltage regulation	In this paper, the possibility of using battery storages in the public low voltage distribution grid, to defer upgrades needed to develop the penetration of PV, is investigated.
[90]	GC	PV and wind	Emissions reduction, estimated cost and social acceptance	In this paper, optimal sizing of a wind-PV system with using various multi-criteria optimization methods is presented.
[91]	SA	Wind, PV and DG	LCE and reliability	In this paper, two algorithms for performing two design scenarios and the results of case studies delivered using the presented design approach is discussed.
[92]	SA	PV, wind, diesel, biodiesel and battery	COE and gas emissions	In this paper, a multi-objective evolutionary algorithm method for the optimum economic and environmental efficiency of HRES is expressed.
[93]	SA-GC	PV, wind, biomass, coal plant	Limits of capital investment, generation and biomass transport	A multi-objective linear programming model that can be used to determine the optimal size of HRES and existing fossil fuel facilities on a regional basis is presented.

Table 7. Summary of hybrid methods (continued)

Reference	SA, GC or SA-GC mode	Energy sources considered	Objectives	Outcome
[94]	SA-GC	Wind, PV and battery	LCE, LPSP	In this paper, the sizing and techno-economical optimization of a HRES including PV and wind systems (in SA mode), for three sites located at Corsica island are presented.
[95]	SA-GC	Wind, PV and battery	Gas emissions, EIR and cost of system	In this paper, a set of trade-off solutions is presented using the multi-criteria metaheuristic approach that offers many design alternatives to the system disigner.
[96]	SA	Wind, PV and battery	ACS, LPSP	In this paper, with using a multi objective genetic algorithm, size of a HRES including wind, PV and battery are optimized.
[97]	SA-GC	Wind, PV, DG, hydrogen and battery	NPC, unmet load, pollutant emissions	In this paper, by expressing 2D and 3D Pareto front, simultaneously optimized three conflicting objectives.
[98]	SA-GC	PV and battery	Gas emission, energy losses and generation cost	According to the results of this paper, betterment of voltage profile was the most suitable for the intermediate values of objective functions.
[99]	SA	Wind and battery	cost of storage system	According to the results of this paper, via more efficient control and harmony of storage systems, the wind power plant output can be buffered to ensure that it produces the prognosis amount of power within a tight tolerance.
[100]	SA-GC	Wind, PV, FC, battery and DG	LLP, NPV and fuel emission	In this paper, due to uncertainty of resources, associated with wind speed and solar irradiation, a new approach to specify the power management strategy of the system, is presented.
[101]	GC	wind farms, nucler, steam units, coal units, gas turbines, geothermal and hydro units	Price risks and import of fuel, costs and environmental impact	In this paper, a multiperiod multi-objective generation expansion planning (MMGEP) model is raised and a framework to solve the MMGEP model)to obtain the Pareto optimal solutions(is presented.
[102]	SA-GC	Wind, PV, FC, battery and DG	Total system cost, CO2 emissions, LLP	In this paper, a novel method for optimizing the size of a HRES including wind, PV, DG, FC, electrolyzer, H2 tank and batteries is presented.

4. CHALLENGES AND FUTURE TRENDS IN HRES

Despite the many benefits of using renewable energy sources, there are challenges that need to be addressed in future research. Some of these challenges include:

- To increase incentives for using renewable energy sources, their production costs should be reduced.
- A significant part of energy in the energy conversion process is eliminated by power converters in HRES.
- Hydrogen economy and hydrogen production should be the subject of future research, because success in this field can be very beneficial.
- Accomplish transient analysis of system by step changes in the variable parameters is required for stability issues of HRES.
- One of the constant topics for research is the use of nanotechnology to improve the various components of the system.
- Many research should be carried out in related to various storage systems, to increases their lifespan and efficiency, also the price reduction of storage systems should also be considered.

5. CONCLUSIONS

In this paper, HRES sizing methods were reviewed and compared using some appropriate indicators. According to the study it was found that each of the sizing methodologies has its specific features but it seems that hybrid methods (combination of two or more of above mentioned methods) may act better than each of them lonely. At the end, some of the challenges and future trends in the field of hybrid systems were discussed.

