Ain Shams Engineering Journal 13 (2022) 101543

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Electrical Engineering

Multi-objective multi-verse optimization of renewable energy sources-based micro-grid system: Real case

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ARTICLE INFO

Article history:
Received 24 February 2021
Revised 29 April 2021
Accepted 22 June 2021
Available online 14 July 2021

Keywords:
Energy system
Micro-grid network
Optimization techniques
Reverse osmosis desalination
Renewable energy resource

ABSTRACT

Hybrid micro-grid systems (HMGS) are small scale power system where the energy sources are installed to supply local customers. These systems may be considered as promising energy solution to meet the increased in energy demand and traditional sources depletion. Cost of electricity, system reliability, and environmental impacts of the system are three design criteria that must be considered in obtaining the accurate parameters of hybrid renewable energy system components. In this paper, hybrid micro-grid renewable energy system includes photovoltaic system, (PV) wind energy system, (WES) battery bank, (BB) and conventional diesel generator (DG) are proposed to meet the energy requirements in remote area, located in Red Sea called city of Bernice, Egypt, at 23° 54′ 31″ N, 35° 28′ 21″ E. Optimization of Cost of Electricity (COE), Renewable Factor (RF), and Loss of Power Supply Probability (LPSP) are main objective of the designing process of the hybrid system considered as the objective functions. Then, Multi-objective multi-verse optimization (MOMVO) algorithm is used with considering two scenarios, the first one is renewable sources and the second is renewable/diesel energy source. All the possible HMGS configurations namely: PV/battery, wind/battery, PV/wind/battery and PV/battery/diesel, wind/battery/diesel, PV/wind/battery/diesel are studied and analyzed. Moreover, one year hourly meteorological weather data for case study are recorded. Reverse osmosis desalination (ROD) is considered in conjunction with the residential load. The proposed power management strategy is used to manage the system operation when supplying the load. A linear fuzzy membership function is used for purpose of decision making. The simulation results show that MOMVO produces appropriate components size and the PV/wind/battery/diesel is the optimum configuration with values of COE = 0.2720$/KWh, LPSP = 0.1397, and RF = 92.37% at w_1 = 0.5, w_2 = 0.3, and w_3 = 0.2. Sensitivity analysis is performed to show the effect of changing system parameters on the objective functions. It is also shown that the techno-economic feasibility of using HMGS for rural electrification systems and enhance energy access.

1. Introduction

Nowadays, most of the world countries face shortage of Petroleum and worst energy crises, so that, most of the countries targeted a considerable access to renewable energy resources which are a promising solution for such problem. However, renewable sources such as solar, wind, or hydro power, which offer promising alternative renewable sources for conventional fossil fuel, even in remote and undeveloped regions which appear as isolated hybrid micro-grid systems. Actually, these energy systems are mainly

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Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.asej.2021.06.028
2090-4479/

implemented rural areas for generating electricity; there are about 1.5 billion people still living in small villages far from electric networks in the world [1].

Egypt has various opportunities for applying renewable energy technologies to achieve sustainability in its energy sector to meet the growing needs of economic growth and development. However, the available energy resources are limited to oil and gas which feed electricity generation plants. The oil is almost internally used, the natural gas is available just to cover 30 years of the current consumption [2]. The Egyptian government has recognized this opportunity in its Integrated Sustainable Energy Strategy, which seeks to availability of energy with constant and clean renewable sources through development of technologies implemented to renewable resources. The government's latest targets are to save 20% of energy generation from renewable resources by 2022, and 42% by 2035 [3].

Quality of power supply and fast power network development are some advantages of the centralized power network architecture. Nowadays, the centralized power distribution systems begin to be decentralized to maximize the renewable energy sources sharing. A Hybrid micro-grid system is known as a small-scale energy distribution system built to be a domestic source for a few number of users. HMGS is incorporated to the utility grid, or works at stand-alone mode [4,5].

Beside energy demand, fresh water is also an urgent need for the well-being of mankind. It is well known that 10.6% of the world's population miss sources of pure water [6]; the majority of them live in rural area. In addition to freshwater leakage, climate change, and the increase in population, the world faces a big problem of saving fresh water currently and in the future [7]. Currently, the utilization of Reverse Osmosis Desalination (ROD) system supplied by renewable energy systems such as PV, and WES offers a promising solution for saving fresh water [8–10].

The establishment of a HMGS needs a thorough analysis for finding the accurate parameters of energy mix and device sizes as per load demand [11].

In accurate capacity systems of the hybrid micro-grid systems with or without storage system, many technical studies have been made [12–15]. For example, in [5], HMGS includes PV/WES and hydrogen energy storage considering the system component outages and applying PSO optimization technique. The effect of system components' outages on its expenses and efficiency are also studied. A hybrid wind and battery system using design-space approach was investigated [15]. A hybrid PV and diesel system has been studied in [16,17], the calculated responses indicate that the combination of PV and wind with diesel generator can improve system reliability, and reduce the energy cost. Ref. [17] proposed a PV system integrated with diesel generator and flywheel energy storage system; the study concluded by increasing the renewable fraction of fuel consumption, Cost of Electricity (COE), total Net Present Cost (NPC), and CO_2 emissions can be minimized. A hybrid system consists of PV/wind/Fuel cell and hydrogen tank as energy storage system was investigated in [18]. The study was to decrease the cost using particle swarm optimization PSO.

Designing (HMGS) with low adverse techno-economic and ecological effect is one of its development challenges. In general, many software tools have been used over the years to determine HMGS, including or without storage system and conventional source. The commonly used software is HYBRID2, HOMER, SOLSIM, PV-DESIGN PRO PVSYST, and SOMES [19–21]. A review of the advantages and disadvantages of the software used to optimize HMGS can be found in [22]. The bio-inspired optimization (BO) techniques have also been intensively developed and used nowadays. They can raise the hybrid system efficiency through implementation of optimization techniques for obtaining the optimum configuration, performance, size and cost. They can optimize the HMGS in a single or multi-objective framework considering technical and economic objectives and finding the accurate system parameters [23]. Genetic algorithm (GA) was commonly used to optimize HMGS that have multiple decisions' variables, and its performance was reported [24,25]. It provides a HMGS with different components sizes to meet the load in a certain region and optimizing them according to the given fitness function. The main drawback of this technique is that it is not easy to be coded [28–30]. Another simple technique is implemented namely, (PSO). It has advantages of easy coding, control parameters robustness, shorter calculation time, computational efficiency and stable convergence characteristics [26,27]. Recently, some studies considered the problem in a multi-objective framework. In [28] MOPSO was used to optimize an HMGS consisting of PV/wind/battery and conventional source to meet power demand. The objectives of the study were the optimization of the COE, and LPSP.

Actually, there are many studies which address HMGS design and optimization. On the other hand, there are few studies that consider a water desalination system as a load demand in conjunction with main electrical load. In some studies, ROD system supplied by renewable energy systems is reported. For example, in [29] ROD system supplied by wind energy is presented, by PV system, in [30], and by hybrid renewable energy in [19,31–34]. Moreover, ROD unit supplied by hybrid (PV and wind) provides a promising solution for fresh water shortage in rural and remote areas [35–38].

GA-PSO is integrated with (MOPSO) for designing Wind Energy-Photovoltaic-Battery system to raise the system reliability and decreasing the total system costs. The GA-PSO is selected for its capability in single objective problems. The MOPSO is able to solve optimization approach with multi-functions in their forms [39]. The optimized parameters of the PV, Wind system and Battery system-based GA-PSO, and MOPSO were compared with HOMER. The comparative study proves the accuracy of the proposed optimization technique in terms of reducing the cost and increasing the hybrid system stability.

Optimization of hybrid photovoltaic (PV) energy system/Diesel generator (DG) is developed via utilizing the HOMER software for Khorfakkan city, Sharjah, U.A.E. The HOMER software was utilized to simulate the suggested model and performing the overall system analysis. The obtained results approved the efficiency and strength of the HOMER software in developing the hybrid PV/Diesel energy system in reducing the costs and reducing gas emission [40].

The mixed-integer linear programming (MILP) optimization technique was utilized for developing hybrid PV/WES to provides the energy needed for industrial loads [41]. The nature of loads and variation of loads through the year were considered for the study. The optimized hybrid Wind-PV energy system was developed for rural areas.

The reduction in (LPSP) of load and whole electricity cost were used as objectives to optimize a standalone hybrid wind/PV energy system improved battery/supercapacitor system [42]. The multi-objectives based genetic algorithms were used to develop the optimum Wind/PV system. The optimum hybrid wind/PV energy system was developed based on various economic analysis.

Hybrid Wind/PV integrated with Diesel generator energy system was utilized for supplying the different configuration of an island load, such as water desalination, and thermal energy. Various processes of desalination were utilized for selecting the suitable one [43]. This indicates that the required parameters of the hybrid energy system for supplying such island loads can be easily determined.

The modified Crow search algorithm (CSA) was applied for finding the accurate parameters of hybrid PV/DG/FC energy system. The optimality process was obtained based on LPSP and renewable energy portion (REP) for decreasing (TNPC). The optimized hybrid PV/DG/FC energy system based on improved CSA provides more reliable, and cost-effective in comparison with convention CSA, GA and PSO [44].

The differential evolution (DE) algorithm was implemented in a form of quantum PSO, (QPSO) and improved QPSO for accurate configuration of hybrid energy systems in two cases. The optimized hybrid renewable sources systems' cases were based on conventional and QPSO and improved QPSO. The suggested hybrid system consists of renewable source/micro-gas turbine/battery system [45]. The results show that the improved QPSO provides better results than the conventional QPSO.

A stochastic model predictive control was applied to energy scheduled in smart home, as well as to cooperative energy distribution for micro-grids [46–48].

The PSO optimization technique was implemented to calculate the accurate parameters of hybrid Wind/Tidal/PV/Battery energy system. The optimization process of the hybrid energy system parameters was calculated according to high reliability, and econometrics [49]. The obtained results prove specific decrease in the system's overall cost, and accuracy. The hybrid energy source was proposed for a rural area in France. A Hybrid PV/Wind/Pumped hydro energy storage (PHES) was designed and optimized based on genetic algorithm approach in a coastline area under the authority of the Nigerian local government [50]. The optimization process was developed in decreasing the whole expenses of the suggested hybrid energy system. The response shows the effectiveness of the proposed technique in supporting sustainable development. A standalone hybrid PV/Wind/Electromechanical storage renewable sources applied in a remote area in Borj Cedria, Tunisia, was optimized and designed based on evolutionary algorithm (EA) [51]. The EA was implemented for determining the accurate parameters of hybrid renewable energy system components. The results show the relevance of the proposed hybrid renewable energy system parameters for such real case. A complete scanning on optimizing the parameters of hybrid PV-Wind energy systems was discussed and investigated [52].

Hybrid Renewable sources incorporated with energy storage system are installed in medium voltage distribution system. The model predictive technique is applied to follow up the variation of power in the system [53]. The technique was successful in reducing the energy losses in the distribution system, which leads to minimize the daily cost of the system. Hybrid model predictive control integrated with both genetic algorithm and linear programming are implemented to adapt the configuration of smart home appliances [48]. The studied smart home has different energy systems such as electric vehicle, photovoltaic system, and diesel generator. Optimal Charging Management of Plug-In Electric Vehicles is implemented for development of robust operation of flexible Distribution system [54]. A complete analysis of the studied system with the proposed techniques was completely investigated and addressed.

Based on this extensive literature review, many configurations of AC, DC, or hybrid microgrids have been optimized in different locations using variety of procedures and optimization techniques. Due to the increasing focus on this area, it is essential to assess the operation of the hybrid systems driven the loads of the remote communities in Egypt using intelligent procedures such as meta-heuristic multi-objective optimization techniques which faces tremendous concern in recent work. Therefore, the target of this paper is to find the optimal components sizing of renewable sources-based hybrid micro-grid system. In order to do this, **(MOMVO) technique** is applied to account for technical, economic, and environmental criteria for designing HMGS. The objective functions considered are COE, LPSP, and RF. The meteorological data for Berenice city in Egypt is used as a case study. The obtained results show high accuracy when compared with other techniques.

