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Grass Hopper Optimization Algorithm for Off-Grid Rural Electrification of an Integrated Renewable Energy System

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Abstract. A suitable alternative to grid expansion has been found in renewable energy sources like wind, solar, and biomass. To put it another way, relying solely on one of the major renewable sources is both inefficient and expensive. As a result, an integrated renewable energy system is a viable option. The purpose of this article is to discuss the use of the Grasshopper Optimization Algorithm (GOA) for renewable energy sizing in the current study area. For an autonomous microgrid network, the proposed technique finds the optimum system size on the basis of Loss of Power Supply Probability (LPSP). The proposed microgrid consists of PV panels, wind turbines, biomass generator and a battery storage system. The proposed GOA algorithm's convergence efficiency in resolving the current optimization problem is investigated and compared with Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) in the MATLAB software environment. The simulation results show that the GOA algorithm outperforms its counterparts, GA and PSO, in terms of system sizing.

1 Introduction

In India's rural areas, the bulk of the people still does not have access to electricity. Extending the grid power supply to such remote areas is neither feasible nor cost-effective [1]. Other drawbacks of typical diesel-powered generators include high maintenance and fuel costs, as well as excessive noise levels and, most importantly, greenhouse emissions. Renewable energy sources that are environmentally friendly can help meet the electrical load requirement. Given the unpredictability of renewable energy resources, the use of an (IRES) is preferable to improving the reliability of the off-grid system. With the IRES, users can meet the energy needs by combining two or more regionally accessible energy sources. In order to maximize efficiency and cost-effectiveness when using renewable energy resources to meet load demand, optimal models must be developed [2].

For the microgrid size problem, this article developed a novel approach named the "Grasshopper Optimization Algorithm" (GOA). 5 villages in an off-grid region in Odisha State, India, were supplied with electricity through a micro-grid approach. Solar panels, wind turbines, a biomass generator, and a battery bank make up the proposed microgrid. Zero Percent LPSP error is assumed to identify the best system configuration.The outcomes of GOA are compared to those of two other well-known optimization algorithms PSO and GA. GOA's performance is clearly seen in the comparison, which results in very quick convergence, local optima avoidance and a balance between exploration and exploitation.

2 Resources and Load Estimation

India has a plentiful supply of renewable energy resources. Five villages in the Indian state of Odisha have been recognized as possible locations for off-grid microgrid development. Fig. 1 depicts the energy demand for residential houses during the summer and winter seasons. This information comes from a door-to-door load demand survey conducted in the proposed rural off-grid villages. There are around 8.35 tonnes of biomass each year that comes from forest vegetation such as pine needles and firewood. Figs. 2 and 3 shows hourly data from a 10-year average of National Renewable Energy Laboratory data on wind speed, solar radiation, and ambient temperature (01/01/2004 to 31/12/2014).

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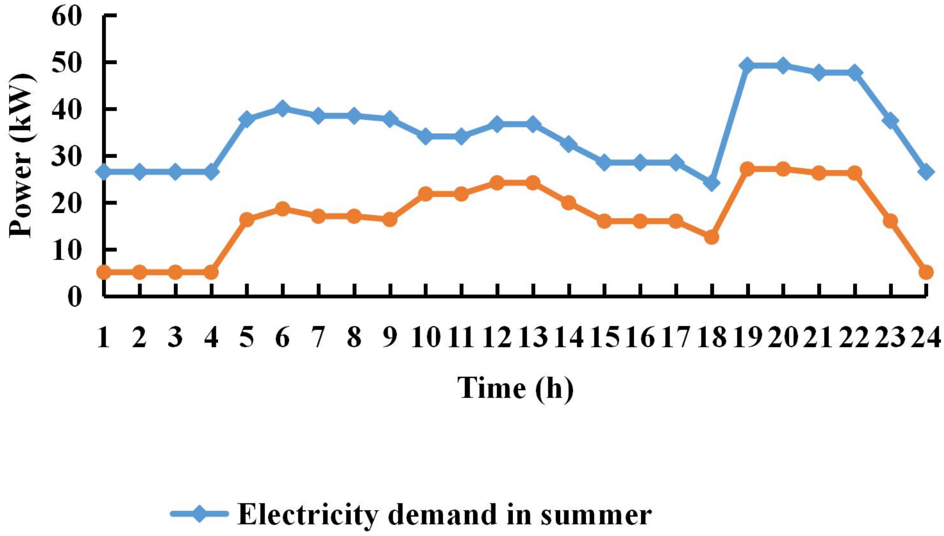

