

A Comprehensive Review of Nature-Inspired Search Techniques Used in Estimating Optimal Configuration Size, Cost, and Reliability of a Mini-grid HRES: A Systemic Review

Samuel Ofori Frimpong(✉), Richard C. Millham, and Israel Edem Agbehadji

ICT and Society Research Group, Department of Information Technology, Durban University of Technology, Durban, South Africa

Abstract. Nature-inspired algorithms use random exploration and exploitation tactics as a searching strategy to explore a search space. These two searching schemes are harmonized in nature-inspired search techniques to solve any optimization problem. Although several traditional approaches have been applied to the design of optimal HRES, there is still a challenge of finding a near-optimal approach to estimate the configuration size, cost, and reliability of mini-grid HRES. In this paper, we reviewed the state-of-the-art optimization approaches that have been applied in estimating the configuration size, cost, and reliability of mini-grid HRES. A desktop-based research method was adopted in which a total of 49 scholarly articles which tie well to the topic was selected for a thorough review. Various nature-inspired search methods proposed and/or applied in the last 5 years (2016–2021) by different researchers in solving the optimization problem of HRES were showcased in this paper. The review suggested that the optimal design of HRES in most cases seeks to minimize a cost function and maximizes the reliability of the system to meet the load requirement. Again, based on the diverse scenarios and increasing complexities of HRES, nature-inspired algorithms promise better near-optimal solutions than their competitors. Furthermore, the review suggested that nature-inspired search techniques have been applied extensively in HRES optimization. Moreover, several studies have also hybridized two or more algorithms to improve the searching strategies for better performance of HRES. These findings among others suggest opportunities for future research in the design of near-optimal HRES. The review holds salient implications for researchers and industry professionals. It elucidates the chances to design a reliable, cost-efficient, and effective mini-grid HRES yet have economic benefits to the users.

Keywords: Nature-inspired search method · Optimization technique · Hybrid renewable energy system · Algorithms · Mini-grid

1 Introduction

The use of renewable energy resources to produce useful energy supply such as electricity is receiving reasonable attention in the global energy economy as the world strives to

© Springer Nature Switzerland AG 2021
O. Gervasi et al. (Eds.): ICCSA 2021, LNCS 12957, pp. 492–507, 2021.
https://doi.org/10.1007/978-3-030-87013-3_37

achieve a net-zero greenhouse gas emission by the end of this century [1, 2]. Renewable energy sources namely, sun, wind, biomass, hydro, etc. abound in nature, and they have the potential of generating energy for industrial, commercial, and domestic consumption [3–6]. Energy derived from these sources are clean, so they have little or no environmental consequences unlike fossil fuel products [7]. Moreover, a renewable energy system accrues economic benefits if the system is optimally designed and configured on the backdrop of economic objectives [8, 9]. They can operate in isolated, or grid-connected mode making its adoption easier for rural settlement and dispersed or cluster communities far-reaching with the grid [10]. These benefits of a renewable energy system do not come without challenges; renewable power production complexity is inherent in the resources used in their generation [11, 12]. The challenges of renewable source of energy and their advantages in power generation are outlined in Table 1. Due to their limitations, combining two or more renewable power generation units into a hybrid energy production system improves the system reliability in supplying power to the attached load [13, 14]. Hybridizing multiple resources to generate sufficient power to match a given load requires a thorough feasibility analysis at the system inception phase; this analysis is to ascertain proper sizing of the hybrid system components and their economic value [15].

Accordingly, an optimal configuration of HRES includes but not limited to maximizing the power generated from the system at a minimum cost. The need to configure HRES optimally is crucial for the economic management of the system as well as satisfying end users' demand. However, the HRES optimization problem is modelled as a nonlinear problem [16], and the difficult nature and complexities in solving such real-world optimization problems with exact methods fail to address the problem within a reasonable time [17] and space. Therefore approximation algorithms have become attractive alternatives to deal with this class of problem [18]. Though they may not find the optimal result, approximate algorithms have greater chances of finding a globally optimal solution. Approximation algorithms, also known as metaheuristics, are more generic approaches to solving a wide range of NP-hard optimization problem in a reasonable time to get a near-optimal solution. One benefit of metaheuristic algorithms is that they are simple to design and implement besides being robust algorithm [19]. Metaheuristic algorithms have wide applications in HRES optimization.

The optimization process involves several steps that result in finding a better solution usually by maximizing or minimizing an objective function of a modelled problem whiles satisfying certain restrictions of variables been considered. Optimizing HRES involves the formulation of a mathematical model to estimate the optimal configuration size of renewable energy technologies, the system reliability, and the economic benefit of the system. In the process, renewable resources availability, load profile, technical data of the power production units, and economic information are supplied to the optimization machinery to determine the optimum result. The dominating method adopted by scientists in this area of study continues to be a nature-inspired algorithm (NIA) [20, 21]. In these regards, the focus of this review is directed to analyzing the advancement in research concerning nature-inspired (metaheuristic) algorithms in dealing with HRES optimization problems.