The paper is organized as the follows: the current Section 1 provides an introduction and a review of literature; Section 2 presents the case study and a description of the HMGS used in the study. Modeling of the components is provided in Section 3; Section 4 presents multi-objective, multi verse optimization algorithm; a discussion of the results is introduced in Section 5; and Section 6 provides the work conclusion.

2. Case study

Egypt has planned to provide 53% of energy by utilization of renewable resources by 2035 [55]. With renewable sources, fuels and heat all factored in, the RE map analysis shows that renewable sources could contribute by about 22% of Egypt's energy supply in 2030, up from just 5% overall in 2014 [56,57]. This study addresses the hourly meteorological data for Berenice city which are used to optimize a HMGS. Berenice is located at the Red Sea castle of Egypt at 23° 54′ 31″ N, 35° 28′ 21″ E. Fig. 1(a), (b) show the location of Berenice city in the Egypt atlas of horizontal solar irradiation and wind speed [58].

3. Modeling of the hybrid micro-grid system

The HMGS implemented, and the system details are given in [57]. Renewable generation mainly depends on whether condition, so, utilizing traditional energy sources are basically required for system stability and power continuity. The configuration of the HMGS is represented according to Fig. 2.

3.1. HMGS components

3.1.1. PV system

Power produced out of the PV energy system is estimated according to the solar radiation and the cell temperature by the formulas [41,59,60]:

$$p_{pv-out} = p_{N-pv} \times \left(\frac{G}{G_{ref}}\right) \times (1 + K_t(T_{amb} + (0.0256 \times G) - T_{ref} \tag{1}$$

The hourly temperature and the global horizontal radiation are as in Fig. 3 and Fig. 4 respectively.

3.1.2. Wind energy system

In general, wind speed is an uncertainty factor. As a result, the wind speed can be obtained using the following formula [61,62].

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{2}$$

The wind turbines power output can be calculated as [63]:

$$\left\{ \begin{array}{cc} 0, & V < V_{cut-in}, V > V_{cut-out} \\ V^3\left(\frac{P_{rated}}{V^3_{rated} - V^3_{cut-in}}\right) - P_{rated}\left(\frac{V^3_{cut-in}}{V^3_{rated} - V^3_{cut-in}}\right), & V_{cut-in} \le V < V_{rated} \\ P_{rated}, & V_{rated} \le V < V_{cut-out} \end{array} \right\} \tag{3}$$

The hourly wind speed is shown in Fig. 5.

3.1.3. Diesel genrator

Light load operation or unbalanced operation of diesel generator should be excluded. Fuel consumption at each hour for the diesel generator is expected using the following formula [13,64,65]:

$$q(t) = \alpha \cdot p(t) + \beta \cdot p_r \tag{4}$$

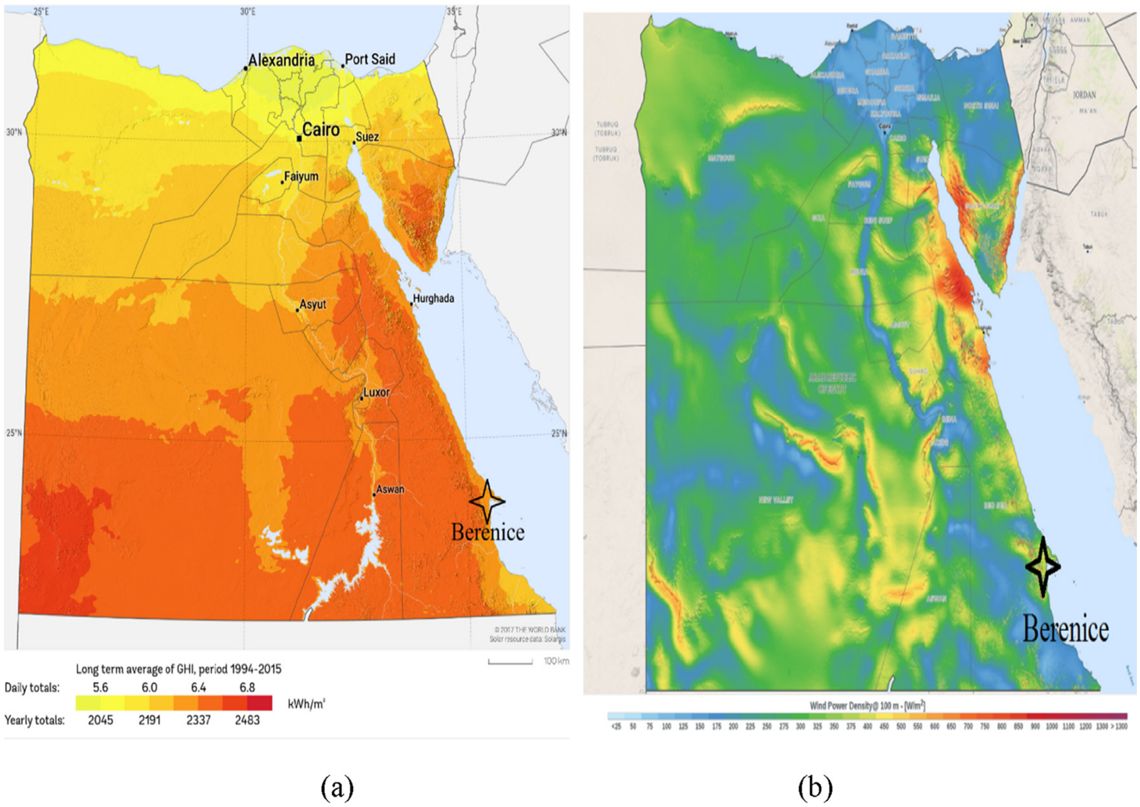

Fig. 1. (a) Global horizontal irradiation in Egypt, (b) Wind power density at height of 100 m.

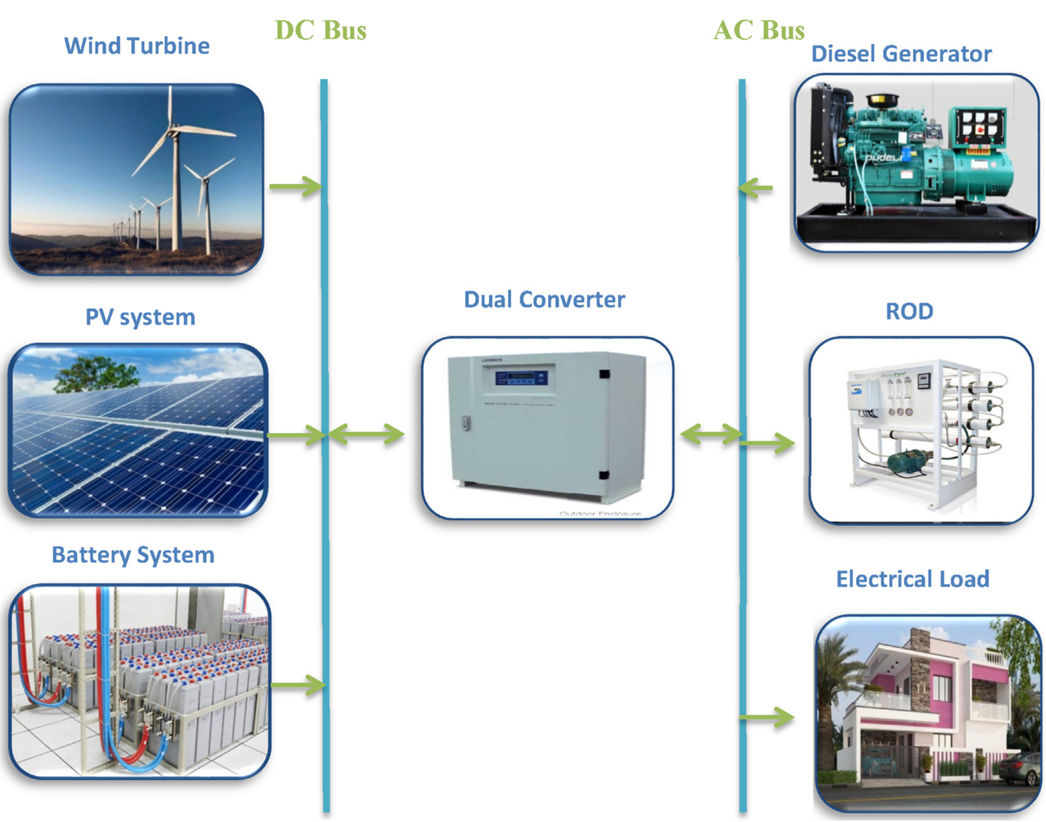

Fig. 2. Proposed HMGS used in the study.

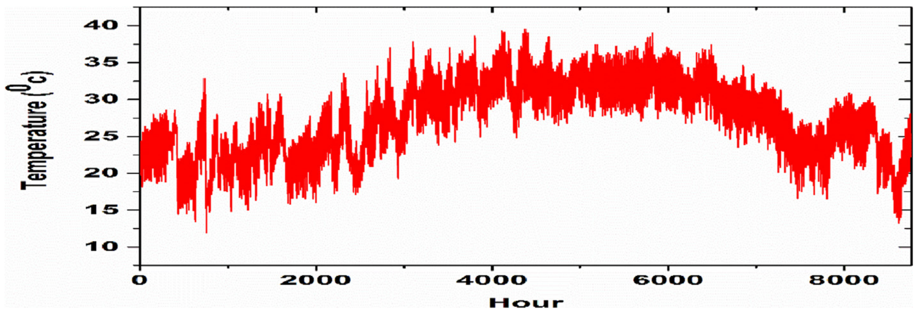

Fig. 3. Hourly ambient temperature.

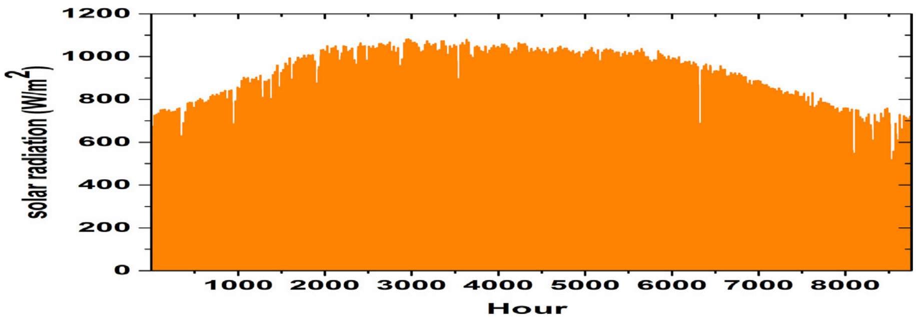

Fig. 4. Hourly solar radiation (W/m^2).

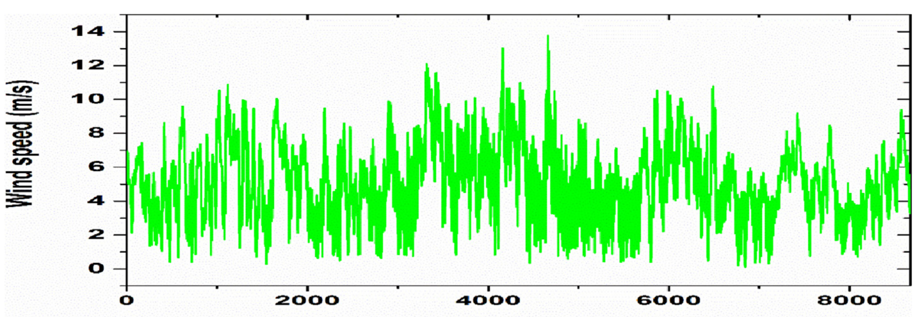

Fig. 5. Hourly wind speed at 10 m height.