Fig. 1. Load demand in the study area

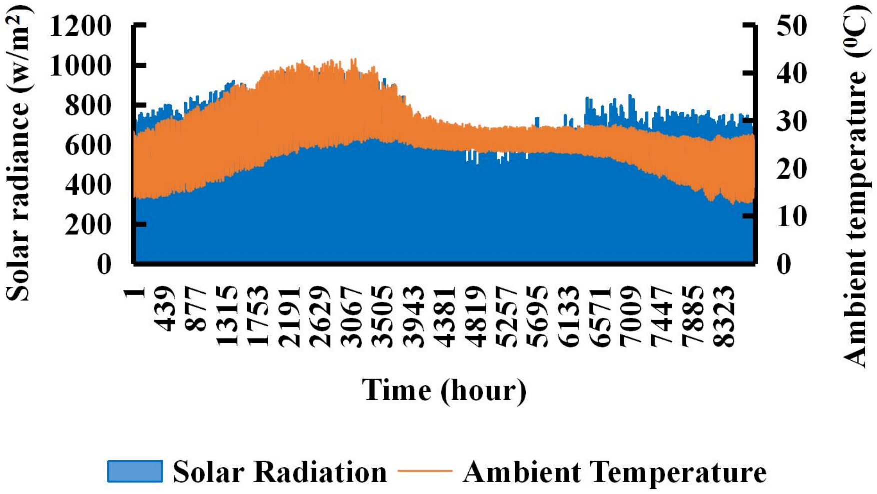

Fig. 2. study area solar radiation and ambient temperature

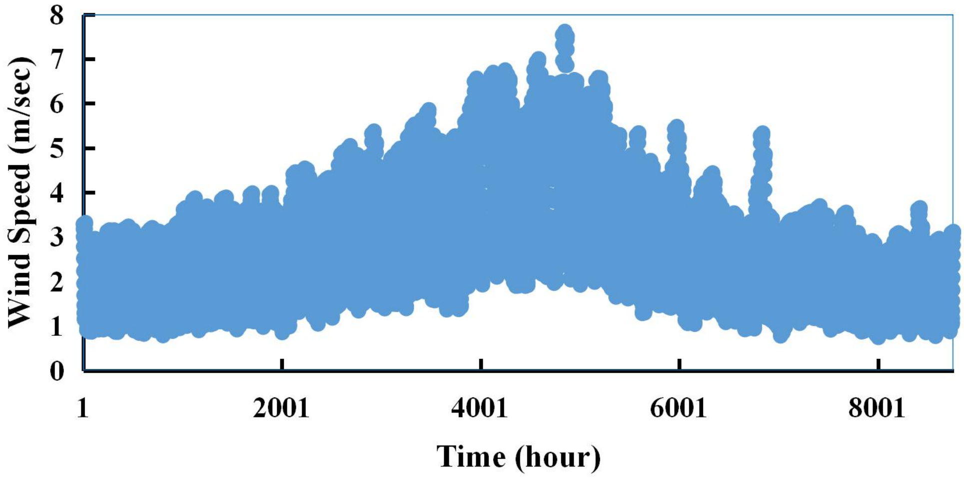

Fig. 3. Study area wind speed

3 Integrated Renewable Energy System Modelling

It is necessary to model the components prior to determining the optimal system size. Wind farms, Pv module, a biomass generator, a converter, and batteries make up the existing system. A schematic of the IRES is depicted in Fig. 4.