HRES design is influenced by various factors, such as the availability of energy sources at specific sites as well as technical and social constraints; these factors directly

affect the power production arrangements of the system with financial repercussion. In this context, an optimal sizing combination is a vital factor to achieve higher reliability with the least cost of the system [22]. The optimal design of HRESs is a complicated task since the configuration depends on the knowledge of energy sources, technical specifications, environmental conditions, and load profiles [23]. Table 1 shows the types of renewable energy resources vis-à-vis their merits and demerits.

Table 1. Advantages and disadvantages of renewable resources in power generation

Renewable resource	Demerit	Merit
Hydro	Demographic oriented with rivers playing the major role Seasonal factors such as rainfall affect its use for power production	The leading contributor of renewable power generation Hydropower is relatively cheap compared to fossil fuel
Wind	Intermittent source of energy. The power source of wind is variable seasonally and demographically	Free resource No pollution hence environmentally friendly
Solar	Not available at night and cloudy days	Available anywhere almost all year round Free resource Environmentally friendly
Geothermal	Limited to geothermal power extraction points (tectonic plate boundaries)	Efficient power supply or backup during hot springs
Biomass	Although feedstock can be free there is an inherent logistic cost to convey raw material to power generation sites Availability of some raw materials are seasonally affected and might compete with human needs	For biomass, several technology options focus on a variety of feedstocks. These options can be used to meet a wide range of energy requirements, from large-scale industrial installations to small-scale rural applications. Biofuels are environmentally safer

It is imperative to determine the economic benefit of the energy system against the alternatives choices in making an informed decision. Moreover, an HRES reliability highly depends on the system's component, therefore proper analysis of an energy system power supply reliability is significant for its adoption. Generally, the capital investment for 100% HRES is high when compared to the grid tide power system operating on fossil fuel/natural gas or diesel generator, but the long-term benefit of HRES includes not only the economic advantage but a cleaner environment [22, 24]. An in-depth analysis of the recent trend of optimization techniques namely, NIAs or metaheuristics is conducted to bring to light a comprehensive knowledge of the methodology used in optimizing hybrid renewable energy systems.

The contributions of this paper are in three folds:

1. It presents a comprehensive assessment and the trending analysis of nature-inspired search techniques for optimization of mini-grid HRES in recent studies.
2. A succinct account of useful designing and implementation techniques of NIAs for optimization of HRES.
3. Lastly, we discuss open challenges and research opportunities for further studies in a mini-grid renewable-based hybrid system.

1.1 Methodology

In the methodology, we explain the criteria used to select and analyze scholarly works on the developments of nature-inspired search techniques in the optimization of mini-grid HRES. Keywords in the subject domain: nature-inspired algorithms and hybrid renewable energy system were searched in Web of Science, Scopus, and Google scholar databases. To narrowed down the scope of the articles of relevance to the study, some combinations of the keywords were used during the search. For example, "hybrid renewable energy system", "nature-inspired algorithm", "bio-inspired", "metaheuristic algorithm", "mini-grid", "microgrid", "optimization algorithm". By using the Keyword criterion, the relevant articles were excluded or included for detailed review. Based on the date of publication of the article available online from 2016 and later were selected from the search results. The candidate articles were chosen based on their close ties to hybrid renewable energy system optimization and nature-inspired search strategies. Initially, 300 research articles were downloaded from online sources, in which the Keyword and date of article publication criteria were applied. A total of 49 related articles were selected for detailed review. Other references are related to the algorithm's details, previous review studies, HRES background, and related articles for future research directions.

1.2 Paper Organization

The rest of the paper is organized as follows: Sect. 2 presents an overview of mini-grid HRES and the requirements for optimizing HRES; Sect. 3 provides a taxonomy of optimization algorithms with analysis of their advantages and disadvantages; Sect. 4 discusses comprehensively the advancements of nature-inspired search methods for optimizing HRES, and Sect. 5 concludes the study with recommendations for scientist and energy stakeholders.

2 Overview of Mini-grid Hybrid Renewable Energy System Optimization

A mini-grid (MG) is a locally-based electricity provider that uses distributed energy infrastructure to lower energy costs and emissions. MGs are preferred alternatives to supplying power in isolated communities or rural settlements where the conventional grid is not economically a viable option. The wide adoption of MG in developing countries particularly in Africa and Asia can increase electricity coverage, as one of the goals of

Sustainable Development Goal (SDG) 7, equitable access to energy is part of the global development agenda [25]. In different parts of the developing world, MGs will play a critical role in closing the electricity gap. The configuration of grid-independent MG must account for the optimal sizing of the system components to derive the economic benefits without compromising on the reliability [26] of power supplied by the system. In an MG, Photovoltaic (PV), wind turbines (WT), and energy storage system (ESS) are more likely to be hybridized to always meet the load demand at both peak and off-peak times [26]. It is crucial, therefore, to select an optimal sizing of power units for a specific goal or objective to be met by the MG. The challenges of meeting all the system constraints yet production adequate power have resulted in many studies investigating the optimization of MG hybrid renewable energy system.