REFERENCES

1. Luna-Rubio R, Trejo-Perea M, Vargas-Va zquez D, Rios-Moreno GJ. Optimal sizing of renewable hybrids energy systems: A review of methodologies. Sol Energy 2012;86:1077–88.
2. Erdinc O, Uzunoglu M. Optimum design of hybrid renewable energy systems: overview of different approaches. Renew Sustain Energy Rev 2012;16:1412–26.
3. Fadaee M, Radzi MAM. Multi-objective optimization of a stand-alone hybrid renewable energy system by using evolutionary algorithms: a review. Renew Sustain Energy Rev 2012;16:3364-9.
4. Mariem Smaoui, Achraf Abdelkafi, Lotfi Krichen. Optimal sizing of stand-alone photovoltaic/wind/hydrogen hybrid system supplying a desalination unit. Solar Energy, 2015, 120: 263–276.
5. Md. Mustafizur Rahman, Md. Mohib-Ul-Haque Khan, Mohammad Ahsan Ullah, Xiaolei Zhang, Amit Kumar. A hybrid renewable energy system for a North American off-grid community. Energy, 2016;97:151-160.
6. Jaesung Junga, Michael Villaran. Optimal planning and design of hybrid renewable energy systems for microgrids. Renewable and Sustainable Energy Reviews, 2017;75: 180-191.
7. Umer Akram, Muhammad Khalid, Saifullah Shafiq. Optimal sizing of a wind/solar/battery hybrid grid-connected microgrid system. IET Renewable Power Generation, 2018;12: 72 - 80.
8. Tony El Tawil, Jean Frederic Charpentier, Sizing and rough optimization of a hybrid renewable-based farm in a stand-alone marine context. Renewable Energy, 2018; 115: 1134-1143.
9. Nehrir MH, Wang C, Strunz K, Aki H, Ramakumar R, Bing J,et al. A review of Hybrid renewable/alternative energy systems for electric power generation: configurations, control, and applications. IEEE Trans Sustain Energy 2011;2(4):392–403.
10. Subho Upadhyay, M.P. Sharma. A review on configurations, control and sizing methodologies of hybrid energy systems. Renew Sustain Energy Rev 2014; 38:47- 63.
11. Anurag Chauhan , R.P.Saini. A review on Integrated Renewable Energy System based power Generation for stand-alone applications: Configurations, storage options, sizing methodologies and control. Renew Sustain Energy Rev 2014; 38:99-120.
12. Ahmed Said Al Busaidi, Hussein A Kazem, Abdullah H Al-Badi, Mohammad Farooq Khan. A review of optimum sizing of hybrid PV–Wind renewable energy systems in oman. Renewable and Sustainable Energy Reviews, 2016;53: 185-193.
13. Borowy BS, Salameh ZM. Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system. IEEE Trans Energy Convers 1996;11(2):367–73.
14. Markvart T. Sizing of hybrid PV–wind energy systems. Sol Energy 1996;59 (4):277–81.
15. Yang HX, Lu L, Burnett J. Weather data and probability analysis of hybrid photovoltaic-wind power generation systems in Hong Kong. Renew Energy 2003;28(11):1813–24.
16. Karaki SH, Chedid RB, Ramadan. Probabilistic production costing of diesel–wind energy conversion systems. IEEE Trans Energy Convers 2000;15(3):284–9.
17. Tina G, Gagliano S, Raiti S. Hybrid solar/wind power system probabilistic modeling for long-term performance assessment. Sol Energy 2006;80 (1):578–88.
18. Karaki SH, Chedid RB, Ramadan R. Probabilistic performance assessment of autonomous solar–wind energy conversion systems. IEEE Trans Energy Convers 1999;14(3):766–72.
19. Tina GM, Gagliano S. Probabilistic modeling of hybrid solar/wind power system. Renew Energy 2011;36(1):1719–27.
20. Vos KD, Morbee J, Driesen J, Belmans R. Impact of wind power on sizing and allocation of reserve requirements. IET Renew Energy Gener 2012;7(1):1-9.
21. Tina G, Gagliano S. Probabilistic analysis of weather data for a hybrid solar/wind energy system. Int J Energy Res 2011;35(3):221-32.