3.1.4. Battery bank

Battery bank energy storage capacity (kWh) can be estimated depending on the load power and autonomy days by implementing the following expression [66]:

$$C_B = \frac{E_L \cdot AD}{DOD \cdot \eta_{inv} \cdot \eta_b} \tag{5}$$

3.1.5. Inverter the inverter efficiency is estimated by [67]

$$\eta_{inv} = \frac{P}{P + P_O + KP^2} \tag{6}$$

$$P_o = 1 - 99\left(\frac{10}{\eta_{10}} - \frac{1}{\eta_{100}} - 9\right)^2 \tag{7}$$

$$K = \frac{1}{\eta_{100}} - P_O - 1 \tag{8}$$

$$P = \frac{P_{out}}{P_n} \tag{9}$$

where, η_{10}, and η_{100} are the inverter efficiencies at minimum and maximum loading conditions. Techno-Economic parameters of the HMGS components used in the study is found in [28].

3.1.6. Reverse osmosis desalination (ROD)

The energy per hour or the power required for the unit (P_{DEM}) can be calculated as following [68]:

$$P_{DEM} = E_{DEM} = H_{WD}.S_{DC} \tag{10}$$

where, H_{WD} is the hourly volumetric freshwater demand, S_{DC} is the mean energy needed for desalination. In recent days, ROD units require about 2–4 kWh to produce 1 m^3 of fresh water [69]. In the current study, a value of 4 kW h/m^3 is taken to present for the entire desalination process and apparatus (pumps, membranes, and energy recovery systems). The daily fresh water that can be produced from the ROD unit can be obtained from the following equation [70]:

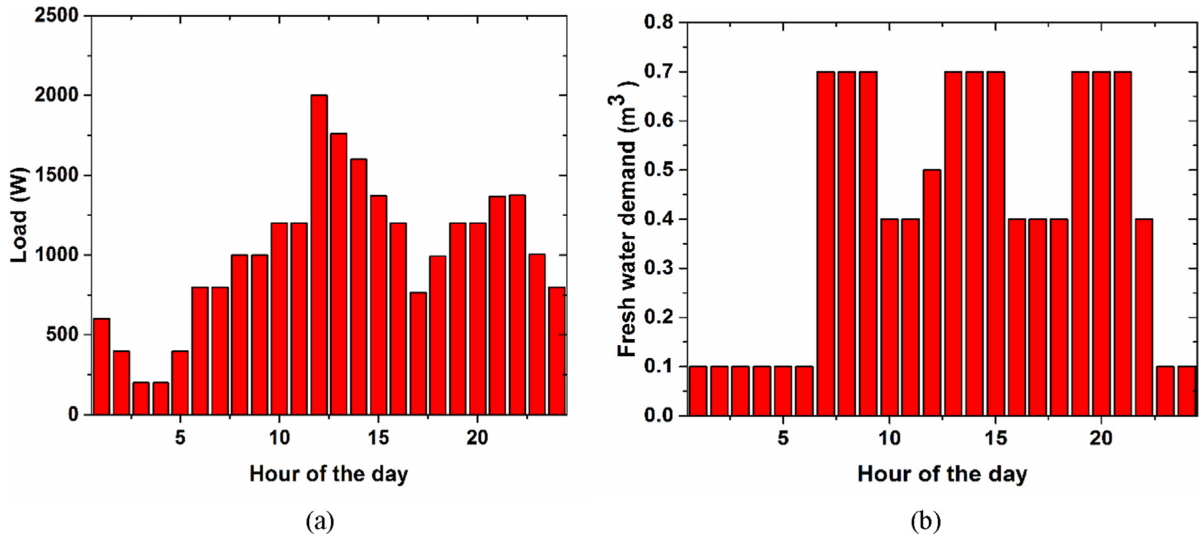

Fig. 6. (a) Hourly load profile for single house (W), (b) Hourly Fresh water demand (m^3).

$$D_{WC} = 24\left(\frac{P_D}{S_{DC}}\right) \quad (11)$$

where P_D is the installed power of desalination system, and it is taken in the study as a free variable. Because of the ROD membrane's characteristic curve, the ROD system is operating within minimum and maximum load demand and nominal established power [71–73].

$$P_{MD} \le P_{DES} \le P_{DI} \quad (12)$$

where, P_{DES} is the hourly power consumed by the desalination system, P_{MD} is the minimum load, and P_{DI} is the installed power. The minimum operation condition is due to the lower pressure needed to avoid the osmotic compression and to locate desalination unit up. Moreover, operating the ROD in low loads has an impact to the pure water production, but this is out of the current study scope. In the current study, the technical minimum power is considered at 25% of the nominal installed power. In the present study, two days are considered as storage autonomy. The pure water reservoir is calculated by:

$$V_{TC} = 2 \cdot D_{WD} \quad (13)$$

where, V_{TC} is capacity of the freshwater tank (m^3), and D_{WD} is the daily pure water needed (m^3). The techno-economic details of the various HMGS devices used in the work are given in [28].

3.2. Techno-economic parameters of the HMGS components

For a well-Optimized hybrid stand-alone micro-grid system, the economic assessment is one of the key variables to guarantee the optimum system configuration and the system parameters is given in [28].

3.3. Load profiles

The load characteristics for a certain area is an important component in optimizing and sizing a reliable and cost effective HMGS. In the present study, two load profiles are considered: one to represent the load of the household, and the other to represent the reverse osmosis system. The hourly load profile is shown in Fig. 6. The upper limit of the load is considered as 2 kW, and the daily main load is 1 KW. Fig. 7 represents the daily freshwater demand.

3.4. HMGS energy management strategy

The proposed HMGS are shown in Fig. 7. There are four scenarios considered for the proposed energy management in this study is given in [28].

4. Multi-objective optimization

Smaller scale grid optimization issue is typically framed in a multi-objective structure related to the following formula:

$$f(x) = \begin{bmatrix} f_1(x) \\ f_2(x) \\ \cdot \\ \cdot \\ \cdot \\ f_n(x) \end{bmatrix}, \quad \text{subjected to} \quad \begin{pmatrix} G(x) \le 0 \\ H(x) = o \end{pmatrix} \quad (14)$$

where $x = [x_1, x_2, x_3, \cdots\cdots\cdots\cdots, x_m]$ is the control vectors, and $f(x) = f_1(x), f_2(x), \cdots ..., f_m(x)$ are the objective functions' values;

4.1. Objective functions

In the current article, three objectives are considered (COE, (LPSP), and Renewable Factor (RF). These objectives are considered during the optimization process to count for the economic, technical, and environmental optimization ceriateria of hybrid renewable sources-based microgrid system.

4.1.1. Cost of Electricty (COE)

It is characterized as unit of cost per unit of delivered energy produced by hybrid micro-grid (\$/kWh) as in the accompanying expression [74,75]:

$$COE = \frac{Total\ Net\ Presnt\ Cost\ (NPC)}{\sum_{h=1}^{h=8760} P_l(h)} \times CRF \quad (15)$$

The capital recovery factor CRF is characterized as:

$$CRF = \frac{i(i+1)^n}{(i+1)^n - 1} \quad (16)$$

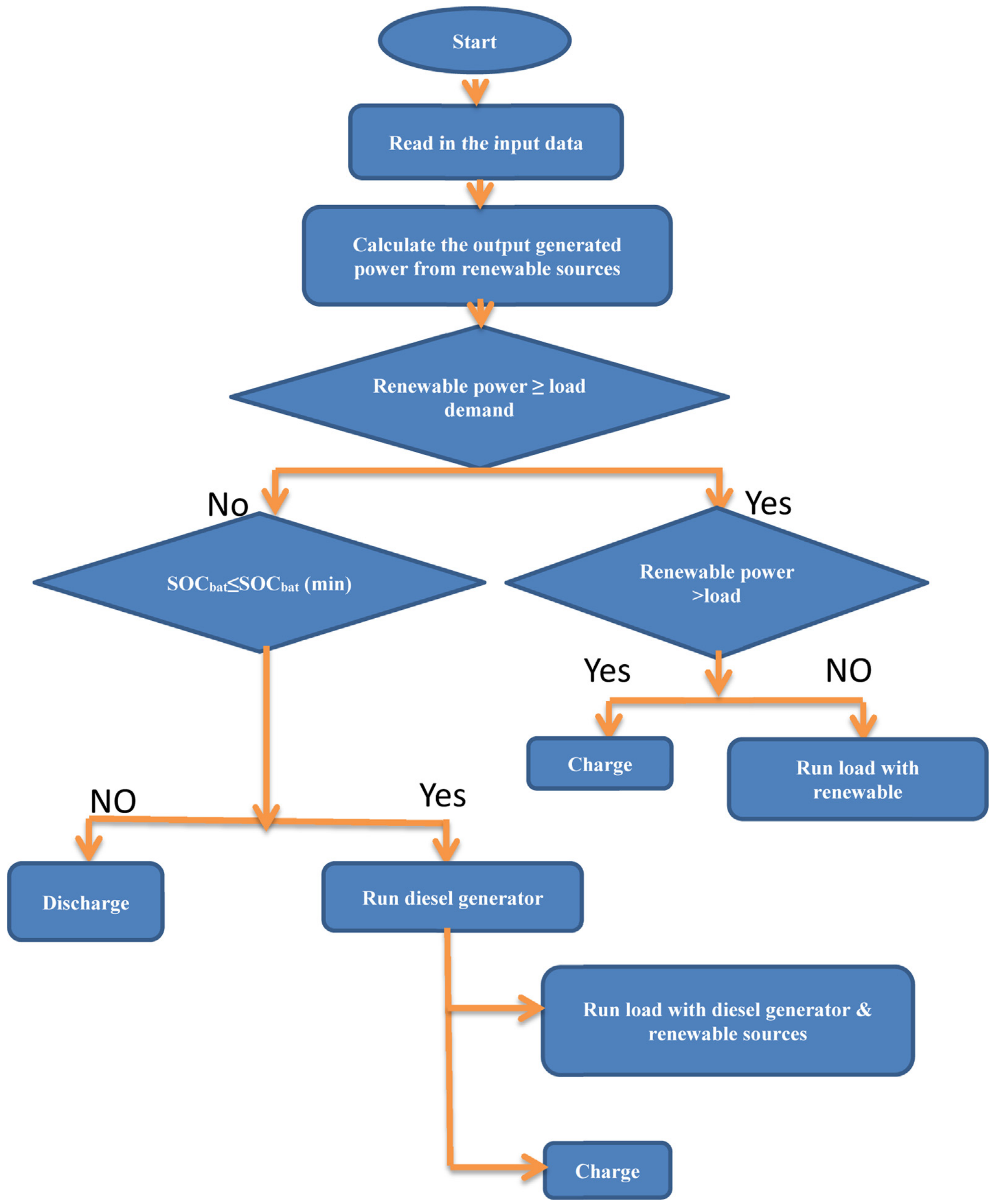

Fig. 7. Main flowchart of the HMGS energy management strategy.

4.1.2. Loss of Power Supply Probability (LPSP)

The subsequent objective function is the (LPSP). Where, the smaller scale structuring in islanded mode; and it is critical to increase the system dependability by minimizing the LPSP due to insufficient energy to supply the load. Factually, (LPSP) can be determined utilizing the accompanying formulas [76,77]:

$$LPSP = \frac{\sum P_L(t) - (P_W(t) + P_{PV}(t) + (E_b(t-1) - E_{bmin}) + P_{diesel})}{\sum P_L(t)} \tag{17}$$

4.1.3. Renewable Factor (RF)

Renewable Factor (RF) is estimated to account for the rate of conventional diesel generation to renewable sources production. Here, the goal is to minimize the conventional diesel power output which results in minimizing operation cost and CO_2 emissions. Renewable Factor can be estimated by the following equation [78,79,80]:

$$RF = \left(1 - \frac{\sum P_{diesel}}{\sum P_{pv} + P_w}\right) \times 100 \tag{18}$$

4.2. Multi-Objective Multi-Verse Optimization Algorithm MOMVO

4.2.1. Multi-verse optimization algorithm (MOMVO)

The Multi-Verse Optimization algorithm [81] simulates one of the physical theories of multiple universes' existence in the world. The model for MVO can be described as follows [82]:

The MVO algorithm's main equation is:

$$x_i^j = \begin{cases} \begin{cases} x_j + TDR \times ((ub_j - lb_j) \times r_4 + lb_j) & r_3 < 0.5 \\ x_j - TDR \times ((ub_j - lb_j) \times r_4 + lb_j) & r_3 \geq 0.5 \end{cases} & r_2 < WEP \\ x_i^j \quad r_2 \geq WEP \end{cases} \tag{19}$$

The (WEP), and (TDR); are represented by the following formulas:

$$WEP = min + l \times \left(\frac{WEP_{max} - WEP_{min}}{L}\right) \tag{20}$$

$$TDR = 1 - \left(\frac{l^{1/p}}{L^{1/p}}\right) \tag{21}$$

where WEP_{min} = 0.2, WEP_{max} = 1, l and L indicate the present iteration and the upper iteration. p is the exploitation quality and its amount equals to 6 as recommended in [82].