The rest of this section is devoted to MG optimization requirements and procedure for designing, assessing, and performing techno-economic analysis of HRESs. Figure 1 showcases a flow chart of the optimization process of HRES; it starts by identifying the ideal combination of renewable technologies which will be suitable for the set-up within the locality. By using meteorological data such as solar irradiation, ambient temperature, wind speed, and the assessment of load to be served by the system, the optimal sizing of a renewable-based hybrid system can be estimated.

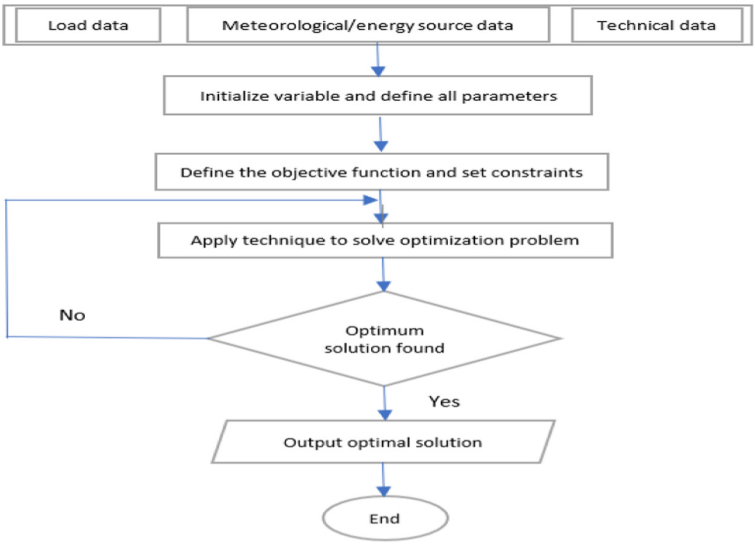


Fig. 1. Flow chart depicting the steps in optimization of HRES

2.1 Requirement for HRES Optimization

An HRES can be designed efficiently to achieve the specified objectives of users [27], here the HRES need an optimum component sizing before its configuration [26, 28]. The requirements for the optimization process are briefly discussed.

Data Requirement. Most importantly, the availability of renewable energy source on the site where the system is to be set up is paramount to realizing the optimal HRES configuration. To achieve the optimization objective(s), a study of the location's meteorological data characteristics is needed. If meteorological records of data are not obtainable for a given area, then satellite-based data or projected data may be used instead [27]. Another critical input data needed for optimal configuration of MG HRES is the electric load characteristics and profile. Since it is extremely difficult to determine and analyze actual load demand for all minute variations, hourly or daily estimates of load demand are commonly used for design optimization [27]. Finally, the specifications on the energy generation units provided by the vendors are equally important. This information details the device performance and efficiencies under various conditions. The permutation of the meteorological data with the device specifications gives a good estimate for the optimal configuration of the HRES. In the absence of actual device data, the web or scholarly literature could provide good representation of that information. With the set of information required for the configuration, the optimal decision can be deduced with the help of well-defined mathematical models. The data serve as input for the models; some of these models are examined in the next subsection.

Energy System Model. The performance of a mini-grid renewable-based hybrid system is highly dependent on components. The proper sizing of the component is usually determined with aid of mathematical models. Energy system models are mathematical models that have been developed to reliably represent various energy-related problems. These models are used in a variety of computing systems to identify and solve problems. For optimization, the accuracy of the developed models for a hybrid system component is critical. As a result, all required variables affecting energy conversion must be included in these models. These mathematical models should be based on simple principles, but in many situations, the sophistication of the model increases, or the researcher may overlook important variables, resulting in inaccuracy. Thereafter, the co-efficient of equations involving the hybrid system components which have been expressed as decision variables are evaluated to meet the optimization objective.

Objective Function. The problem of HRES optimization is generally posed in both economic and technological metrics when designing an optimal hybrid system. These two indices are used to determine the optimum system equipment sizing for a cost-effective and reliable system. The goal of the design issue is to reduce the cost feature, reduce CO_2 emissions, or increase system reliability. Cases of HRES optimization problems and the objective functions that needed to be solved are shown in Table 2. Since a technical evaluation should be performed for the mini-grid hybrid system to satisfy the load demand, reliability indices such as power supply probability (PSP), loss of power supply probability (LPSP), and loss of load probability (LLP) are frequently presented as reliability constraints (technical design index) in design studies for renewable energy systems.

Accordingly, the result of the HRES optimization problem revolves around the objective function and the defined constraints if any, to accurately estimate the co-efficient of all decision variables. The optimization results must be precise enough to avoid surplus or deficit power, and this is achieved if the data requirements for the proposed system and the corresponding equipment specifications are met.