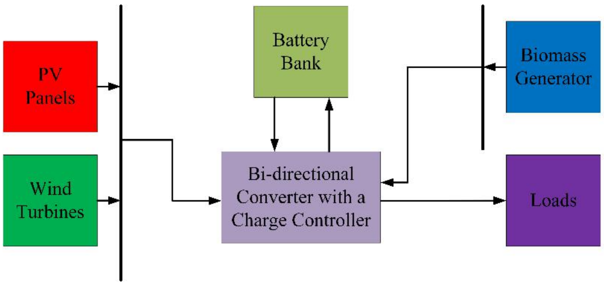

Fig. 4. Block diagram representation of the IRES

3.1 Solar energy

The PV panel's power output (P_{PV}) may be computed as follows [3]:

$$P_{pv}(t) = N_{pv} * P_{pv-rated} \times G_t(t) \big/ 1000 \times \left[1 + alpha_t \times \left(t_{amb}(t) + (0.0256 * G_t)\right) - T_{C\_STC})\right] \tag{1}$$

Here, $G_t(t)$ is hourly solar radiation, $P_{pv-rated}$ is the esteemed power of the PV panel, $alpha_t$ = -3.7×10^{-3} (1/^{0}C), $t_{amb}(t)$ is the hourly ambient temperature (^{0}C). N_{pv} is the no of PV panels, T_{C_STC} is the cell temperature.

3.2 Wind energy

This is done by calculating the wind speed and converting it to a power output for the wind turbine ($v_1(t)$) is first converted into the corresponding wind turbine hub height ($v_2(t)$) by the power rule equation.

$$v_2(t) = v_1(t) \times \left(\frac{h}{h_{ref}}\right)^g \tag{2}$$

Where g is the power law exponential.

The power generated by the WT (P_{WT}) can be calculated as [3]:

$$P_{WT}(t) = N_{wt} * \begin{cases} 0, \; v_2 < V_{cut-in}, v_2 > V_{c} \\ v_2^3(t)\left(\frac{P_r}{V_{rated}^3 - V_{cut-in}^3}\right) - P_r\left(\frac{V_{cut-in}^3}{V_{rated}^3 - V_{cut-}^3}\right. \\ P_r, \; V_{rated} \le v_2 \le V_{cut-} \end{cases} \tag{3}$$

Where N_{wt} is the number of wind turbines, V_{cut-in}, $V_{cut-out}$ and V_{rated} are the cut-in, cut-out and rated speed of the wind turbine respectively.

3.3 Biomass energy

The biomass generator's output power can be calculated as [4]:

$$P_{bms}(t) = \frac{q_{bm} \times \eta_{bm} \times cv_{bm} \times 1000}{doh_{bm} \times 365 \times 860} \tag{4}$$

Here, calorific value of biomass , cv_{bm} = 4015 kcal/kg , q_{bm} is the volume of biomass (tons/year), doh_{bm} is the daily operating hours of the biomass generator.

3.4 Battery bank

The process of charging a battery bank may be described as follows [5]:

$$E_{bat}(t) = E_{bat}(t-1) + \left(E_g(t) - E_l(t)/\eta_{Con}\right) \times \eta_{cc} \times \eta_{chg} \tag{5}$$

The process of discharging a battery bank may be described as follows [5]:

$$E_{bat}(t) = (1-\sigma) \times E_{bat}(t-1) - \left(E_l(t)/\eta_{Con} - E_g(t)\right) \big/ \eta_{dchg} \tag{6}$$

Here, $E_g(t)$ is hourly-generated energy, E_{bat} is the energy stored in the battery, $E_l(t)$ is hourly load demand, η_{Con} efficiency of converter, η_{cc} efficiency of charge controller, σ a battery's hourly self-discharge rate , η_{chg} charging effectiveness of the battery, η_{dchg} is discharging efficiency of the battery.

3.5 Bidirectional converter having charge controller (BDC-CC)

The rated power (kW) of the BDC-CC can be calculated as [6]:

$$P_{bdc-cc} = E_{t,max} \times 1.1 \tag{7}$$

Here,
the multiplication factor 1.1 shows here that the BDC-CC has 10% overload capacity.

4 Objective Significance and Limitation

The objective function is aimed to minimize the Life Cycle Cost (LCC) of an independent off-grid renewable energy system with an LPSP value of 0%. The system's LCC is determined by decision variables such as wind turbines, PV panels and batteries. The LCC can be calculated as:

$$min\ LCC(N_{pv}, N_{wt}, N_{bat}) = \sum_{p=pv,wt,bms,bat,BDC-CC}^{min} (LCC)_p \quad (8)$$