4.2.2. The multi-objective version of the MVO

The modification version of MVO is the same as those in MOPSO and PAES [83].

MOMVO is needed to choose the optimum, and enhance the distribution, so that the following formula is implemented through the desired objectives:

$$P_i = \frac{c}{N_i} \tag{22}$$

The following formula is applied to exclude the undesired probability solutions by MOMVO algorithm.

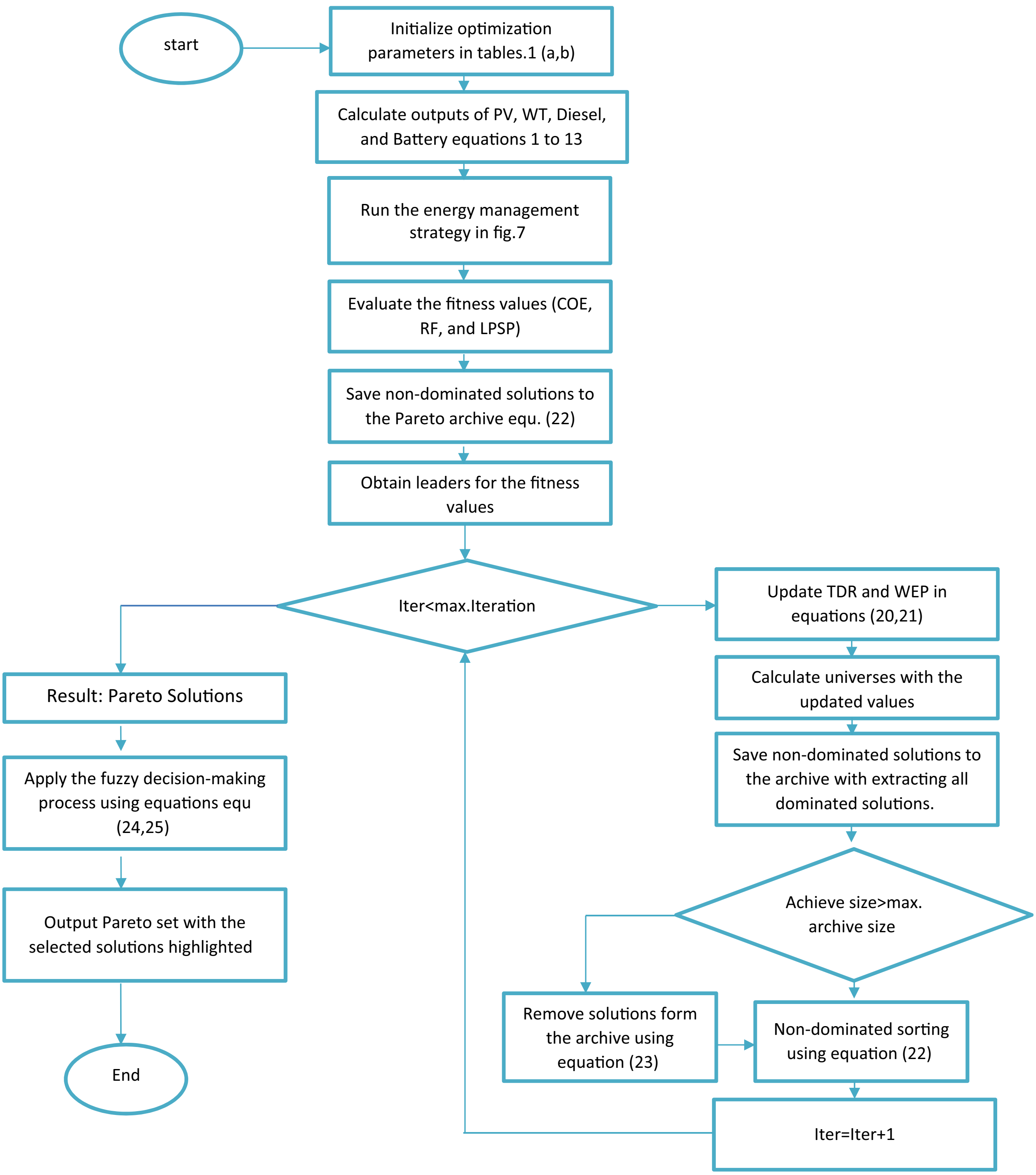

Fig. 8. Complete flowchart for the optimization process with the proposed MOMVO.

Table 1
(a) Minimum and maximum limits of the decision variables.

Variable	Min	Max
PV	15	45
WT	1	10
AD	1	5
Pg	1	4

Table 2
(b) Parameters of the proposed MOMVO.

Max_iter	100
Max.archive size	100
WEP.max	1
WEP.min	0.2
Max. number of members	100

$$P_i' = \frac{N_i}{c} \quad (23)$$

Where c is a constant and must be >1 and N_i is the available of solutions in the vicinity of the *i-th* solution [84].

4.3. Fuzzy decision making

The multi-objective optimization process produces a set of optimal solutions rather than one single solution, then, the decision maker ought to select the best compromise; one which depends on many factors like the decision maker experience and the priority of the design criteria. The fuzzy method can be used to obtain the best compromise solution. Generally, each objective function is expressed in a distinct membership function that can be designed according to the decision maker's experience. In this work, for each objective function, a simple membership function in a linear form has been considered. The linear membership function may be obtained as follow [85,86]:

$$\mu_i = \begin{cases} 1 & f_i \le f_i^{min} \\ \frac{f_i^{max} - f_i}{f_i^{max} - f_i^{min}} & f_i^{max} < f_i < f_i^{max} \\ 0 & f_i > f_i^{max} \end{cases} \quad (24)$$

where f_i is the i^{th} objective function, andf_i^{min} andf_i^{max} are the minimum and maximum limits of the satisfaction of the decision maker for the objective function. The satisfaction degree for each of the objective function has been represented as a membership function variates from zero to one [0,1]. The value $\mu_i$accounts for the satisfaction degree. Where, (μ_i = 1) means completely satisfactory and (μ_i = 0) completely unsatisfactory. The decision maker can be realized by the fuzzy membership function, as well as normalizing the different objective functions units into the same range of 0 ~ 1. The fuzzy normalized function μ^kcan be obtained by [87]:

$$\mu^k = \frac{\sum_{i=1}^{Nobj} \omega_i \mu_i^k}{\sum_{k=1}^{M} \sum_{i=1}^{Nobj} \omega_i \mu_i^k} \quad (25)$$

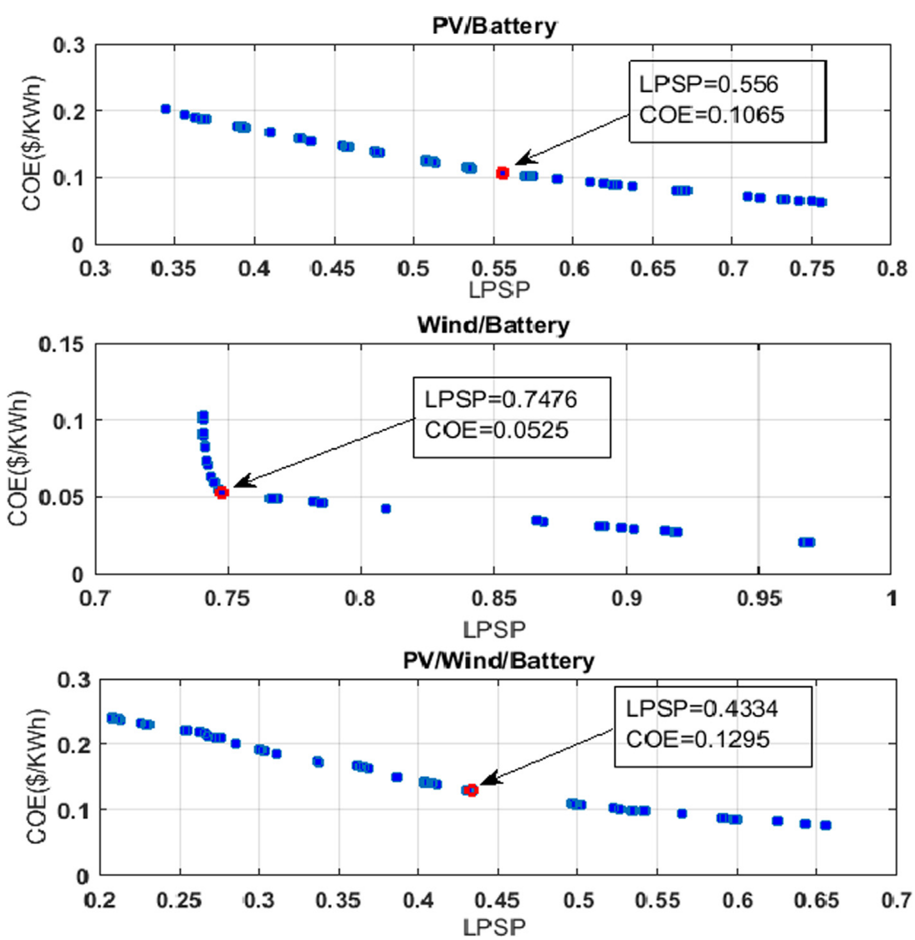

Fig. 9. Pareto solutions obtinaed by MOMVO for all the three cases in scenario (1).

Table.3
Best compromise solutions for scenario (1).

HMGS	PV	AD	WT	COE	LPSP
PV/Battery	30.2	1	–	0.1065	0.556
Wind/battery	–	1.04	10	0.0525	0.7476
PV/wind/battery	25.63	1	10	0.1295	0.4334

where$k$,Nob, and $\omega_i$are k^{ih} value of the non-dominated solution, the objective functions number, and the i^{th} objective function's weight factor, respectively. A Complete flowchart for the optimization process with the proposed MOMVO Fig. 8.

4.4. Decision variables and optimization parameters

The decision variables considered are given in Table 1. And the optimization parameters are in Table 2

5. Results and discussion

The city of Bernice is implemented as a case study to investigate the availability of designing a micro-grid system in the Egyptian rural areas. First, the simulation results will be discussed. Then, a sensitivity analysis and a comparative study will be made.

5.1. Simulation results

In order to study all the available configuration of the renewable sources based micro-grid system, the work is divided into two main scenarios namely, Only Renewable, and Renewable with diesel generator.

5.1.1. Scenario (1): Only renewable/Reverse osmosis desalination system (ROD)

In the first scenario, only renewable sources are considered and optimized. Combining all the renewable sources results in three different shapes namely, PV/Battery, Wind/Battery, and, PV/Wind/Battery. In this scenario, no diesel generator is used; therefore, only two objective functions are considered COE and LPSP. The Pareto solutions calculated for these three cases are illustrated in Fig. 9. The MOMVO algorithm is run with100 individual population and100 iteration. And for purpose of compression, the weight factor of the fuzzy membership function is taken to be $w_1 = w_2 = 0.5$. Hence, the best compromise solutions obtained for the three cases are listed in Table 3. One of the advantages of Pareto solutions is to provide a set of solutions available to the decision-making, rather than one single solution. For PV/Battery, the best compromise solution is found to be LPSP = 0.556, and COE = 0.1065 $/KWh. It is clear the COE is good, but the value of the LPSP is slightly high which means that the reliability of the system is poor. For Wind/Battery, the best compromise solution is LPSP = 0.7476, and COE = 0.0525 $/KWh. The initial and maintenance cost of the wind turbines are relatively low which results in lower value of the COE. But the wind speed in the selected case study is relatively low all over the year which results in high value for the LPSP. When complaining PV/Wind/Battery the value of the COE is 0.1295 $/KWh, and LPSP is 0.4334. The COE is higher than both of the two previous cases, but when combining PV with wind turbines the system reliability improves.