Table 2. Sample cases of recent MG HRES optimization using AI methods

Ref	Year	Components/Energy sources	Optimization Algorithm	Objective	Optimization result
[29]	2020	PV, WT, DG and Battery,	NSGAII, NSGA III and MOPSO	Multi-objective: minimize LPSP, COE and maximize RF	NSGA II outperform the competitors with a minimum COE of 0.0588 $/kWh and a maximum of 0.14611 $/kWh
[30]	2020	PV, WT, micro-hydro turbines, fuel cell, electrolyser, hydrogen tank, compressors, power converters, supercapacitors (SCs), biopower plant	MFOA, DA, SSA, ALO, GWO, GOA	Optimal sizing of HRES components	MFOA found to result in a significant reduction in NPC, and it outperformed GA and PSO in terms of solution quality by 2.1% and 3.2% respectively
[31]	2021	PV, WT, and battery	Hybrid GWO and GA (HGWOGA)	Minimize annual cost	HGWOGA, GA and GWO found the optimal solution to be $ 5 572.01
[32]	2021	WT, PV, DG, and batteries	NSGA-II	Multi-objective model to size HRES	the renewable energy efficiency of 80% is achievable for the chosen climate
[33]	2021	PV, WT, FC, water electrolyser and Hydrogen gas tank	IAEO	Minimizing the Cost of Energy (COE), the reliability index presented by the Loss of Power Supply Probability (LPSP), and excess energy	the estimation of each energy component with the NPC of the system was deduced as: PV (17%), WT (20%), electrolyze (23%), hydrogen tank (32%), FC (2%) and inverter (6%)

(*continued*)

Table 2. (*continued*)

Ref	Year	Components/Energy sources	Optimization Algorithm	Objective	Optimization result
[34]	2020	PV, DG and FC	Modified CSA	Optimal sizing	CSA adaptive-AP found the optimal solution
[35]	2021	PV, WT, DG, and battery	PSO and ε-constraint method	Minimize the cost of energy (COE) and maximizing system reliability and RF	different optimal configurations were found for various sites
[36]	2020	PV, DG, and battery	cEHO	Minimize loss of load probability, CO_2 emissions value, and the annualized cost of the system	the initial capital of $48,680 can provide reliable supplementary energy for the load demand such that the PV penetration has an impact of 97.9% to emit 1735 kg/year of CO_2 less than the result of PSO and HOMER
[37]	2021	PV, WT, DG, and battery	EO	Minimize the net present cost (NPC)	the best NPC, LCOE, and LPSP are obtained via EO achieving 74327 $, 0.0917 $/kWh, and 0.0489, respectively

In addition, an accurate mathematical model can positively influence the HRES optimal result. However, central to the optimization processes is the approach or technique for optimizing. In the next section, we will discuss in detail the techniques which have been applied to the HRES optimization problems.

3 Optimization Techniques for HRES

Algorithms for computing the maximum or minimum of mathematical functions are known as optimization algorithms. When designing a mini-grid HRES, it is crucial to consider the efficiency of its components. The key aim is to improve efficiency while

lowering costs. These objectives can be met by optimizing the system model as described in the previous section. To achieve this goal an optimization technique is employed to solving the problem. There are several approaches to optimizing MG HRES. Classical, Computational/Artificial Intelligence and hybrid approaches are the three most widely used techniques for mini-grid hybrid systems.

3.1 Classical Techniques

The classical optimization methods are also referred to as analytical, traditional, or conventional methods. These optimization methods find the solution to an HRES optimization problem by utilizing information such as gradient or derivative of functions [38, 39]. The most widely used classical method for HRES optimization includes linear programming (LP), mixed-integer linear programming (MILP), Iterative Approach, Trade-off Approach. Some studies on HRES have been carried out their advantages and disadvantages have been thoroughly discussed in [39, 40].

Even though these methods are easier to use, understand, and have a wide variety of applications, these methods have a high risk of being stuck in the local optimum rather than the global optimum [27]. Table 3 summarizes the merits and demerits of the commonly used classical optimization techniques employed to solving MG HRES optimization problems.

3.2 AI Methods

The design of algorithmic models to solve increasingly complex problems is the focus of the algorithmic progress. These models may be based on mathematical models or they may be modelled on natural intelligence has resulted in what is known as Nature-inspired or meta-heuristic algorithms, which have had enormous success [39, 41, 42]. Evolutionary computation, swarm intelligence, artificial immune systems, are examples of these nature-inspired algorithms. These algorithms are part of the field of Artificial Intelligence (AI), and their application in HRES optimization have advanced the field. Several studies have applied AI techniques including particle swarm optimization (PSO), genetic algorithm (GA), ant colony optimization (ACO), biogeography based optimizations (BBO), differential evolution (DE), evolutionary programming (EP), evolution strategies (ES), artificial bee colony (ABC), honey bee mating optimization (HBMO), artificial immune system (AIS), harmony search (HS), and combinations of them.

The techniques here have some major disadvantages and advantages, some of which have been outlined in Table 4. Complex optimization problem, many of the algorithms fail to find out the optimal solution. In Table 4.