22. Karki R, Billington R. Reliability/cost implications of PV and wind utilization in small isolated power systems. IEEE Trans Energy Convers 2001;16(4):368–73.

23. Bagul AD, Salameh ZM, Borowy B. Sizing of a stand-alone hybrid wind photovoltaic system using a three-event probability density approximation. Sol Energy 1996;56(4):323–35.

24. Lujano-Rojas JM, Dufo-López R, Bernal-Agustín JL. Probabilistic modeling and analysis of stand-alone hybrid power systems. Energy 2013;63:19–27.

25. Ekren O, Ekren BY. Size optimization of a PV/wind hybrid energy conversion system with battery storage using response surface methodology. Appl Energy 2008;85:1086–101.

26. Kaldellis JK, Zafirakis D, Kavadias K. Minimum cost solution of windphotovoltaic based stand-alone power systems for remote consumers. Energy Policy 2012;42(1):105–17.

27. Gupta A, Saini RP, Sharma MP. Steady-state modeling of hybrid energy system for off grid electrification of cluster of villages. Renew Energy 2010;35:520–35.

28. Nikhil PG, Subhakar D. Sizing and parametric analysis of a stand-alone photovoltaic power plant. IEEE J Photovolt 2013;3(2):776–84.

29. Yang H, Lu L, zhou W. A novel optimization sizing model for hybrid solar-wind power generation system. Sol Energy 2007;81(1):76–84.

30. Kaldellis JK, Kondili E, Filios A. Sizing a hybrid wind-diesel stand-alone system on the basis of minimum long-term electricity production cost. Appl Energy 2006;83(1):1384–403.

31. Zhang X, Tan SC, Li G, Li J, Fang Z. Components sizing of hybrid energy systems via the optimization of power dispatch simulations. Energy 2013;52:165–72.

32. Li C-H, Zhu X-J, Cao G-Y, Sui S, Hu MR. Dynamic modeling and sizing optimization of stand-alone photovoltaic power systems using hybrid energy storage technology. Renew Energy 2009;32(3):815–26.

33. Xu L, Ruan X, Mao C, Zhang B, Luo Y. An improved optimal sizing method for wind-solar-battery hybrid power system. IEEE Trans Sustain Energy 2013;4 (3):774–84.

34. Kellogg WD, Nehrir MH, Venkataramanan G, Gerez V. Generation unit sizing and cost analysis for stand-alone wind, photovoltaic and hybrid wind/PV systems. IEEE Trans Energy Convers1998;13(1):70–5.

35. Prasad AR, Natarajan E. Optimization of integrated photovoltaic-wind power generation systems with battery storage. Energy 2006;31:1943–54.

36. Ashok S. Optimised model for community-based hybrid energy system. Renew Energy 2007;32(7):1155–64.

37. Yang H, Zhou W, Lou C. Optimal design and techno-economic analysis of a hybrid solar-wind power generation system. Appl Energy 2009;86(2):163–9.

38. Ekren BY, Ekren O. Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions. Appl Energy 2009;86(9):1387-94.

39. <www.homerenergy.com>[accessed 11.04.15].

40. Rehman S, El-Amin IM, Ahmad F, Shaahid SM, Al-Shehri AM, Bakhashwain JM. Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant. Renew Sustain Energy Rev2007;11(4):635–53.

41. Bekele G, Palm B. Feasibility study for a stand alone solar–wind-based hybrid energy system for application in Ethiopia. Appl Energy 2010;87(2):487–95.

42. Beccali M, Brunone S, Cellura M, Franzitta V. Energy economic and environmental analysis on RET-hydrogen systems in residential buildings. Renew Energy 2008;33(3)366–82.

43. Shaahid SM, El-Amin I. Techno-economic evaluation of off-grid hybrid photovoltaic-diesel-battery power systems for rural electrification in Saudi Arabia - a way forward for sustainable development. Renew Sustain Energy Rev 2009;13(3):625–33.