The operation of the HMGS for one week horizon is shown in Fig. 10. The resedintial load demand $Load_{(Res)}$, power demand for reverse osmosis desalination system P_{Des}, the output power of the various devices in the system and the battery energy are all plotted versus the time in hour. For the case of PV/Battery, the sun rises for part of the day, the produced energy of the PV system in these hours of the day supplies the load required and charges the battery which is dicharged at the end hours of the day to provides the required energy. Other part of the day and the night the battery is at its lower limit of charge and the system fails to supply the resedential load and the desalination system. For the second case, wind/battery HMGS, the output of the wind turbine is lower than that for the PV system in the first case, where the wind speed is slightly low, especially at day hours, the battery is charged at night and charges at the first hours of the day. It is obvious that the hours of the day at which the system is unable to supply the load needed is higher than the first case of PV/battery. The third case is a combination of both PV with wind power PV/Wind/Battery. It is clear that the HMGS operation is improved where the hours of the day at which the system is unable to meet the load are much lower than both the two prevoius cases. At day hours, the production of PV system combined with the production of wind can cover the required energy if the wind speed is high enough to generate power; the remainning power is applied to provides e battery which discharges and supplies the load at afternoon hours of the day, but the system is still unable to meet the load at all the day hours.

The power contribution of the various components in the HMGS for the three cases in scenario (1) are shown in Fig. 11. Where, for the first case of PV/battery, the PV panels participate by 93% of the overall power supplied to the load, and the battery by only 7%, where there is small power amout to charge the battery which can be discharged again and supply the load. And in the second case, the wind participates by 96% and the battery only 4%. For the system of PV/Wind/Battery, the PV produces 57%, the wind trubine produces 38%, and the battery participates by 5% of the overall power supplied to the load in one year.

5.1.1.1. Scenario (2): Renewable/Diesel/Reverse osmosis desalination system (ROD). In scenario (2), a conventional diesel generator is applied as a backup source which is turned on when the renewable sources are unable to supply the required loads. As a result of using diesel generator, the environmental impact of the diesel could be considered. Hence, the objective functions are the COE, LPSP, and the RF. The MOMVOA is run with100 individual population and100 iteration. And for purpose of compression, the weight factor of the fuzzy membership function is taken to be $w_1 = 0.5$, $w_2 = 0.3$, and $w_3 = 0.2$. Hence, the best compromise solutions obtained for the three cases are listed in Table 4. The Pareto solutions obtained for the three cases in scenario (2) are shown in Fig. 12. For PV/battery/diesel, the system reliability is obviously improved where, the LPSP is 0.2447, but the cost of the electricity is higher without using diesel where, the COE is 0.2494 $/KWh, and the renewable factor is RF = 84.25%. For the second case of wind/battery/diesel, the fuzzy best compromise solution is at LPSP = 0.3901, COE = 0.3257, and RF = −34.65%. As previously explained, the renewable factor is considered to account for the renewable penetration and is equal to one minus the sum of diesel output divided by the renewable output all over the year. When the RF equal unity it means that the system operates at full renewable sources and no diesel is used, and if the RF close to zero, it means that the diesel output is equal to the renewable output all over the year. The negative value of the RF factor in this case means

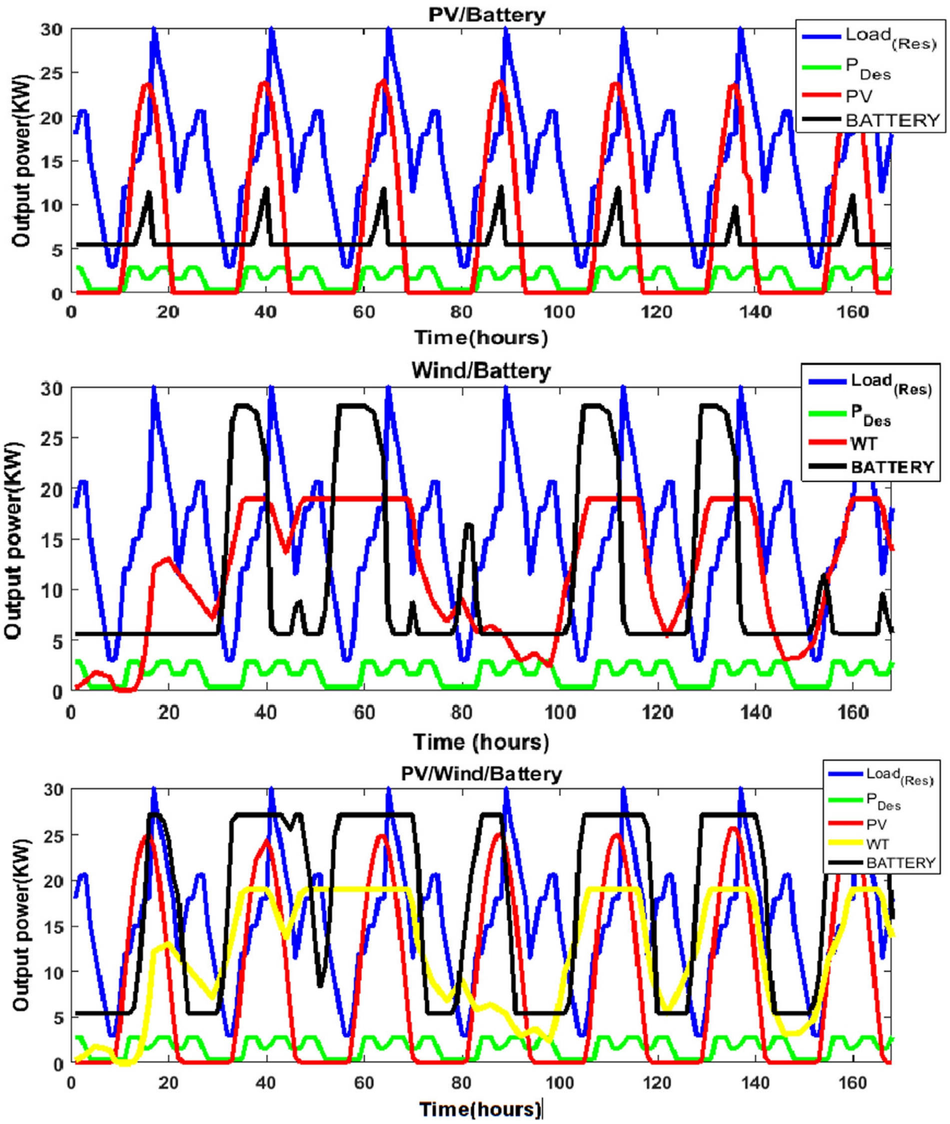

Fig. 10. One week operation of the HMGS for all the three cases in scenario (1).

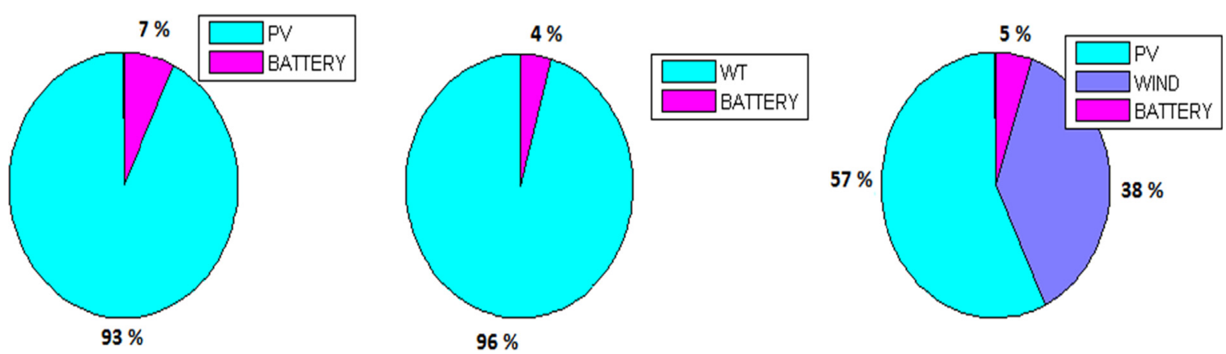

Fig. 11. Yearly power contribution of the various components in the HMGS for scenario (1).

Table.4
Best compromise solutions for scenario (2).

HMGS	PV	Wind	AD	Diesel	COE($/KWh)	LPSP	RF (%)
PV/Battery/diesel	45	–	4.4728	1	0.2494	0.2447	84.25
Wind/battery/diesel	–	10	4.4559	2	0.3257	V	−34.65
PV/wind/battery/diesel	45	10	4.9717	1	0.2720	0.1397	92.37

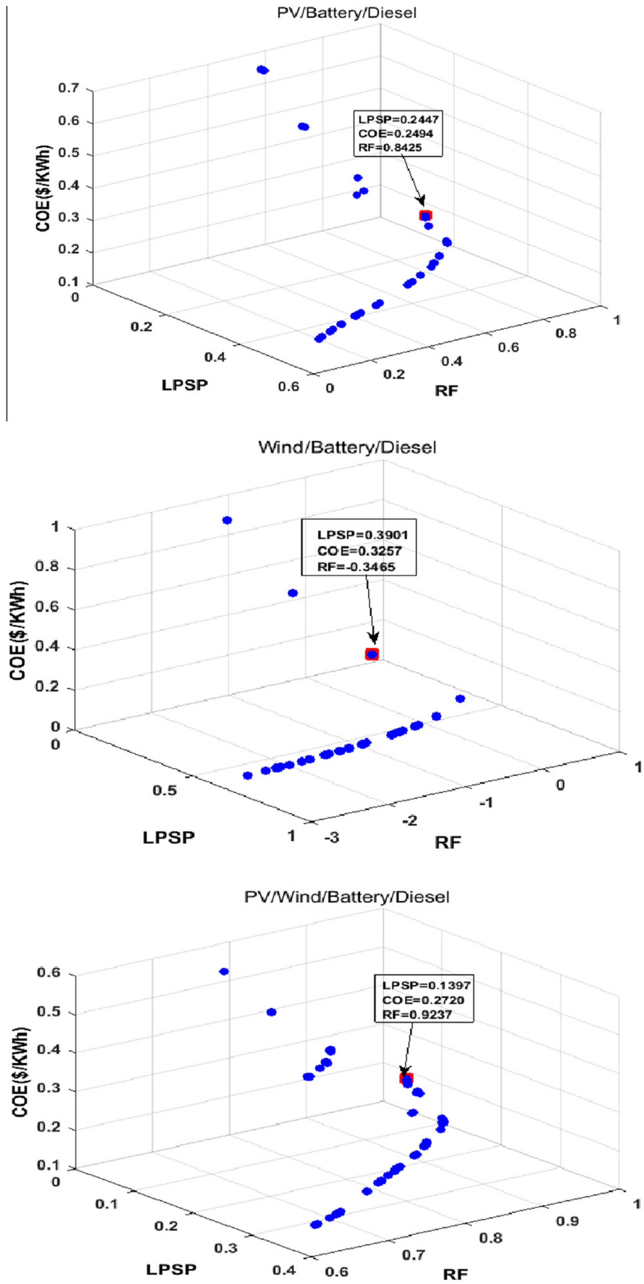

Fig. 12. Pareto solutions obtained for all the three cases in scenario (2).

that the diesel output is greater than the renewable output and the system mainly depends on the diesel to supply the load due to low wind output power through the year.