3.3 Hybrid Algorithms

The premature convergence affects most evolutionary computational techniques. These strategies take a long time to emerge from the local maxima or minima. By combining two or more optimization search techniques into a hybrid algorithm, these techniques can be used to solve a wide range of optimization problems. Hybrid techniques can overcome

Table 3. Advantages and disadvantages of classical optimization techniques for MG HRES adopted from [27]

Technique	Highlights	Strength	Weakness
Graphical	Provides a graphical representation of the solution to the optimization problem	Easy to visualize, understand, and simple to use	Cannot model several decision variables, and certain details cannot be captured
Probabilistic	Based on the random effects upon the performance of the system	Simple and straightforward to use	Difficult representing the dynamic changes and performances of hybrid systems
Iterative	It is a recursive process that stops when the best configuration is reached as per the design specifications	Easy to understand Tracks defects at early stages	Each iteration phase is rigid and does not overlap to accommodate any intermediaries
Linear programming	Model mathematical relationships of the system based on linear equations and inequalities	Best for solving a complex problem that can be express linearly, simple to implement, flexible, it can solve a wide range of problems	Linearity about variables, assumptions of linear programming are also unrealistic, there is a change in the relation between input, output gain, loss etc.
Trade-off	Based on a situation that involves losing one quality or accepting something in return for gaining another quality or aspect	Easy to understand	Application in renewable energy is limited

the limitations of individual techniques, resulting in more effective and reliable HRES solutions. In recent years, there has been a lot of interest in hybrid technique research [47].

While hybrid optimization techniques improve overall optimization performance, they may have drawbacks. For example, the hybrid MCS-partial PSO's optimism, hybrid iterative/suboptimal GA's solutions, random adjusting of the evolutionary algorithm's inertia weight, and optimization coding complexity [49].

Table 4. Advantages and disadvantages of some nature-inspired algorithms for MG HRES optimization

Algorithm	Advantage	Disadvantage	Ref
PSO	Simple to code; high convergence speed; minimum storage requirement	It converges prematurely. Difficult to design the parameters, it may be trapped in local optimum	[43]
GA	Can solve problems with multiple solutions; available in MATLAB toolbox	Fitness function calculation is repeated for each generation. It may not converge on global optimum if it is not carefully and properly implemented	[42, 44, 45]
ABC	Algorithms have both local and global search abilities; it is easy to use	With more decision variables the convergence rate is slow, and a global optimum may not be found	[31, 46]
ACO	Performs well in both local and global search; a vast range of application domain	The algorithm has several parameters that must be tuned. Initialization is done randomly	[27]
HGWOGA	blends the strength of GWO and GA to improve the searching strategy; MATLAB code is available for testing	Designing complexity and difficult to implement. It has so many parameters	[31, 46]
BBO	Good convergence	It may result in many infeasible solutions	[47]
HS	Requires few parameters value setting, and it can solve continuous and discontinuous function; it has good exploitation and exploration abilities	It has a complex solving process; not easy to implement	[48]

4 Advancements of Nature-Inspired Search Methods for Optimizing HRES

The application of NIAs in HRES optimization has taken a huge leap in recent times with a high success rate of finding an optimal/near-optimal solution. This high growth rate of NIA is attributed to many factors includes flexibility and robustness in solving complex scientific and engineering optimization problem. The complex nature of designing an optimal mini-grid hybrid energy architecture whiles incorporating multiple energy sources with several decision variables and constraints has given rise to the high usage of NIA for renewable energy optimization. Although NIA has wide application in HRES optimization it has extensively been applied to solar PV and wind energy optimization, but it has less coverage on geothermal, ocean-based renewable energy and biomass (biofuel). Moreover, the latter resource has shown greater potential [6] of alleviating

the recurring energy crisis confronting most developing countries [4]. These renewable resources have varying decision variables, for instance, geothermal is continuous and ocean-based energy is periodic. An enhancement of NIA to accommodate these special situations would improve the optimal solution as well as management of the power system. In the advent of the massive improvements of NIA, it would be necessary for scientists to explore further the other renewable resources to augment the power supply industry. Here, NIA comes in handy.

New, enhanced, stochastic, advanced or hybrid optimization algorithms are proposed yearly to be solving various optimization problems. There is no single algorithm that supersedes all others in every problem. Therefore, identifying the appropriate search method for any optimization task addresses a scientific quest in making an informed decision. Table 5 summarizes the major optimization techniques employed in MG-HRES with their advantages and disadvantages.

Table 5. Advantages and disadvantages of optimization techniques

Optimization Technique	Advantages	Disadvantages
Classical Methods	Very simple (intuitive) to understand the logical flow of instructions and the analysis It is easy to write the code It has wider application areas	Computational time complexity is very high due to several mathematical or analytical operations Application in constraint satisfactory problem is problematic: does not handle constraints satisfactory High tendencies of been trapped in local optimum rather than global optimum
CI Methods	Ability to escape local minima or local maxima to finding a global optimum It achieves the global optimum with relatively low computational complexity Good computational time More efficient and robust Ability to handle several constraints Suitable for a wide range of decision variables Applicable in many areas of study Literature is readily available, and it is expanding at a high pace	May converge prematurely Can take a long time to leave the local optimum Not easy to code complex problems For a large set of decision variables and constraints, the response time could be very high