44. Alzola JA, Vechiu I, Camblong H, Santos M, Sall M, Sow G. Microgrids project. Part 2. Design of an electrification kit with high content of renewable energy sources in Senegal. Renew Energy 2009;34(10):2151-9.

45. Himri Y, Stambouli AB, Draoui B, Himri S. Techno-economical study of hybrid Power system for a remote village in Algeria. Energy 2008;33(7):1128–36.

46. Prodromidis GN, Coutelieris FA. Simulation and optimization of a stand-alone power plant based on renewable energy sources. Int J Hydrog Energy 2010;35(19):10599–603.

47. Haidar AMA, John PN, Shawal M. Optimal configuration assessment of renewable energy in Malaysia. Renew Energy 2011;36(2):881–8.

48. Dalton GJ, Lockington DA, Baldock TE. Case study feasibility analysis of renewable energy supply options for small to medium-sized tourist accommodations. Renew Energy 2009;34(4):1134-44.

49. Ramos JS, Ramos HM. Sustainable application of renewable sources in water pumping systems: optimized energy system configuration. Energy Policy 2009;37(2):633–43.

50. Nandi SK, Ghosh HR. Techno-economical analysis of off-grid hybrid systems at Kutubdia Island, Bangladesh. Energy Policy 2010;38(2):976–80.

51. Patil ABK, Saini RP, Sharma MP. Sizing of integrated renewable energy system based on the load profiles and reliability index for the state of Uttarakhand in India. Renew Energy 2011;36(1):2809–21.

52. Gupta A, Saini RP, Sharma MP. Steady-state modeling of hybrid energy system for off grid electrification of cluster of villages. Renew Energy 2010;35(1):520–35.

53. Khatod DK, Pant V, Sharma J. Analytical approach for well-being assessment of small autonomous power systems with solar and wind energy sources. IEEE Trans Energy Convers 2010;25(2):535–45.

54. Makarov YV, Du P, Meyer MCWK, Jin C, Illian HF. Sizing energy storage to accommodate high penetration of variable energy resources. IEEE Trans Sustain Energy 2012;3(1):34–40.

55. Kaldellis JK, Zafirakis D, Kondili E. Optimum autonomous stand-alone photovoltaic system design on the basis of energy pay-back analysis. Energy 2009;34(9):1187–98.

56. Muis ZA, Hashim H, Manan ZA, Taha FM, Douglas PL. Optimal planning of renewable energy-integrated electricity generation schemes with CO2 reduction target. Renew Energy 2010;35(1):2562–70.

57. Dufo-Lo´pez R, Bernal-Agustı´n JL, Mendoza F. Design and economical analysis of hybrid PV–wind systems connected to the grid for the intermittent production of hydrogen. Energy Policy 2009;37(8):3082–95.

58. Chen SX, Gooi HB, Wang MQ. Sizing of energy storage for microgrids. IEEE Trans Smart Grid 2012;3(1):142–51.

59. Ru Y, Kleissl J, Martinez S. Storage size determination for grid connected photovoltaic systems. IEEE Trans Sustain Energy 2013;4(1):68 81.

60. Atwa YM, El-Saadany EF, Salama MMA, Seethapathy R. Optimal renewable resources mix for distribution system energy loss minimization. IEEE Trans Power Syst 2010;25(1):360–70.

61. Huneke F, Henkel J, Gonzalez JAB, Erdmann G. Optimization of hybrid off-grid energy system by linear programming. Energy Sustain Soc 2012;2:1–19.

62. Shakti Singh, Subhash Chandra Kaushik. Optimal sizing of grid integrated hybrid PV-biomass energy system using artificial bee colony algorithm. IET Renewable Power Generation, 2016; 10, 642 - 650.

63. Sarangthem Sanajaoba Singh, Eugene Fernandez. Modeling, size optimization and sensitivity analysis of a remote hybrid renewable energy system. Energy, 2018;143: 719-731.