When combining PV with the wind turbines and diesel generator the results are COE = 0.2720$/KWh, LPSP = 0.1397, and RF = 92.37%. The system reliability is improved and is better than all the previous configurations. The COE is slightly greater than first case but is lower than the second case. And the renewable factor is better than both the two previous cases, where the system mainly function of renewable power from the solar system and the produced energy from the wind. The diesel generator operates as a backup energy source when the solar system and the wind turbines are unable to provide the required load. Simulation results for all the three cases in scenario (2) are listed in Table 4.

The operation of all the three possible configurations for the second scenario is described in Fig. 13. The output of the sources and the power of the battery are plotted for one week time horizon. For the first case of PV/Battery/Diesel, the solar power reaches its maximum value at the midday hours, this energy is enough to supply the required loads and the extra energy is applied to provide the battery bank. At this time, the diesel generator is off. In the afternoon when the output of the PV system falls the battery deliver the energy to cover the required load. At night, there is no energy from the PV panels and the battery bank is at its lower state of charge; at this time, the diesel is turned on to supply the load and charge the battery if there is extra energy. For the second configuration Wind/battery/diesel, the generated energy of the wind system is much lower than the solar power which results in higher number of diesel generators and the diesel hours of operation is higher than the first case. Finally, when combining both PV with wind system integrated with diesel generator, the HMGS operation is improved. Where, at the sunny hours of the day, the output power from the PV panels may be sometimes enough to cover the needed loads, and the excess power combined with the power from the wind system is applied to deliver the energy to the battery which is used when the PV power fails to cover the load with the wind power. The diesel generator operates only if the output from the renewable system is not enough to cover the load and the battery at its lower state of charge; so, the diesel usually operates at night as a backup energy system.

Another simulation results are plotted in Fig. 14. This shows the yearly power contribution for the various components in the HMGS for all the three cases in scenario (2). For the first configuration of PV/battery/diesel, the PV system participates by 73% of the total power supplied to the load; the battery participates by 16% and the diesel by the remaining 11%. For the second configuration, the system mainly depends on the diesel generator as previously mentioned; so, the diesel participates by 55%, the wind system by only 41%, and the battery by 4%. In this case there is not enough excess power to charge the battery which is the reason for only 4% participation of the battery bank. Finally, for the third configuration of PV/Wind/Battery/diesel, the PV system participates by 57%, the wind system by 22%, the battery bank by 15%, and the diesel by 4%.

5.2. Sensitivity analysis results

The sensitivity analysis is estimated to quantify the impact of the design parameter on the HMGS system behavior, as shown in Fig. 15. The techno-economic and environmental criteria are plotted versus the variation of the design parameters and the number of houses as varied from 0% to 200% of the optimal solution for the configuration consists of PV/Wind/Battery/Diesel. For the variation of the capacity of the PV, it affects somewhat linearly the COE; the LPSP decreases to 50 KW of the PV then its variation can be neglected. Also, the RF increases to about 50KW, and its value is constant. The impact of wind turbines uncertainty on the system is less than that for the PV capacity. Where, both RF and LPSP are slightly affected by the variation, but the COE are linearly affected. The AD variation has similar effect on the system performance as the wind turbine.

5.3. Comparative study

Tables 5, and 6 depict a comparative study between the proposed MOMVO algorithms output results with MOPSO, MOGWO, and NSGA-III for the two considered scenarios. The results indicate

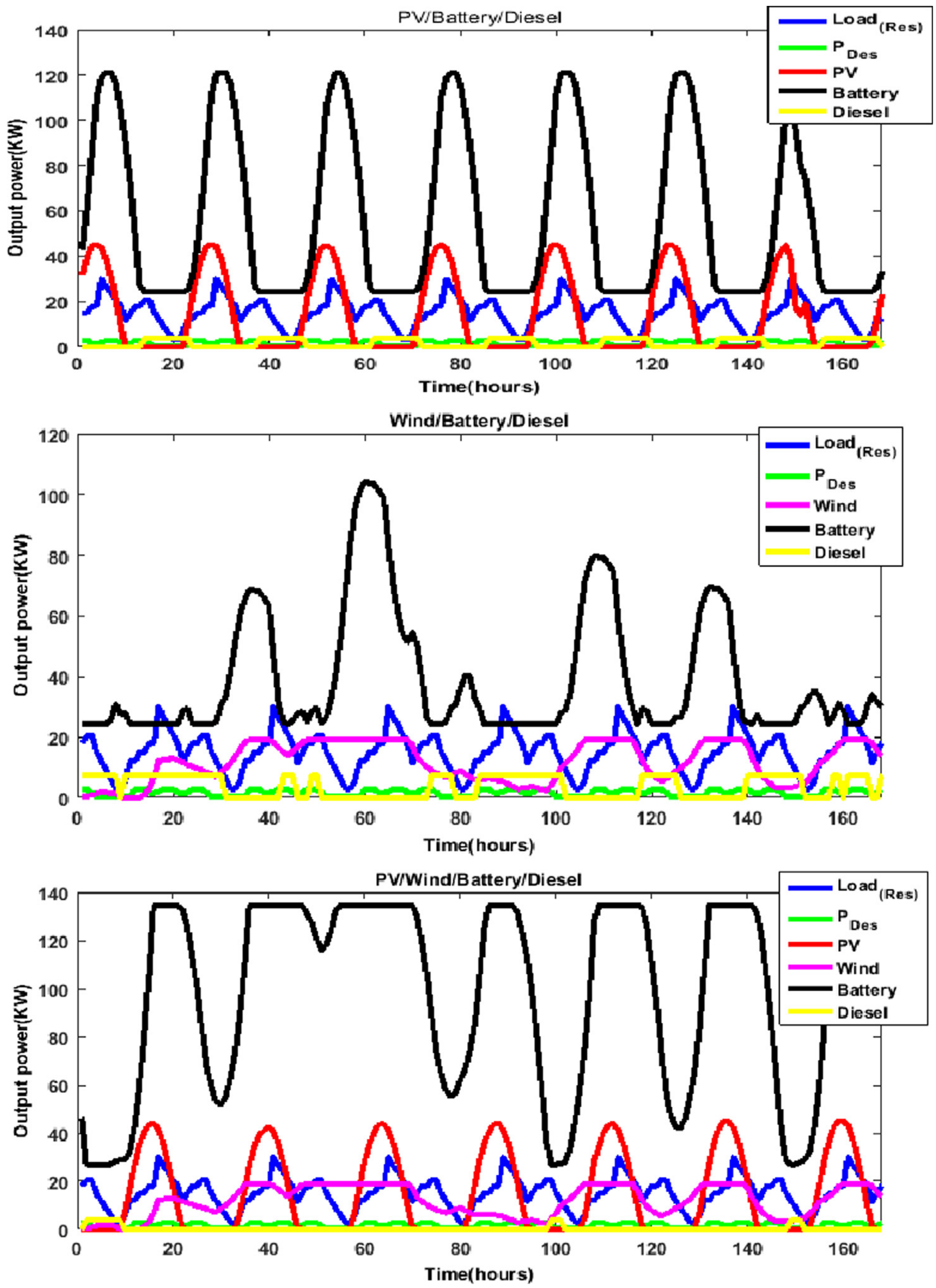

Fig. 13. One week operation of the HMGS for all the three cases in scenario (2).

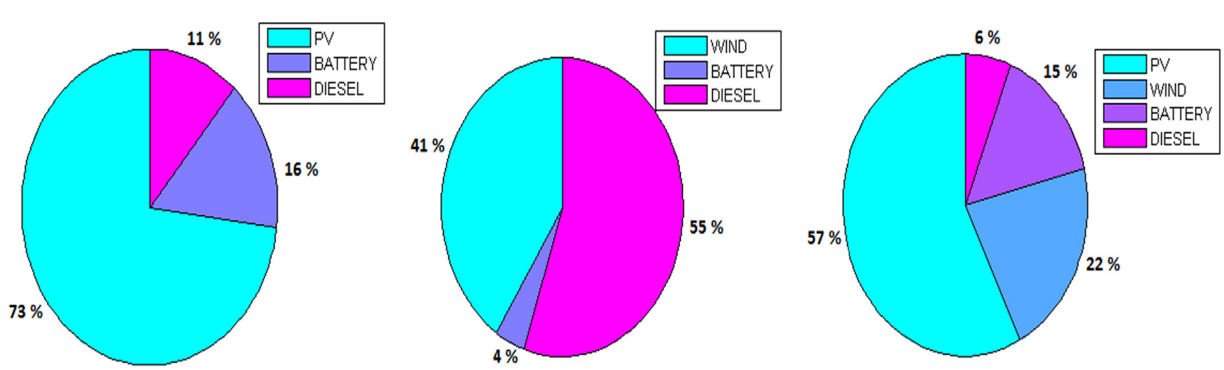

Fig. 14. Yearly power contribution of the various components in the HMGS for scenario (2).

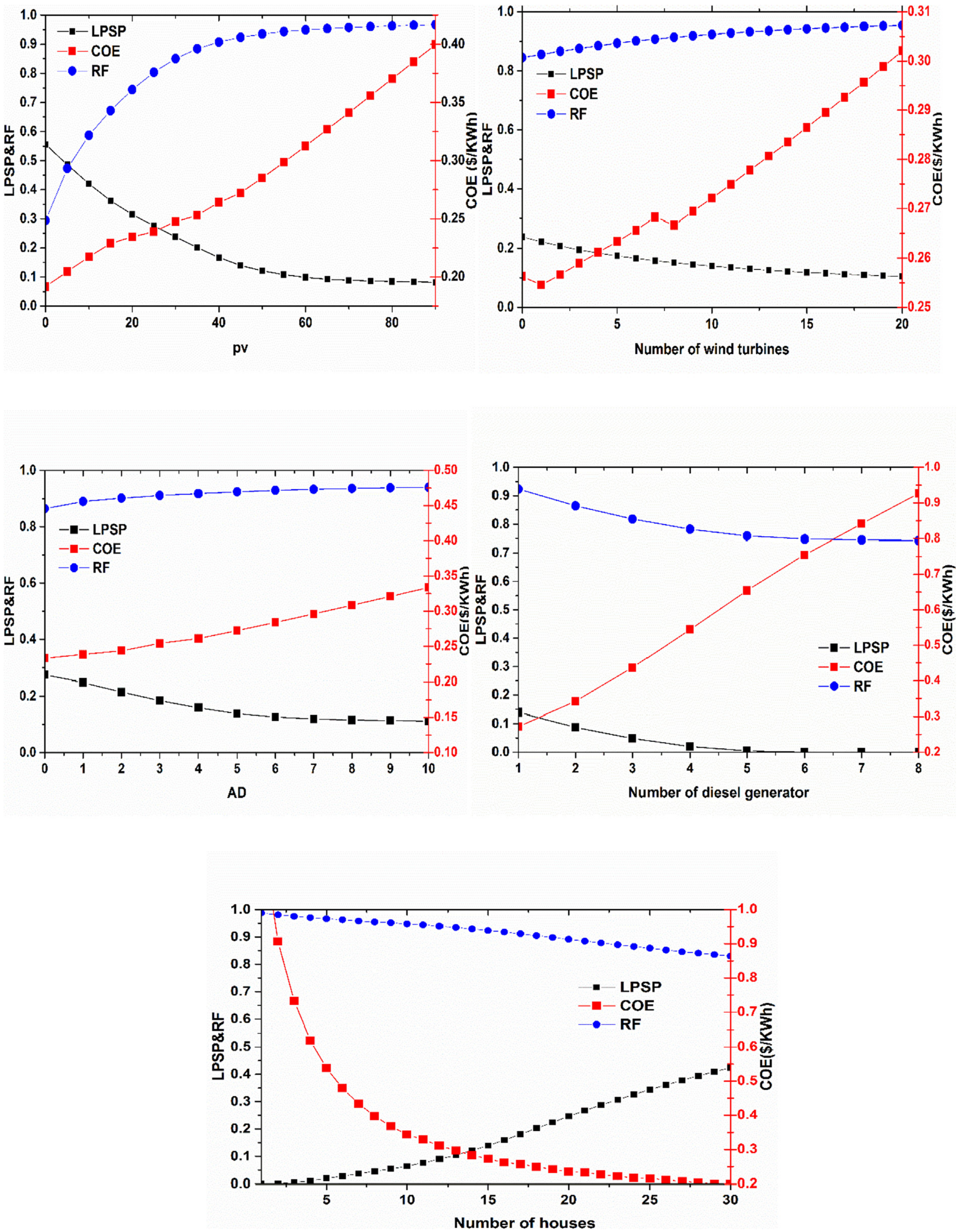

Fig. 15. Sensitivity analysis.

the accuracy of the proposed MOMVO technique in compared to other techniques for the same operating conditions.