(*continued*)

Table 5. (*continued*)

Optimization Technique	Advantages	Disadvantages
Hybrid Methods	Better convergence Harnesses the strength of individual techniques to be more competitive	It has a complicated structure It is difficult to analyse
Software tools	Freely and commercially application programs easy to use suitable for multi-objective and mono-objective optimization problem on the fly techno-economic analysis of the system Can include many system components	Limited to a specific application domain Codes are not accessible for analysis or evaluations

5 Conclusion and Future Research

This paper presents an updated literature review of optimization techniques including hybrid algorithms used in mini-grid hybrid renewable energy system research, focusing on recent metaheuristic techniques which have been employed to solve the MG HRES optimization problem. It is found in the last few years several more non-conventional approaches have been implemented in renewable-based MG HRESs for system sizing, reliability and techno-economic analysis. In the past few years, a new trend has been observed in the growth of meta-heuristic particularly, swarm intelligence-based optimization algorithms. Although new algorithms are being developed, studies on hybridizing two or more techniques to solving MG HRES optimization is on the rise in the current literature. Moreover, different optimization methods used have varying performance efficiency when compared with other algorithms in some other studies, as no single method showed superiority in all comparative studies. Therefore, the selection of a suitable optimization technique may depend on several factors that will invariably inform the objective function result. Future studies could focus on improving the self-adaptive nature of metaheuristic algorithms to accommodate the marginalised renewable resources such as biomass, ocean-based energy etc. which have a high potential of mitigating the energy crisis in most developing economies. Finally, a data collection and analysis framework based on advanced IoT analytics viz hybrid renewable energy system optimization needs more attention to streamline the scientific frontiers for real-time data to predict or generate power to meet a changing load.

References

1. Committee on Climate Change: Net Zero Technical Report (2019). https://www.theccc.org.uk/publication/net-zero-technical-report/

2. Quarton, C.J., et al.: The curious case of the conflicting roles of hydrogen in global energy scenarios. Sustain. Energy Fuels **4**(80), 80–95 (2020). https://doi.org/10.1039/c9se00833k
3. Frank, C., Fiedler, S., Crewell, S.: Balancing potential of natural variability and extremes in photovoltaic and wind energy production for European countries Christopher. Renew. Energy (2020). https://doi.org/10.1016/j.renene.2020.07.103
4. Mugodo, K., Magama, P.P., Dhavu, K.: Biogas production potential from agricultural and agro-processing waste in South Africa. Waste Biomass Valor. **8**(7), 2383–2392 (2017). https://doi.org/10.1007/s12649-017-9923-z
5. Votteler, R., Brent, A.: A literature review on the potential of renewable electricity sources for mining operations in South Africa. J. Energy Southern Africa **27**(2), 1–21 (2016)
6. Adesanya, A., Misra, S., Maskeliunas, R., Damasevicius, R.: Prospects of ocean-based renewable energy for West Africa's sustainable energy future. Smart Sustain. Built Environ. **10**(1), 37–50 (2021). https://doi.org/10.1108/SASBE-05-2019-0066
7. Ghenai, C., Salameh, T., Merabet, A.: Technico-economic analysis of off grid solar PV/Fuel cell energy system for residential community in desert region. Int. J. Hydrogen Energy **45**(20), 11460–11470 (2020). https://doi.org/10.1016/j.ijhydene.2018.05.110
8. Singh, S., Singh, M., Kaushik, S.C.: Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system. Energy Convers. Manag. **128**, 178–190 (2016). https://doi.org/10.1016/j.enconman.2016.09.046
9. Zafar, A., Shafique, A., Nazir, Z., Zia, M.F.: A comparison of optimization techniques for energy scheduling of hybrid power generation system. In: Proceedings 21st International Multi Topic Conference INMIC 2018, no. June 2019, pp. 1–6 (2018). https://doi.org/10.1109/INMIC.2018.8595665
10. Khezri, R., Mahmoudi, A.: Review on the state-of-the-art multi-objective optimisation of hybrid standalone/gridconnected energy systems. IET Gener. Transm. Distrib. **14**(20), 4285–4300 (2020). https://doi.org/10.1049/iet-gtd.2020.0453
11. Hou, R., Yang, Y., Yuan, Q., Chen, Y.: Research and application of hybrid wind-energy forecasting models based on cuckoo search optimization. pp. 1–18 (2019)
12. Lu, J., Wang, W., Zhang, Y., Cheng, S.: Hybrid energy system using entropy weight method (2017). https://doi.org/10.3390/en10101664
13. Donado, K., Navarro, L., Christian, G., Quintero, M., Pardo, M.: HYRES: a multi-objective optimization tool for proper configuration of renewable hybrid energy systems. Energies **13**(1), 26 (2019). https://doi.org/10.3390/en13010026
14. Yong, Z., Shaowu, L.: Economic evaluation and configuration optimization strategy of hybrid renewable energy generation system: a review. In: Proceedings 32nd Chinese Control and Decision Conference (CCDC) 2020, pp. 729–734 (2020). https://doi.org/10.1109/CCDC49329.2020.9164560
15. Torres-madroñero, J.L., Nieto-londoño, C.: Hybrid energy systems sizing for the colombian context : a genetic algorithm and particle swarm, pp. 1–30 (2020). https://doi.org/10.3390/en13215648
16. Urbanucci, L., Ettorre, F.D., Testi, D.: A comprehensive methodology for the integrated optimal sizing and operation of cogeneration systems with thermal energy storage (2019). https://doi.org/10.3390/en12050875
17. Nguyen, T., Nguyen, L.V., Jung, J.J., Agbehadji, I.E.: Bio-inspired approaches for smart energy management : state of the art and challenges, pp. 1–24 (2020). https://doi.org/10.3390/su12208495
18. Khan, A., et al.: Enhanced evolutionary sizing algorithms for optimal sizing of a stand-alone PV-WT-battery hybrid system. Appl. Sci. **9**(23), 5197 (2019). https://doi.org/10.3390/app9235197
19. Frimpong, S.O.: Nature-inspired search method for cost optimization of hybrid renewable energy generation at the edge (2020)

