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Optimal Designing of the Capacity and the Operation of the CCHP System Using Balanced Collective Animal Behavior Algorithm: A Case Study

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ABSTRACT

The combined heating, cooling, and power source (CCHP) system is a good tool for the optimal consumption of fossil fuel thermal energy. In CCHPs, the produced waste heat from the hot gases can be recycled for generating power, heat, and water cooling and oil in electrical power generation systems which can improve the efficiency of the system to more than 85%. This study presents an optimum structure for the combined heating, cooling, and power source energy flow to decrease the power demand in a building in Yazd city, Iran. In this research, a developed version of collective animal behavior optimizer is introduced to develop the combined heating, cooling, and power source system efficiency compared to the separation generation system. Two different scenarios have been studied for analyzing system efficiency. In one scenario, a constant value (670 kW) was assumed to the capacity while the electric cooling (EC) to cool load ratio (CLR) is assumed variant in a determined range and at the other scenario, an opponent condition with 0.75 constant EC to CLR were assumed. Simulation achievements of the presented technique are put in comparison with standard balanced moth search optimizer and genetic algorithm to indicate the efficiency of the algorithm.

Keywords: *combined heating, cooling, and power source; balanced moth search algorithm; balanced; collective animal behavior algorithm; genetic algorithm*

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1. INTRODUCTION

Due to the steady rise in electricity prices and the willingness of the industries to manage wasted energy in the production process, the need for electricity is well felt. Energy has a high growth rate. Energy optimization has been proposed as a fundamental strategy to reduce energy consumption and to reduce environmental pollutants in developed countries. Today, these countries are looking at energy optimization and management as a new source of energy. One of the most important energy optimization strategies implemented in all of these countries is to develop the performance of energy production and to optimize the use of fuel resources with an overall efficiency of 75 to 90 percent, using the CCHP Systems.

This is an energy-saving procedure in which electricity and heat are produced simultaneously. Cogeneration heat will be used for heating the area and the industries. The primary mover of a CCHP can be based on various techniques such as steam turbines, combustion engines, gas turbines, and its primary energy source can contain biomass, fossil fuels, solar energy, geothermal, etc.

The CCHP systems are used as one of the most effective solutions to supply building energy in the commercial and residential sectors. While meeting the energy needs of the building at the same time, these systems, due to their high energy efficiency, reduce energy consumption and thus reduce fossil

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fuel consumption and have cost-effective results, including significant cost savings and energy savings. It will reduce environmental pollution. The energy costs of a building include the electrical costs of providing lighting and other electrical equipment for the building, as well as the costs of providing heating and cooling.

There are several research works about the analysis of the CCHP systems. for instance, Feng et al. [1] analyzed theoretical discussions about the CCHP users and the relations of energy-matching between user demands and providing system. To do the analysis, the general formulation of the users' load demands were performed on three categories CCHP users with time dependent parameters. The method was a di,mensionless load matching parameter analysis. Two capacity design modes were applied to fifty-three different kinds matching relations for the simulation. Te paper also analyzed the impact of the time-related parameters and the load on matching relations.

Jiang et al. [2] evaluated the robustness and the cost of the configured redundancy in a CCHP plant. In that paper, redundant design was used to develop the CCHP system robustness. The maintenance scheduling cost and the cost of downtime during the failure happened is analyzed in the total cost analysis of the CCHP plant. The final results showed that the redundant procedure can decrease the total cost and develop the CCHP system availability within a specific capacity.

Yang et al. [3] introduced a combined solar and CCHP systems to utilize as a proper solution to the urgent environmental and energy problems. The mathematical model of the proposed system along with solar thermal collectors was determined. A PSO optimizer was then used to achieve the best values of the parameters of the designed system. Five operation strategies were tuned and applied to the proposed system. The method was applied to a hotel building in Atlanta and the results showed that the hybrid CCHP system gives good achievements.

Liu et al. [4] evaluated the efficiency of a combined heating, cooling, and power system using CO2/SOFC/GT cycle, organic Rankine cycle (ORC) and LNG cold energy utilization along with carbon dioxide capture. The system was mathematically modeled and its efficiency was analyzed by considering the exergy and energy methods. The results showed that the presented CCHP plant gives a satisfying performance for energy consumption with close zero emissions.