6. Conclusion

A hybrid micro-grid system consists of PV system, wind turbines, and battery bank integrated with a conventional diesel generator is proposed. The main goal of the work was to find the optimal configuration and optimal component sizes of the proposed hybrid micro-grid energy system. A location at the Red Sea coast of Egypt (Bernice) was considered as the case study location. The problem of finding sizes of the HMGS components was framed in a multi-objective framework and three objective functions were considered. The considered objective functions were COE, LPSP,

Table 5
Comparison between the proposed MOMVO and other algorithms in case of 1st Scenario.

Optimization Technique	PV/Battery Parameter		Wind/Battery		PV/Wind/Battery	
	COE	LPSP	COE	LPSP	COE	LPSP
MOMVO	0.1065	0.556	0.0525	0.7476	0.1295	0.4334
MOPSO	0.1081	0.569	0.0596	0.8386	0.1378	0.4612
MOGWO	0.1161	0.562	0.0687	0.8887	0.1526	0.5723
NSGA-III	0.1073	0.557	0.0587	0.8013	0.1312	0.4515

Table 6
Comparison between the proposed MOMVO and other algorithms in case of 2nd Scenario.

Optimization Technique	PV/Battery/Diesel Parameter			Wind/Battery/Diesel			PV/Wind/Battery/Diesel		
	COE	LPSP	RF	COE	LPSP	RF	COE	LPSP	RF
MOMVO	0.2494	0.2447	84.25	0.3257	0.3901	−34.65	0.2720	0.1397	92.37
MOPSO	0.3566	0.2504	71.66	0.4073	0.6615	−55.91	0.2899	0.1683	90.33
MOGWO	0.4623	0.2613	79.76	0.4213	0.6734	−53.51	0.3231	0.1884	91.12
NSGA-III	0.3012	0.2455	80.12	0.3283	0.4335	−45.85	0.2832	0.1572	91.76

and RF. The Problem was suggested to account for the economical, technical, and ecological criteria of designing hybrid micro-grid energy systems. Then, the proposed (MOMVO) was applied. Furthermore, the problem was divided into two main scenarios namely, micro-grid of only renewable sources, and micro-grid of renewable sources and diesel generator. All the possible configurations in each scenario were modeled and optimized. So, each scenario was divided into three cases namely, PV/battery, wind/battery, PV/wind/battery for the first scenario: and PV/battery/diesel, wind/battery/diesel, PV/wind/battery/diesel for the second scenario. Reverse osmosis desalination (ROD) was considered as a load in conjunction with the residential load profile at the two case studies. A proposed power management strategy was followed to manage the system operation during supplying the load. The simulation results showed that MOMVO optimization produces appropriate components size. They also showed the techno-economic feasibility of using HMGS for rural electrification systems and enhancement of energy access.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors would like to acknowledge the financial support received from Taif University Researchers Supporting Project Number (TURSP-2020/146), Taif University, Taif, Saudi Arabia.

References

[1] Ma JPT, Yang H, Lu L. Technical feasibility study on a standalone hybrid solarewind system with pumped hydro storage for a remote island in Hong Kong. Renew Energy 2014;69:7–15.
[2] Nakhla DA, Hassan MG, El Haggar S. Impact of biomass in Egypt on climate change. Nat Sci 2013;05(06):678–84. doi: https://doi.org/10.4236/ns.2013.56083.
[3] IRENA. Renewable Energy Outlook: Egypt; 2018
[4] Ramli MAM, Bouchekara HREH, Alghamdi AS. Optimal sizing of PV / wind / diesel hybrid microgrid system using multi-objective self-adaptive differential evolution algorithm. Renew Energy 2018;121:400–11. doi: https://doi.org/10.1016/j.renene.2018.01.058.
[5] Hemeida AM, El-Ahmar MH, El-Sayed AM, Hasanien Hany M, Senjyu T. Optimum design of hybrid wind/PV energy system for remote area. Ain Shams Eng. J. 2020;11:11–23.
[6] Almansoori A, Saif Y. Structural optimization of osmosis processes for water and power production in desalination applications. Desalination 2014;344:12–27. doi: https://doi.org/10.1016/j.desal.2014.03.002.
[7] Kim DI, Kim J, Shon HK, Hong S. Pressure retarded osmosis (PRO) for integrating seawater desalination and wastewater reclamation: Energy consumption and fouling. J Memb Sci 2015;483:34–41. doi: https://doi.org/10.1016/j.memsci.2015.02.025.
[8] Bourouni K, M'Barek TB, Al Taee A. Design and optimization of desalination reverse osmosis plants driven by renewable energies using genetic algorithms. Renew Energy 2011;36:449–64.
[9] Koroneos C, Dompros A, Roumbas G. Renewable energy driven desalination systems modelling. J Clean Prod 2007;15(5):449–64. doi: https://doi.org/10.1016/j.jclepro.2005.07.017.
[10] Ghaffour N, Lattemann S, Missimer T, Ng KC, Sinha S, Amy G. Renewable energy-driven innovative energy-efficient desalination technologies. Appl Energy 2014;136:1155–65.
[11] Azaza M, Wallin F. Multi objective particle swarm optimization of hybrid micro-grid system: A case study in Sweden. Energy 2017;123:108–18. doi: https://doi.org/10.1016/j.energy.2017.01.149.
[12] Maleki A, Askarzadeh A. Comparative study of artificial intelligence techniques for sizing of a hydrogen-based stand-alone photovoltaic/wind hybrid system. Int J Hydrogen Energy 2014;39(19):9973–84. doi: https://doi.org/10.1016/j.ijhydene.2014.04.147.
[13] Diaf et al. S. A methodology for optimal sizing of autonomous hybrid PV/wind system to cite this version: HAL Id : hal-00183357; 2007.
[14] 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(10):3057–71. doi: https://doi.org/10.1016/j.solener.2012.07.014.
[15] Saad Naggar H, El-Sattar Ahmed A, Mansour Abd El-Aziz M. Mansour, A novel control strategy for grid connected hybrid renewable energy systems using improved particle swarm optimization. Ain Shams Eng. J. 2018;9:2195–214.
[16] Hu Xuefeng, Ma Penghui, Gao Benbao, Zhang Meng. An Integrated Step-Up Inverter Without Transformer and Leakage Current for Grid-Connected Photovoltaic System. IEEE Trans Power Electron 2019;34(10):9814–27.
[17] Bernal-Agustín JL, Dufo-López R. Simulation and optimization of stand-alone hybrid renewable energy systems. Renew Sustain Energy Rev 2009;13 (8):2111–8. doi: https://doi.org/10.1016/j.rser.2009.01.010.
[18] Mohamed Mokhtar, Mostafa I. Marei, Mahmoud A. Attia, Hybrid SCA and adaptive controller to enhance the performance of grid-connected PV system, Ain Shams Engineering Journal..
[19] Zuo Xue, Dong Mingyu, Gao Fengkai, Tian Shiming. The Modeling of the Electric Heating and Cooling System of the Integrated Energy System in the Coastal Area. J Coast Res 2020;103(sp1):1022–9. doi: https://doi.org/10.2112/SI103-213.1.
[20] Mills A, Al-Hallaj S. Simulation of hydrogen-based hybrid systems using Hybrid2. Int J Hydrogen Energy 2004;29(10):991–9. doi: https://doi.org/10.1016/j.ijhydene.2004.01.004.
[21] Swief RA, El-Amary Noha H. Optimal probabilistic reliable hybrid allocation for system reconfiguration applying WT/PV and reclosures. Ain Shams Eng. J. 2020;11:109–18.
[22] Sinha S, Chandel SS. Review of software tools for hybrid renewable energy systems. Renew Sustain Energy Rev 2014;32:192–205. doi: https://doi.org/10.1016/j.rser.2014.01.035.
[23] Alsayed M, Cacciato M, Scarcella G, Scelba G. Multicriteria Optimal Sizing of Photovoltaic-Wind Turbine Grid Connected Systems; 2013. p. 1–10.