4.1 Constraints

Fixed-power biomass generators, such as a 5kW model, are assumed with a daily operational capacity of 4kWh of energy per hour for 5 hours. As a result, it is not constrained by any constraints. Furthermore, the following limitations are applicable on remaining sources, such as wind and solar, are explained as follows:

$$0 \leq N_{pv} \leq N_{pv-max} \quad (9)$$

$$0 \leq N_{wt} \leq N_{wt-max} \quad (10)$$

In addition, battery storage system is bound by the following constraint.

$$0 \leq N_{bat} \leq N_{bat-max} \quad (11)$$

4.2 Limits on battery bank energy storage

The following phrase limits the amount of energy kept in the battery system at any given time 't' [5]:

$$E_{bat\_min} \leq E_{bat}(t) \leq E_{bat\_max} \quad (12)$$

The E_{Bat_max} can be calculated as:

$$E_{Bat\_max} = \left(\frac{N_{bat} \times V_{bat} \times S_{bat}}{1000}\right) \times SOC_{max} \quad (13)$$

Meanwhile, E_{Bat_min} can be calculated as:

$$E_{Bat\_min} = \left(\frac{N_{bat} \times V_{bat} \times S_{bat}}{1000}\right) \times SOC_{min} \quad (14)$$

Here, SOC_{min} and SOC_{max} are the minimum maximum and state of charges of the battery.

4.3. Power reliability index

Batteries and renewable energy resources will be unable to meet load demand for a few hours per year. The power supply will then be lost in those hours. This can be calculated as follows:

$$lps(t) = \frac{E_l(t)}{\eta_{con}} - E_g(t) - [(1-\sigma) \times E_{bat}(t-1) - E_{bat\_min}] \times \eta_{dchg} \quad (15)$$

For evaluation of the system's power reliability its reliability index should be considered for various LPSP values and it can be defined as follows:

$$LPSP = \frac{\sum_{t=1}^{T} lps(t)}{\sum_{t=1}^{T} E_l(t)} \quad (16)$$

5 Grasshopper Optimization Algorithm

The Grasshopper Optimizations Algorithm (GOA) was developed by Saremi et[7] al in 2017 as a new optimization algorithm. The algorithm imitates the actions of the grasshopper in the nature in the food hunt.

Grasshopper's swarm behaviour is mathematically modelled, where the authors proposed the following equations for resolving optimization problem.

$$x_i^d = C\left(\sum_{J=1,J\neq 1}^{n} C\frac{UB_d - LB_d}{2} s\left(\left|x_j^d - x_i^d\right|\right)\frac{X_j - X_i}{D_{ij}}\right) + t_d \quad (17)$$

The component C can be determined by Eq. (18)

$$C = Cmax - L\frac{Cmax - Cmin}{l} \quad (18)$$

The current optimization problem of optimal off-grid sizing with the proposed Grass hopper optimization algorithm is described with a neat flowchart in Fig. 5.