64. Yashwant Sawle, S.C. Gupta, Aashish Kumar Bohre. Socio-techno-economic design of hybrid renewable energy system using optimization techniques. Renewable Energy, 2018;119: 459-472.

65. Shuli Wen, Hai Lan, David. C. Yu, Qiang Fu, Ying-Yi Hong, LijunYu, RuiruiYang. Optimal sizing of hybrid energy storage sub-systems in PV/diesel ship power system using frequency analysis. Energy 2017;140: 198-208.

66. Yashwant Sawle, S.C. Gupta, Aashish Kumar Bohre. Review of hybrid renewable energy systems with comparative analysis of off-grid hybrid system. Renewable and Sustainable Energy Reviews, 2018;81: 2217-2235.

67. Mellit A, Benghanem M, Hadj Arab A, Guessoum A. An adaptative artificial neural network model for sizing stand-alone photovoltaic systems: application for isolated sites in Algeria. Renew Energy 2005;30(10):1501–24.

68. Hakimi SM, Moghaddas-Tafreshi SM. Optimal sizing of a stand-alone hybrid power system via particle swarm optimization for Kahnouj area in south- east of Iran. Renew Energy 2009;34:1855–62.

69. Koutroulis E, Kolokotsa D, Potirakis A, Kalaitzakis K. Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms. Sol Energy 2006;80(1):1072–88.

70. Kaviani AK, Riahy GH, Kouhsari SHM. Optimal design of a reliable hydrogen-based stand-alone wind/PV generating system, considering component outages. Renew Energy2009;34:2380–90.

71. Pourmousavi SA, Nehrir MH, Colson CM, Wang C. Real-time energy management of a stand-alone hybrid wind-microturbine energy system using particle swarm optimization. IEEE Trans Sustain Energy 2010;1(3):193–201.

72. Yang H, Zhou W, Lu L, Fang Z. Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. Sol Energy 2008;82:354–67

73. Ekren O, Ekren BY. Size optimization of a PV/wind hybrid energy conversion system with battery storage using simulated annealing. Appl Energy 2010;87 (1):592–8.

74. Kumar R, Gupta RA, Bansal AK. Economic analysis and power management of a stand-alone wind/photovoltaic hybrid energy system using biogeography based optimization algorithm. Swarm Evol Comput 2013;8:33–43.

75. Vrettos EI, Papathanassiou SA. Operating policy and optimal sizing of a high penetration RES-BESS system for small isolated grids. IEEE Trans Energy Convers 2011;26(3):744–56.

76. Merei G, Berger C, Sauer DU. Optimization of an off-grid hybrid PV–wind–diesel system with different battery technologies using genetic algorithm. Sol Energy2013;97:460–73.

77. Paliwal P, Patidar NP, Nema RK. Determination of reliability constrained optimal resource mix for an autonomous hybrid power system using particle swarm optimization. Renew Energy 2014;63:194–204.

78. Bansal AK, Kumar R, Gupta RA. Economic analysis and power management of a small autonomous hybrid power system (SAHPS) using biogeography based optimization (BBO) algorithm. IEEE Trans Smart Grid 2013;4(1):638–48.

79. Askarzadeh A. A discrete chaotic harmony search-based simulated annealing algorithm for optimum design of PV/wind hybrid system. Sol Energy 2013;97:93–101.

80. Xu D, Kang L, Chang L, Cao B. Optimal sizing of standalone hybrid wind/PV Power systems using genetic algorithms. In: Proceedings of the Canadian conference on electrical and computer engineering; 2005.p.1722–5.

81. Arabali A, Ghofrani M, Amoli ME, Fadali MS, Baghzouz Y. Genetic algorithm-based optimization approach for energy management. IEEE Trans Power Deliv 2013;28(1):162–70.

82. Konak A, Coit DW, Smith AE. Multi-objective optimization using genetic algorithms: a tutorial. Reliability Engineering and System Safety 2006;91:992–1007.

83. Bernal-Agustín JL, Dufo-López R, Rivas-Ascaso DM. Design of isolated hybrid systems minimizing costs and pollutant emissions. Renew Energy 2006;31(14):2227–44.