[24] Zhang Weiping, Maleki Akbar, Pourfayaz Fathollah, Shadloo Mostafa Safdari. An artificial intelligence approach to optimization of an off-grid hybrid wind/ hydrogen system. Int J Hydrogen Energy 2021;46(24):12725–38. doi: https://doi.org/10.1016/j.ijhydene.2021.01.167.
[25] Mohammadi M, Hosseinian SH, Gharehpetian GB. Electrical Power and Energy Systems GA-based optimal sizing of microgrid and DG units under pool and hybrid electricity markets. Int J Electr Power Energy Syst 2012;35(1):83–92. doi: https://doi.org/10.1016/j.ijepes.2011.09.015.
[26] Rı GJ. Optimal sizing of renewable hybrids energy systems : A review of methodologies 2012;86:1077–88. doi: 10.1016/j.solener.2011.10.016.
[27] Shaheen Mohamed AM, Hasanien Hany M. Abdulaziz Alkuhayli, A novel hybrid GWO-PSO optimization technique for optimal reactive power dispatch problem solution. Ain Shams Eng. J. 2021;12:621–30.
[28] Borhanazad H, Mekhilef S, Gounder V, Modiri-delshad M, Mirtaheri A. Optimization of micro-grid system using MOPSO. Renew Energy 2014;71:295–306.
[29] Gökçek M, Begüm Ö. Technical and economic evaluation of freshwater production from a wind-powered small-scale seawater reverse osmosis system (WP-SWRO). DES 2016;381:47–57. doi: https://doi.org/10.1016/j.desal.2015.12.004.
[30] Khayet M, Essalhi M, Armenta-déu C, Cojocaru C, Hilal N. Optimization of solar-powered reverse osmosis desalination pilot plant using response surface methodology. DES 2010;261(3):284–92. doi: https://doi.org/10.1016/j.desal.2010.04.010.
[31] Quazi Nafees Ul Islam, Ashik Ahmed, Saad Mohammad Abdullah, Optimized controller design for islanded microgrid using non-dominated sorting whale optimization algorithm (NSWOA), Ain Shams Eng. J..
[32] Shahabi MP, Mchugh A, Anda M, Ho G. Environmental life cycle assessment of seawater reverse osmosis desalination plant powered by renewable energy. Renew Energy 2014;67:53–8. doi: https://doi.org/10.1016/j.renene.2013.11.050.
[33] Maleki A, Pourfayaz F, Rosen MA. A novel framework for optimal design of hybrid renewable energy- based autonomous energy systems : A case study for Namin, Iran. Energy 2016;98:168–80. doi: https://doi.org/10.1016/j.energy.2015.12.133.
[34] Abaza Amlak, Fawzy Asmaa, El-Sehiemy Ragab A, Alghamdi Ali S, Kamel Salah. Sensitive reactive power dispatch solution accomplished with renewable energy allocation using an enhanced coyote optimization algorithm. Ain Shams Eng. J. 2021;12:1723–39.
[35] Koutroulis E, Kolokotsa D. Design optimization of desalination systems power-supplied by PV and W / G energy sources. DES 2010;258(1–3):171–81. doi: https://doi.org/10.1016/j.desal.2010.03.018.
[36] Spyrou ID, Anagnostopoulos JS. Design study of a stand-alone desalination system powered by renewable energy sources and a pumped storage unit. DES 2010;257(1–3):137–49. doi: https://doi.org/10.1016/j.desal.2010.02.033.
[37] Garc L. Renewable energy applications in desalination : state of the art 2003;75:381–93. doi: 10.1016/j.solener.2003.08.005.
[38] Ma Q, Lu H. Wind energy technologies integrated with desalination systems : Review and state-of-the-art. DES 2011;277(1–3):274–80. doi: https://doi.org/10.1016/j.desal.2011.04.041.
[39] Ghorbani N, Kasaeian A, Toopshekan A, Bahrami L, Maghami A. Optimizing a hybrid wind-PV-battery system using GA-PSO and MOPSO for reducing cost and increasing reliability. Energy 2018;154:581–91. doi: https://doi.org/10.1016/j.energy.2017.12.057.
[40] Yu Dongmin, Mao Yingying, Gu Bing, Noajavan Sayyad, Jermsittiparsert Kittisak, Nasseri Maryam. A new LQG optimal control strategy applied on a hybrid wind turbine/solid oxid fuel cell/in the presentce of the interval uncertainties. Sustain Energy Grid Netw 2020;21:. doi: https://doi.org/10.1016/j.segan.2019.100296100296.
[41] Abdelkader A, Rabeh A, Mohamed Ali D, Mohamed J. Multi-objective genetic algorithm based sizing optimization of a stand-alone wind/PV power supply system with enhanced battery/supercapacitor hybrid energy storage. Energy 2018;163:351–63. doi: https://doi.org/10.1016/j.energy.2018.08.135.
[42] Lamedica R, Santini E, Ruvio A, Palagi L, Rossetta I. A MILP methodology to optimize sizing of PV - Wind renewable energy systems. Energy 2018;165:385–98. doi: https://doi.org/10.1016/j.energy.2018.09.087.
[43] Mehrjerdi H. Modeling and optimization of an island water-energy nexus powered by a hybrid solar-wind renewable system. Energy 2020;197. doi: https://doi.org/10.1016/j.energy.2020.117217.
[44] Ghaffari A, Askarzadeh A. Design optimization of a hybrid system subject to reliability level and renewable energy penetration. Energy 2020;193. doi: https://doi.org/10.1016/j.energy.2019.116754.
[45] Xin-gang Z, Ze-qi Z, Yi-min X, Jin M. Economic-environmental dispatch of microgrid based on improved quantum particle swarm optimization, vol. 195. Elsevier Ltd; 2020.
[46] Rahmani-Andebili Mehdi. Chapter 9: Cooperative Distributed Energy Scheduling in Microgrids," Electric Distribution Network Management and Control, Book. Springer; 2018. p. 235–54.
[47] Rahmani-Andebili M, Shen H. Cooperative distributed energy scheduling for smart homes applying stochastic model predictive control. IEEE Int Conf Commun 2017:1–6. doi: https://doi.org/10.1109/ICC.2017.7996420.
[48] Rahmani-Andebili M. Scheduling deferrable appliances and energy resources of a smart home applying multi-time scale stochastic model predictive control. Sustain Cities Soc 2017;32(April):338–47. doi: https://doi.org/10.1016/j.scs.2017.04.006.
[49] Mohammed OH, Amirat Y, Benbouzid M. Particle swarm optimization of a hybrid wind/tidal/PV/battery energy system. Application to a remote area in Bretagne, France. Energy Procedia 2019;162(April):87–96. doi: https://doi.org/10.1016/j.egypro.2019.04.010.
[50] Nyeche EN, Diemuodeke EO. Modelling and optimisation of a hybrid PV-wind turbine-pumped hydro storage energy system for mini-grid application in coastline communities. J Clean Prod 2020;250. doi: https://doi.org/10.1016/j.jclepro.2019.119578.
[51] Belouda M, Hajjaji M, Sliti H, Mami A. Bi-objective optimization of a standalone hybrid PV–Wind–battery system generation in a remote area in Tunisia. Sustain Energy, Grids Networks 2018;16:315–26. doi: https://doi.org/10.1016/j.segan.2018.09.005.
[52] Anoune K, Bouya M, Astito A, Ben Abdellah A. Sizing methods and optimization techniques for PV-wind based hybrid renewable energy system: A review. Renew Sustain Energy Rev 2018;93(May):652–73. doi: https://doi.org/10.1016/j.rser.2018.05.032.
[53] Rahmani-Andebili M. Stochastic, adaptive, and dynamic control of energy storage systems integrated with renewable energy sources for power loss minimization. Renew Energy 2017;113:1462–71. doi: https://doi.org/10.1016/j.renene.2017.07.005.
[54] Rahmani-Andebili Mehdi. Planning and Operation of Plug-In Electric Vehicles: Technical, Geographical, and Social Aspects, Book. Springer Nature Switzerland AG; 2019. https://doi.org/10.1007/978-3-030-18022-5.
[55] IEA. World Energy Outlook. Inernational Energy Agancy; 2007. https://www.iea.org/.
[56] Egyptian Electricity Holding Company Report. http://www.eehc.gov.eg/eehcportal/Eng/.
[57] Egyptian Electricity Holding Company Report.2013/2014 Avaliable online. http://www.moee.gov.eg/english_new/report.aspx.
[58] The Solar Atlas of Egypt Avalibale online: http://www.nrea.gov.eg/.
[59] Zhang W, Maleki A, Rosen MA, Liu J. Sizing a stand-alone solar-wind-hydrogen energy system using weather forecasting and a hybrid search optimization algorithm. Energy Convers Manage 2019;180(May 2018):609–21. doi: https://doi.org/10.1016/j.enconman.2018.08.102.
[60] Amrollahi MH, Bathaee SMT. Techno-economic optimization of hybrid photovoltaic/wind generation together with energy storage system in a stand-alone micro-grid subjected to demand response. Appl Energy 2017;202:66–77. doi: https://doi.org/10.1016/j.apenergy.2017.05.116.
[61] Fathy A. A reliable methodology based on mine blast optimization algorithm for optimal sizing of hybrid PV-wind-FC system for remote area in Egypt. Renew Energy 2016;95:367–80. doi: https://doi.org/10.1016/j.renene.2016.04.030.
[62] Rehman S, Al-abbadi NM. "Wind shear coefficients and energy yield for Dhahran. Saudi Arabia" 2007;32:738–49. doi: https://doi.org/10.1016/j.renene.2006.03.014.
[63] Wang L, Singh C. PSO-Based Multi-Criteria Optimum Design of A Grid-Connected Hybrid Power System With Multiple Renewable Sources of Energy. no. Sis; 2007. p. 250–7.
[64] Hussain A, Muhammad S, Aslam M, Danial S, Shah A. Optimal siting and sizing of tri-generation equipment for developing an autonomous community microgrid considering uncertainties. Sustain Cities Soc 2017;32(September 2016):318–30. doi: https://doi.org/10.1016/j.scs.2017.04.004.
[65] Khatib T, Mohamed A, Sopian K. Optimization of a PV / wind micro-grid for rural housing electrification using a hybrid iterative / genetic algorithm : Case study of Kuala Terengganu, Malaysia. Energy Build 2012;47:321–31. doi: https://doi.org/10.1016/j.enbuild.2011.12.006.
[66] Hemmati M, Amjady N, Ehsan M. Electrical Power and Energy Systems System modeling and optimization for islanded micro-grid using multi-cross learning-based chaotic differential evolution algorithm. Int J Electr Power Energy Syst 2014;56:349–60. doi: https://doi.org/10.1016/j.ijepes.2013.11.015.
[67] Schimd J. Inverter for photovoltaic system. In: Fifth contractor's meeting of the European community photovoltaic demonstration projects; 1991. p. 122–32.
[68] Manolakos D, Kosmadakis G, Kyritsis S, Papadakis G. Identification of behaviour and evaluation of performance of small scale, low-temperature Organic Rankine Cycle system coupled with a RO desalination unit. Energy 2009;34(6):767–74. doi: https://doi.org/10.1016/j.energy.2009.02.008.
[69] Padrón I, Avila D, Marichal GN, Rodríguez JA. Assessment of Hybrid Renewable Energy Systems to supplied energy to Autonomous Desalination Systems in two islands of the Canary Archipelago. Renew Sustain Energy Rev 2019;101 (February 2018):221–30. doi: https://doi.org/10.1016/j.rser.2018.11.009.
[70] Gökçek M. Integration of hybrid power (wind-photovoltaic-diesel-battery) and seawater reverse osmosis systems for small-scale desalination applications. Desalination 2017;no. April:1–11. doi: https://doi.org/10.1016/j.desal.2017.07.006.
[71] Atallah MO, Farahat MA, Lotfy ME, Senjyu T. Operation of conventional and unconventional energy sources to drive a reverse osmosis desalination plant in Sinai Peninsula, Egypt. Renew Energy 2019. doi: https://doi.org/10.1016/j.renene.2019.05.138.
[72] Mokheimer EMA, Sahin AZ, Al-sharafi A, Ali AI. Modeling and optimization of hybrid wind – solar-powered reverse osmosis water desalination system in Saudi Arabia. ENERGY Convers Manag 2013;75:86–97. doi: https://doi.org/10.1016/j.enconman.2013.06.002.
[73] Maleki A. Design and optimization of autonomous solar-wind-reverse osmosis desalination systems coupling battery and hydrogen energy storage by an improved bee algorithm. Desalination 2018;435(May 2017):221–34. doi: https://doi.org/10.1016/j.desal.2017.05.034.

[74] Kolhe M. Techno-Economic Optimum Sizing of a Stand-Alone Solar Photovoltaic System, vol. 24, no. 2; 2009. p. 511–9.
[75] Sharma V, Colangelo A, Spagna G. Photovoltaic technology: basic concepts, sizing of a stand-alone photovoltaic system for domestic applications and preliminary economic analysis. Energy Convers Manag 1995;36:161–74.
[76] 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 2008;82:354–67. doi: 10.1016/j.solener.2007.08.005.
[77] Rajkumar RK, Ramachandaramurthy VK, Yong BL, Chia DB. Techno-economical optimization of hybrid pv / wind / battery system using Neuro-Fuzzy. Energy 2011;36(8):5148–53. doi: https://doi.org/10.1016/j.energy.2011.06.017.
[78] Azaza M, Wallin F. Multi objective particle swarm optimization of hybrid micro-grid system : A case study in Sweden. Energy 2017;123:108–18. doi: https://doi.org/10.1016/j.energy.2017.01.149.
[79] Rahmani-Andebili M. Distributed Generation Placement Planning Modeling Feeder's Failure Rate and Customer's Load Type. IEEE Trans Ind Electron 2016;63(3):1598–606. doi: https://doi.org/10.1109/TIE.2015.2498902.
[80] Rahmani-Andebili M. Simultaneous placement of DG and capacitor in distribution network. Electr Power Syst Res 2016;131:1–10. doi: https://doi.org/10.1016/j.epsr.2015.09.014.
[81] Mirjalili S, Mirjalili SM, Hatamlou A. Multi-verse optimizer: a nature-inspired algorithm for global optimization. Neural Comput Appl 2016;27:495–513.
[82] Mirjalili S, Jangir P, Mirjalili SZ, Saremi S, Trivedi IN. Optimization of Problems with Multiple Objectives using The Multi-Verse Optimization Algorithm. Knowledge-Based Syst 2017. doi: https://doi.org/10.1016/j.knosys.2017.07.018.
[83] Coello CAC, Pulido GT, Lechuga MS. Handling multiple objectives with particle swarm optimization. IEEE Trans Evol Comput 2004;8:256–79.
[84] Deb K, Jain H. An Evolutionary Many-Objective Optimization Algorithm Using Reference-point Based Non-dominated Sorting Approach, Part I. Ieeexplore.Ieee.Org, vol. 18, no. c; 2013. p. 1–1. doi: 10.1109/TEVC.2013.2281534.
[85] Hu CF, Adivar M, Fang SC. Non-LR Type Fuzzy Parameters in Mathematical Programming Problems. IEEE Trans Fuzzy Syst 2014;22(5):1062–73.
[86] Sheng W et al. Research and practice on typical modes and optimal allocation method for PV-Wind-ES in Microgrid. Electr Power Syst 2015;120:242–55.
[87] Niknam T, Jabbari M, Malekpour AR. A modified shuffle frog leaping algorithm for multi-objective optimal power flow. Energy 2011;36(11):6420–32.