As can be concluded, the best performance can be achieved while optimum operating and designing the combined heating, cooling, and power system can be obtained by applying operations cost, primary energy consumption (PEC), and carbon dioxide emission reduction (CDER). There are several primary movers that can be used in CCHP systems. For instance, steam turbine [5, 6], Organic Rankine Cycle (ORC) [7, 8], gas engine [9], and gas turbine [10]. Two popular methods that were applied in optimization of these systems are non-linear and linear programming (NLP and LP). Linear programming is a simple and possible technique for optimization of this system. In this context, Piacentino et al. [11] presented a linear programming method for optimization of the tri-generation systems. The system was based on Matlab platform to consider a relevant contribute of thermo-economics, pressurized heat storage, and energo-environmental analysis. Ren et al. [12] suggested a different LP technique for achieving a low cost distributed energy systems for a test year by considering the operating schedules. Furthermore, the effect of environment, energy, and economy of the system was studied. The method was applied as an optimized economy system in an area in Japan. In the area of nonlinear programming, Lu et al. [13] suggested a different configuration for optimal energy control of a building. The proposed configuration was nonlinear mixed-integer programming. To validate the method, four different scenarios have been investigated and then, the technique has been used to the Zero Carbon Building. Final achievements showed that the proposed configuration reduced the operating energy cost, specifically with thermal energy storage. In addition to linear and nonlinear programming, there are various methods that were used for CCHP systems optimization, for instance, Karush-Kuhn-Tucker [14], sequential quadratic programming [15], and bio-inspired algorithms [16, 17]. Due to the global exploring and fast results of bio-inspired algorithms, they are known as the most popular methods for energy problems. In the present research, a new optimal configuration is developed for the flow energy of the CCHP system. In the next section, the problem statement of the study has been explained. Section 3 explains about the new meta-heuristic, balanced moth search algorithm. Section 4 shows the procedure of the study in using the BMSA to optimize the combined heating, cooling, and power system. The results of simulation have been studied in Section 5 and Section 6 declares about the research conclusions.

2. PROBLEM STATEMENT

In this research, the economic analysis of the CCHP plant is carried out in detail in a residential building in Yazd city. CCHP demand for the studied building has been met. The optimization model is developed based on a new bio-inspired method. The investigated CCHP unit contains an absorption chiller (AC), an electric chiller (EC), a heating coil (HC), an auxiliary boiler, and a heat recovery system. The CCHP unit works with natural gas (NG) utilized by power generating unit (PGU) to meet the building's heat and electricity demands. Lighting and equipment were provided to the building consumer through the combination of direct unit operation, CHP electricity purchased from an external network. Any surplus electricity generated by the CHP unit in the summer at the electric chiller will be used to generate its surplus and will be sold if the surplus is available to the external grid. If the unit's power supply is insufficient, the CHP will be bought from the power network. The building heat demand spplied by the recovered heat generated by the CHP unit activity and the heat generated by the auxiliary boiler. Excess heat recycled by the CHP unit will be applied in the summer in the AC to produce cooling. If the heat generated by the unit is insufficient, the CHP boiler aids the remaining heat demand. The cooling demand was matched by the EC and the AC. The input electricity for the chiller has been supplied by the CHP unit or by purchasing from the grid, and the required input heat to the absorption chiller has been supplied by the CHP unit heat recovery system (HRS).

2.1. The main configuration of the energy flow in the combined heating, cooling, and power system

For modeling the configuration of the suggested system, it is first necessary to create an energy flow diagram, which in fact represents the conceptual model of the energy flow. The major drivers usually contain a steam turbine, a reciprocating internal combustion engine, a micro-turbine, a fuel cell, a gas turbine, and a Stirling engine. Fig. (1) depicts the general structure of the investigated combined heating, cooling, and power system including various, possible and comprehensive equipment.