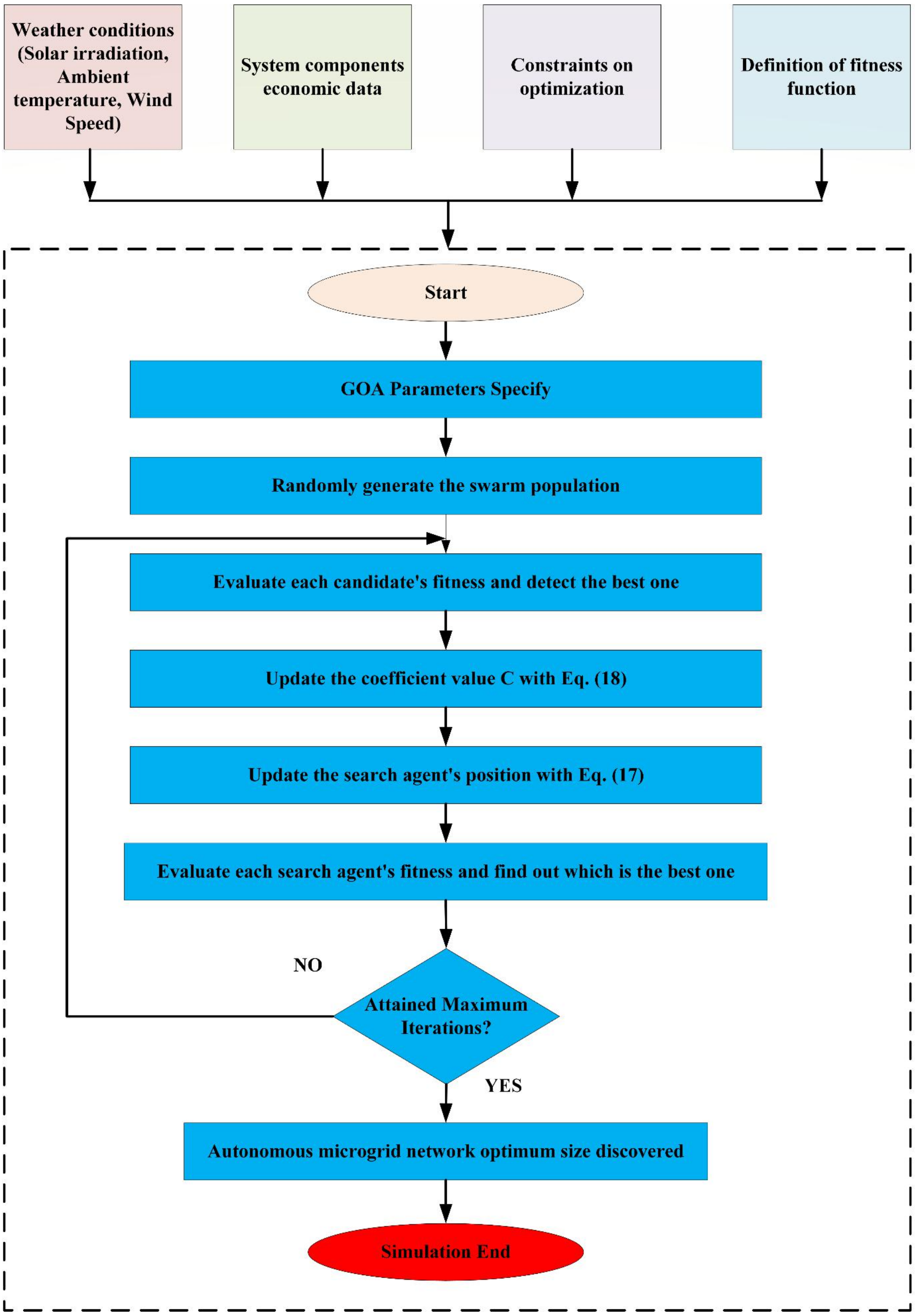

Fig. 5 The Grass Hopper Optimization algorithm flow chart is used to optimize the IRES

6 Results and Discussion

The case study examined the availability of electricity for the proposed study area. The PV (Photo Voltaic Panels)/WT (Wind Turbines)/BMS (Biomass Generator)/BAT (Batteries) configuration is tested for the proposed study area in the MATLAB environment with GA, PSO and GOA algorithms. These algorithms have been developed with their default parameters, population of 100 and maximum number of iterations as100. Table 1 shows the input values for off-grid microgrid optimization process.

Table 1. input values of the all components

Component	Life span	Rated power	Capital cost ($)	Replacement cost ($)	Annual O&M cost ($)
PV panel [6]	25 years	0.25 (kWp)	250	0	6.25
Wind turbine [6]	25 years	1 kW	2500	0	75
Biomass generator [6]	1500 hours	5 kW	4505	3153	135
Battery [6]	5 years	360 Ah	300	300	0.75

Converter [6]	10 years	55 kW	5940	5940	15

Table 2. optimization values of the IRES with proposed algorithms

configuration	**component**	**GA**	**PSO**	**GOA**
PV/WT/ BMS/BAT$_{(LA)}$	N_{pv}	935	933	**932**
	N_{wt}	2	1	**0**
	N_{bat}	308	306	**304**
	Converter (kW)	55	55	**55**
	LCC ($)	8,23,975	8,15,969	**8,08,374**

The optimal configuration of IRES is achieved by simulating hourly load demand at an LPSP value of 0%, Table 2 shows the corresponding optimization results with three optimization algorithms: GA, PSO and GOA. The optimal off-grid microgrid includes 932 number of PV panels (N_{pv}), 304 number of LA batteries (N_{bat}), 0 wind turbines (N_{wt}) and one 55 kW converter with Life Cycle Cost (LCC) of $8,08,374. Table 2 shows that GOA has the least number of components and the lowest life-cycle cost when compared to other well-known GA and PSO algorithms. Fig. 6 shows a detailed review of the GA, PSO, and GOA algorithms convergence processes to find the optimum configuration in the off-grid microgrid framework.