84. Meza JLC, Yildirim MB, Masud ASM. A model for the multiperiod multiobjective power generation expansion problem. IEEE Trans Power Syst 2007;22(2):871–8.

85. Moura PS, DeAlmeida AT. Multi-objective optimization of a mixed renewable system with demand-side management. Renew Sustain Energy Rev 2010;14(5):1461–8.

86. Katsigiannis YA, Georgilakis PS, Karapaidakis ES. Hybrid simulated annealing-tabu search method for optimal sizing of autonomous power systems with renewables. IEEE Trans Sustain Energy 2012;3(3):330–8.

87. Abbes D, Martineza A, Champenois G. Life cycle cost, embodied energy and loss of power supply probability for the optimal design of hybrid power systems. Math Comput Simul 2014;98:46–62.

88. Nasiraghdam H, Jadid S. Optimal hybrid PV/WT/FC sizing and distribution system reconfiguration using multi-objective artificial bee colony (MOABC) algorithm. Sol Energy 2012;86(1):3057–71.

89. Tant J, Geth F, Six D, Tant P, Driesen J. Multiobjective battery storage to improve PV integration in residential distribution grids. IEEE Trans Sustain Energy 2013;4:182–91.

90. Alsayed M, Cacciato M, Scarcella G, Scelba G. Multicriteria optimal sizing of photovoltaic-wind turbine grid connected systems. IEEE Trans Energy Convers 2013;28(2):370–9.

91. Maheri A. Multi-objective design optimization of standalone hybrid wind–PV–diesel systems under uncertainties. Renew Energy 2014;66:650–61.

92. Katsigiannis YA, Georgilakis PS, Karapidakis ES. Multi-objective genetic algorithm solution to the optimum economic and environmental performance problem of small autonomous hybrid power systems with renewables. IET Renew Power Gener 2010;4(5):404–19.

93. Arnette A, Zobel CW. An optimization model for regional renewable energy development. Renew Sustain Energy Rev 2012;16:4606–15.

94. Diaf S, Belhamel M, Haddadi M, Louche A. Technical and economical assessment of hybrid photovoltaic/wind system with battery storage in Corsica island. Energy Policy 2008;36:743–54.

95. Wang L, Singh C. Multicriteria design of hybrid power generation systems based on a modified practice swarm optimization algorithm. IEEE Trans Energy Convers 2009;24(1):163–72.

96. Ould B, Sambou V, Ndiaye PA, Kébé CMF, Ndongo M. Optimal design of a hybrid solar–wind–battery system using the minimization of the annualized cost system and the minimization of the loss of power supply probability (LPSP). Renew Energy 2010;35(10):2388–90.

97. Dufo-López R, Bernal-Agustín JL. Multi-objective design of PV–wind–diesel–hydrogen–battery systems. Renew Energy 2008;33(12):2559–72.

98. Ippolitoa MG, Di Silvestre ML, Sanseverino ER, Zizzo G, Graditi G. Multi-objective optimized management of electrical energy storage systems in an islanded network with renewable energy sources under different design scenarios. Energy 2014;64:648–62.

99. Brekken TKA, Yokochi A, Jouanne AV, Yen ZZ, Hapke HM, Halamay DA. Optimal energy storage sizing and control for wind power applications. IEEE Trans Sustain Energy 2011;2(1):69–77.

100. Abedi S, Alimardani A, Gharehpetian GB, Riahy GH, Hosseinian SH. A Comprehensive method for optimal power management and design of hybrid RES-based autonomous energy systems. Renew Sustain Energy Rev 2012;16(3):31577–87.

101. Aghaei J, Akbari MA, Roosta A, Gitizadeh M, Niknam T. Integrated renewable-conventional generation expansion planning using multiobjective framework. IET Gener Transm Distrib 2012;6(8):773–84.

102. Sharafi M, ELMekkawy TY. Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach. Renew Energy 2014;68:67–79.

103. Atefeh Behzadi Forough, Ramin Roshandel. Multi objective receding horizon optimization for optimal scheduling of hybrid renewable energy system. Energy and Buildings, 2017;150: 583-597.