20. Alzahrani, A., Zohdy, M., Yan, B.: An overview of optimization approaches for operation of hybrid distributed energy systems with photovoltaic and diesel turbine generator. Electric Power Syst. Res. **191**, 106877 (2021). https://doi.org/10.1016/j.epsr.2020.106877
21. Diab, A.A.Z., Sultan, H.M., Kuznetsov, O.N.: Optimal sizing of hybrid solar/wind/hydroelectric pumped storage energy system in Egypt based on different meta-heuristic techniques. Environ. Sci. Pollut. Res. **27**(26), 32318–32340 (2019). https://doi.org/10.1007/s11356-019-06566-0
22. Das, B., Hassan, R., Mohammad Shahed, H.K., Tushar, F., Hasan, M., Das, P.: Techno-economic and environmental assessment of a hybrid renewable energy system using multi-objective genetic algorithm: a case study for remote Island in Bangladesh. Energy Convers. Manag. **230**, 113823 (2021). https://doi.org/10.1016/j.enconman.2020.113823
23. Clarke, D.P., Al-Abdeli, Y.M., Kothapalli, G.: Multi-objective optimisation of renewable hybrid energy systems with desalination. Energy **88**, 457–468 (2015). https://doi.org/10.1016/j.energy.2015.05.065
24. Barakat, S., Ibrahim, H., Elbaset, A.A.: Multi-objective optimization of grid-connected pv-wind hybrid system considering reliability, cost, and environmental aspects. Sustain. Cities Soc. **60**, 102178 (2020). https://doi.org/10.1016/j.scs.2020.102178
25. Micangeli, A., Duenas-Martinez, P.: Optimal design of isolated mini-grids with deterministic methods: matching predictive operating strategies with low computational requirements. Energies **13**(16), 4214 (2020). https://doi.org/10.3390/en13164214
26. Khan, F.A., Pal, N., Saeed, S.H.: Review of solar photovoltaic and wind hybrid energy systems for sizing strategies optimization techniques and cost analysis methodologies. Renew. Sustain. Energy Rev. **92**(March), 937–947 (2018). https://doi.org/10.1016/j.rser.2018.04.107
27. Sinha, S., Chandel, S.S.: Review of recent trends in optimization techniques for solar photovoltaic – wind based hybrid energy systems. Renew. Sustain. Energy Rev. **50**, 755–769 (2015). https://doi.org/10.1016/j.rser.2015.05.040
28. Eriksson, E.L.V., Gray, E.M.: Optimization and integration of hybrid renewable energy hydrogen fuel cell energy systems – a critical review. Appl. Energy **202**, 348–364 (2017). https://doi.org/10.1016/j.apenergy.2017.03.132
29. Husain, S., Shrivastava, N.A.: A comparative analysis of multi-objective optimization algorithms for stand-alone hybrid renewable energy system. In: ICIMIA, pp. 255–260 (2020)
30. Mohseni, S., Brent, A.C., Burmester, D.: A comparison of metaheuristics for the optimal capacity planning of an isolated, battery-less, hydrogen-based micro-grid. Appl. Energy **259**, 114224 (2020). https://doi.org/10.1016/j.apenergy.2019.114224
31. Geleta, D.K., Manshahia, M.S.: A hybrid of grey wolf optimization and genetic algorithm for optimization of hybrid wind and solar renewable energy system. J. Oper. Res. Soc. China (2021). https://doi.org/10.1007/s40305-021-00341-0
32. Ebrahimi, A., Attar, S., Farhang-Moghaddam, B.: A multi-objective decision model for residential building energy optimization based on hybrid renewable energy systems. Int. J. Green Energy, 1–18 (2021). https://doi.org/10.1080/15435075.2021.1880911
33. Sultan, H.M., Menesy, A.S., Kamel, S., Korashy, A., Almohaimeed, S.A., Abdel-Akher, M.: An improved artificial ecosystem optimization algorithm for optimal configuration of a hybrid PV/WT/FC energy system. Alexandria Eng. J. **60**(1), 1001–1025 (2021). https://doi.org/10.1016/j.aej.2020.10.027
34. Ghaffari, A., Askarzadeh, A.: Design optimization of a hybrid system subject to reliability level and renewable energy penetration. Energy **193**, 116754 (2020). https://doi.org/10.1016/j.energy.2019.116754
35. Mokhtara, C., Negrou, B., Settou, N., Settou, B., Samy, M.M.: Design optimization of off-grid hybrid renewable energy systems considering the effects of building energy performance and climate change: case study of Algeria. Energy **219**, 119605 (2021). https://doi.org/10.1016/j.energy.2020.119605