The Hot Exhaust Gases of PGU has been recovered to utilize the thermal load for providing the heating and cooling system (CS) respectively of the cold season and the hot season. To evaluate the balanced electricity in the proposed CCHP system,

$$E_{grid} + E_{pgu} = E + E_{ec} + E_p \qquad (1)$$

where, E describes the power consumption in the building, E_{pgu} describes the generated power using the PGU, E_{grid} is the achieved electrical power from the power network, E_p is the parasitic use of electricity in the CCHP system, and E_{ec} represents the electrical power needed for

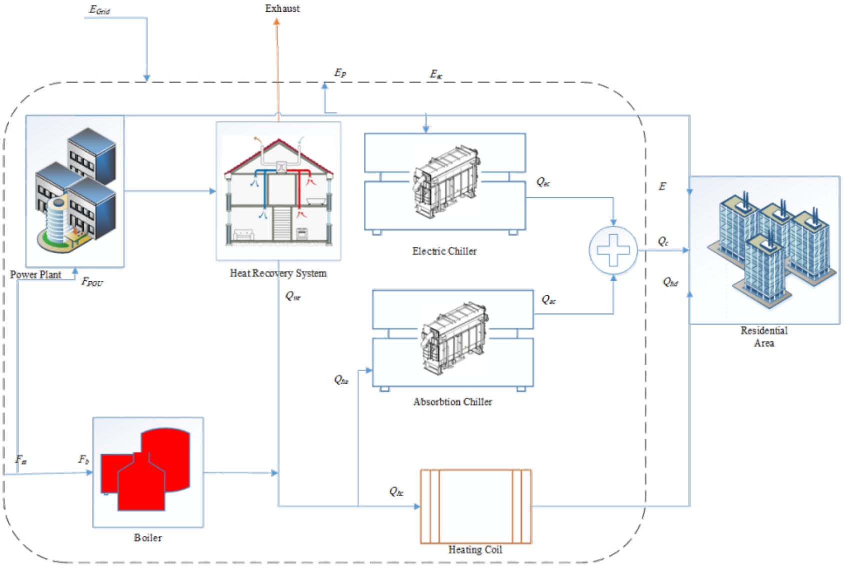


Fig. 1. The general structure of the investigated combined heating, cooling, and power system

compression chillers.

The PGU energy use fuel (F_{pgu}) can be obtained by follows [18]:

$$F_{pgu} = E_{pgu} \times \eta_e^{-1} \tag{2}$$

where, η_e is the generation performance of the GPU.

To achieve the required electrical energy required for the condensing chiller, we have:

$$E_{ec} = \frac{Q_{ec}}{COP_{ec}} \tag{3}$$

where, COP_{ec} describes the performance coefficient of the electric chiller, and Q_{ec} is the generated cooling based on the electric chiller.

The required heat and cold have been used respectively for supplying the heating coil and the cooling system, can be as below:

$$Q_{sb} + Q_{wr} = Q_{ha} + Q_{hc} \tag{4}$$

where, Q_{sb} describes the boiler complementary heat, and Q_{ha} and Q_{hc} describe the provided heat for chiller absorption and the heat provided to the heating coil, respectively, i.e.

$$Q_{ha} = Q_{ac} \times COP_{ac}^{-1} \tag{5}$$

$$Q_{hc} = Q_{hd} \times \eta_{hc}^{-1} \tag{6}$$

here, COP_{ac} is the performance coefficient of the AC, Q_{ac} shows the cool generated based on absorption chiller, Q_{hd} is the heat demand for domestic hot water and space heating, and η_{hc} describes the domestic transmission operation of the HC.

And the prime mover's recovered waste heat has been achieved by the following formula:

$$Q_{wr} = \eta_{hr} \times (1 - \eta_e) \times F_{pgu} \tag{7}$$

Where, η_{hr} describes the operation of the HRS.

And the building balance for the cool load is obtained by the following equation [19]:

$$Q_{cd} = Q_{ac} + Q_{ec} \tag{8}$$

where, Q_{cd} describes space cooling demand.

Hence, the rate of AC to CL is obtained as follows [19]:

$$R_{cl} = \frac{Q_{ac}}{Q_{cd}} \tag{9}$$

Such that if $R_{cl} = 0$, the AC is adopted for the CS, and if $R_{cl} = 1$, the EC is employed for providing the building's cooling, and finally if R_{cl} has a value between these two values, a combination of these two chillers were used for the CS.

The complementary fuel power value used to the boiler has been defined as below:

$$F_b = \frac{Q_{ha} + Q_{hc} - Q_{wr}}{\eta_b} \tag{10}$$

where, η_b determines the back-up efficiency of the boiler.