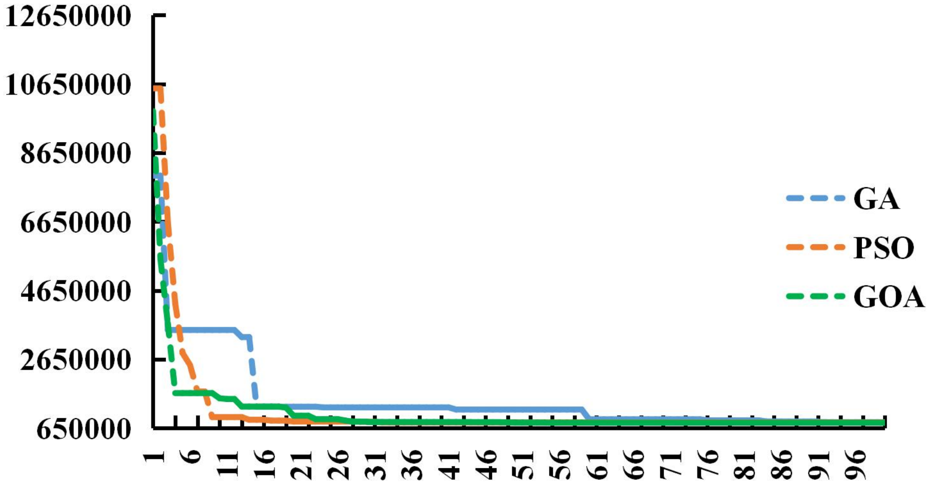

Fig. 6. Convergence curves of all proposed algorithms for IRES optimization

7 Conclusions

A framework for rural electrification utilising renewable resources such as wind, solar and biomass is presented in this paper. Five remote villages in India's Odisha state have been identified as a study area. A model of interconnected renewable sources has been Using the GOA algorithm, the proposed Integrated Renewable Energy System (IRES) model is optimised in the MATLAB environment to minimize the system Life Cycle Cost (LCC). Furthermore, the LCC obtained with the Grass Hopper Optimization algorithm has been provided at the lowest cost in comparison to its counterparts, GA and PSO algorithms. For developers of off-grid projects the proposed rural electricity IRES model may be useful.

References

1. P. P Kumar and R. P. Saini, "Optimization of an off-grid integrated hybrid renewable energy system with various energy storage technologies using different dispatch strategies," Energy Sources, Part A Recover. Util. Environ. Eff., vol. 00, no. 00, pp. 1–30, doi: 10.1080/15567036.2020.1824035. (2020)
2. P. P. Kumar and R. P. Saini, "Optimization of an off-grid integrated hybrid renewable energy system with different battery technologies for rural electrification in India," J. Energy Storage, vol. 32, no. September, p. 101912, doi: 10.1016/j.est.2020.101912. (2020)
3. A. L. Bukar, "Optimal sizing of an autonomous photovoltaic/wind/battery/diesel generator microgrid using grasshopper optimization algorithm," vol. 188, no. May, pp. 685–696 (2019)
4. A. Chauhan and R. P. Saini, "Techno-economic optimization based approach for energy management of a stand-alone integrated renewable energy system for remote areas of India," Energy, vol. 94, pp. 138–156, doi: 10.1016/j.energy.2015.10.136. (2016)
5. A. Chauhan and R. P. Saini, "Discrete harmony search based size optimization of Integrated Renewable Energy System for remote rural areas

of Uttarakhand state in India," Renew. Energy, vol. 94, pp. 587–604, doi: 10.1016/j.renene.2016.03.079. (2016)

6. A. M. Patel and S. K. Singal, "Optimal component selection of integrated renewable energy system for power generation in stand-alone applications," Energy, vol. 175, pp. 481–504, doi: 10.1016/j.energy.2019.03.055. (2019)
7. S. Saremi, S. Mirjalili, and A. Lewis, "Grasshopper Optimisation Algorithm: Theory and application," Adv. Eng. Softw., vol. 105, pp. 30–47, doi: 10.1016/j.advengsoft.2017.01.004. (2017)