36. Ashraf, M.A., Liu, Z., Alizadeh, A., Nojavan, S., Jermsittiparsert, K., Zhang, D.: Designing an optimized configuration for a hybrid PV/Diesel/battery energy system based on metaheuristics: a case study on Gobi desert. J. Clean. Prod. **270**, 122467 (2020). https://doi.org/10.1016/j.jclepro.2020.122467
37. Kharrich, M., Kamel, S., Abdeen, M., Mohammed, O.H., Akherraz, M.: Developed approach based on equilibrium optimizer for optimal design of hybrid PV/Wind/Diesel/Battery Microgrid in Dakhla, Morocco, pp. 13655–13670 (2021). https://doi.org/10.1109/ACCESS.2021.3051573
38. Ganguly, P., Kalam, A., Zayegh, A.: Solar–wind hybrid renewable energy system: current status of research on configurations, control, and sizing methodologies. In: Hybrid-Renewable Energy Systems in Microgrids, Elsevier Ltd., pp. 219–248 (2018)
39. Twaha, S., Ramli, M.A.M.: A review of optimization approaches for hybrid distributed energy generation systems: off-grid and grid-connected systems. Sustain. Cities Soc. **41**(April), 320–331 (2018). https://doi.org/10.1016/j.scs.2018.05.027
40. Theo, W.L., Lim, J.S., Ho, W.S., Hashim, H., Lee, C.T.: Review of distributed generation (DG) system planning and optimisation techniques: comparison of numerical and mathematical modelling methods. Renew. Sustain. Energy Rev. **67**, 531–573 (2017). https://doi.org/10.1016/j.rser.2016.09.063
41. Zahraee, S.M., Khalaji Assadi, M., Saidur, R.: Application of artificial intelligence methods for hybrid energy system optimization. Renew. Sustain. Energy Rev. **66**, 617–630 (2016). https://doi.org/10.1016/j.rser.2016.08.028
42. Mohamed, M.A., Eltamaly, A.M., Alolah, A.I.: Swarm intelligence-based optimization of grid-dependent hybrid renewable energy systems. Renew. Sustain. Energy Rev. **77**, 515–524 (2017). https://doi.org/10.1016/j.rser.2017.04.048
43. Tezer, T., Yaman, R., Yaman, Gül.şen: Evaluation of approaches used for optimization of stand-alone hybrid renewable energy systems. Renew. Sustain. Energy Rev. **73**, 840–853 (2017). https://doi.org/10.1016/j.rser.2017.01.118
44. Xiao, H., Pei, W., Dong, Z., Kong, L., Wang, D.: Application and comparison of metaheuristic and new metamodel based global optimization. https://doi.org/10.3390/en11010085
45. Mandal, S.: Modeling of photovoltaic systems using modified elephant swarm water search algorithm. Int. J. Modell. Simul. **40**(6), 436–455 (2020). https://doi.org/10.1080/02286203.2019.1650488
46. El-salam, M., Beshr, E., Eteiba, M.: A new hybrid technique for minimizing power losses in a distribution system by optimal sizing and siting of distributed generators with network reconfiguration. Energies **11**(12), 3351 (2018). https://doi.org/10.3390/en11123351
47. Aala Kalananda, V.K.R., Komanapalli, V.L.N.: Nature-inspired optimization algorithms for renewable energy generation, distribution and management—a comprehensive review. In: Vinoth Kumar, B., Sivakumar, P., Rajan Singaravel, M. M., Vijayakumar, K. (eds.) Intelligent Paradigms for Smart Grid and Renewable Energy Systems. AIS, pp. 139–226. Springer, Singapore (2021). https://doi.org/10.1007/978-981-15-9968-2_6
48. Nazari-heris, M., Mohammadi-ivatloo, B., Asadi, S., Kim, H., Geem, Z.W.: Harmony search algorithm for energy system applications: an updated review and analysis. J. Exp. Theor. Artif. Intell. **31**(5), 723–749 (2019). https://doi.org/10.1080/0952813X.2018.1550814
49. Ashraf, M.M., Malik, T.N.: A hybrid teaching–learning-based optimizer with novel radix-5 mapping procedure for minimum cost power generation planning considering renewable energy sources and reducing emission. Electr. Eng. **102**(4), 2567–2582 (2020). https://doi.org/10.1007/s00202-020-01044-0