Therefore, on-site fuel energy use can be modeled as below:

$$F_{on-site} = F_{pgu} + F_b \tag{11}$$

And hence,

$$F_T = \begin{cases} \dfrac{E_G \times S}{\eta_G \times \eta_{ge}^p} + F_{on-site} & E_G \geq 0 \\ F_{on-site} & E_G < 0 \end{cases} \tag{12}$$

where, η_{ge}^p and η_G represent the generation operation of the plant, and the transmission and distribution of the electric network, respectively.

Accordingly, the test function can be selected by assuming the highest inputted fuel power for the PGU (F_{max}), such that:

$$\begin{aligned} & F_{max} \times (1 - \eta_e) \times \eta_{hr} \leq Q_{hc} \\ & + (1 - R) \times Q_{cd} \times COP_{ch}^{-1} \end{aligned} \tag{13}$$

Such that:

$$\begin{cases} F_{max} + \dfrac{E_G \times S}{\eta_G \times \eta_{ge}^p} + \dfrac{\frac{(1-R) \times Q_{cd}}{COP_{ch}} + Q_{hc} \geq F_{max} \times (1-\eta_e) \times \eta_{hr}}{\eta_b} \\ \dfrac{E_G \times S}{\eta_G \times \eta_{ge}^p} + \dfrac{\frac{(1-R) \times Q_{cd}}{COP_{ch}} + Q_{hc}}{(1-\eta_e) \times \eta_{hr}} \end{cases} \tag{14}$$

$if\ test\ function = true$

$if\ test\ function = false$

where,

$$\begin{cases} E_G = E + E_p + \dfrac{R \times Q_{cd}}{COP_{ec}} - F_{max} \times \eta_e \\ E_G = E + E_p + \dfrac{R \times Q_{cd}}{COP_{ec}} - \dfrac{\dfrac{(1-R) \times Q_{cd}}{COP_{ch}} + Q_{hc}}{(1-\eta_e) \times \eta_{hr}} \times \eta_e \end{cases} \tag{15}$$

$$if\ test\ function = true$$

$$if\ test\ function = false$$

In this research, two various scenarios with various structures have been studied. The scenario one is to provide a simple operation strategy for the constant ratio of EC to CL utilized in the performance phase stage (R_{cl}). Indeed, if the R_{cl} is time-variant, we have to use a more complicated control system for the operation mode. The second scenario is to consider the capacity of the selected power generating unit that is an important subject due to the CCHP plant sizing to obtain the capital cost and the performance mode. Determining the volume of the power generating unit, make it easy to specify also the capacity of some other parts like boiler and heat recovery. Here, to regulate the production effectiveness of system at a pre-determined value, an improved bio-inspired optimization algorithm has been employed. To do the optimization, some assumptions have been considered:

1) The CCHP system is considered 100% reliable.
2) Very minor technical constraints in the CCHP system have been neglected.
3) The extra generated electricity by the CCHP will not be sold back to the grid.

To ensure the proper achievements of the CCHP plant, the results have been put in comparison with an existing reference (*Rf*) system. In the *Rf*, the building electric power is supplied by the local electrical power network, the electric chiller has been utilized by the CS, and the heating system for the building has been distributed to the consumer by HCs that have been supplied by gas boiler.

Generally, the primary energy consumption with considering the reference system is obtained by the following formula [19]:

$$F^{RF} = \frac{\left(E + E_p^{RF}\right)}{\eta_e^{RF} \times \eta_{grid}} + \frac{Q_{hd}}{\eta_b^{RF} \times \eta_h^{RF}} + \frac{Q_c}{COP_e \times \eta_e^{RF} \times \eta_{grid}} \tag{16}$$

where, E_p^{RF} represents the excessive electric power employed by the distribution elements such as fans and pumps in a *Rf*, η_b^{RF} and η_h^{RF} describe the effectiveness of the boiler and the HC, respectively. Here, some evaluation criteria have been used to comparison of the economic and environmental assessment of the presented system with reference system.

1) The yearly overall cost-saving (YOCS): this criterion includes the yearly energy and the yearly capital cost (CC) as follows [19]:

$$YOC = R_c \times \sum_{i=1}^{k} p_i \times c_i + \sum_{j=1}^{365} \sum_{i=1}^{24} \left(E_{g,ji} \times c_{ji,e} + f_{ji} \times c_{ji,g} \right) \tag{17}$$

here, p represents the installed elements power, c determines the first CC of the elements, k is the elements' number, $E_{g,ji}$ and f_{ji} defines respectively the hourly demands of the NG purchased from the electricity and network, and $c_{ji,g}$ and $c_{ji,e}$ describe respectively the hourly energy charges of NG and electric power,. R_c describes the capital recovery factor and can be achieved as follows:

$$R_c = \frac{r_i \times (r_i + 1)^n}{(r_i + 1)^n - 1} = 1 - \frac{F}{F^{RF}} \tag{18}$$

Where, n describes the components service life and r_i represents the interest rate.

The sum of different types of components has been assumed equal to the values of r_i and *n*. Accordingly, the criterion YOCS is obtained by the following equation:

$$YOCS = \frac{YOC^{RF} - YOC}{YOC^{RF}} = 1 - \frac{YOC}{YOC^{RF}} \tag{19}$$

where, YOC^{RF} represents the yearly overall cost of the reference source.

2) The primary energy saving (PES): This criterion represents the level of energy-saving in the system for the energy use of the RF system. The PES is achieved as follows :

$$PES = \frac{F^{RF} - F}{F^{RF}} = 1 - \frac{F}{F^{RF}} \tag{20}$$

The carbon dioxide emission (CDE): This criterion represents the level of CO_2 emission in this system. The mathematical formulation for this criteria is as follows:

$$CDE = \omega_{co_2,e} E_G + \omega_{co_2,g} F \tag{21}$$

where, $\omega_{co_2,e}$ and $\omega_{co_2,f}$ respectively represent the emission conversion factor for electric power and NG from the grid.

3) The CO_2 emission ratio (CDER): Based on the explanations about CDE, the third criterion, CDER describes the carbon dioxide emission ratio of this system compared with reference source that can be formulated as below:

$$CDER=\frac{CDE^{RF}-CDE}{CDE^{RF}}=1-\frac{CDE}{CDE^{RF}} \tag{22}$$

where, CDE^{RF} represents the CDE amount from the reference source.

3. BALANCED MOTH SEARCH OPTIMIZER

A significant and crucial process in engineering is optimization. Optimization techniques can assist the designers to produce better designs for saving time and cost [20-23]. Many optimization problems in engineering are naturally more complicated to solve with conventional optimization techniques such as deterministic optimization algorithms. Meta-heuristic optimization algorithms are some kinds of new optimization techniques to find the optimal point of functions [24-27]. Today, several optimization problems, often including NP-Hard problems, are almost soluble with existing computers. Meta-heuristic algorithms are one of the solutions to such problems [17, 28]. These algorithms do not guarantee that the obtained result is optimal and only very time consuming one can obtain a fairly accurate answer and in fact the accuracy of the answer varies depending on the time taken [29, 30].

The variation of the Meta-heuristic algorithms is constantly enhancing and several kinds of these algorithms are continuously introducing, such as Gaussian Distribution (VRGD) [31], World Cup Optimization (WCO) algorithm [32], Emperor Penguin Optimizer (EPO) [33], Owl Search Algorithm (OSA) [34], Improved Cat Swarm Optimizer (ICSO) [35], Butterfly Optimizer (BOA) [36], and Moth Search Optimizer [37].

A new meta-heuristic Optimizer that present better achievements in optimizing problems is Moth Search Algorithm (MSA) [37]. The MSA is an inspiration of two main behaviors of the Moth, which are Lévy flights and Phototaxis. Phototaxis behavior forces the moths to fly into the light resource. Still, this is an unknown phenomenon for scientists. Several models have been performed for this phenomenon. One of the reasonable models is to consider the angle of the moth and light source, however at most times these phenomena have been neglected due to the long distance. Furthermore, by navigating the closest light source with moth, the angle will be varied. In this condition, the moth moves toward the light source as the best orientation which makes a spiral flight path to reach near to the light resource [38]. Lévy flight (LF) is the other behavior for moth. This determines a class of random walks by Lévy distribution steps. The smallest distance between the moths and the best one of them is performed by modeling their flight based on Lévy flights, i.e. the position updating is based on Lévy flights process. This is modeled by the following equation:

$$x_i^{t+1}=x_i^t+\alpha F(s) \tag{23}$$

here, t is the present iteration, i is the moths' number, x_i^t and x_i^{t+1} are respectively the original and the updated location of iteration t, , $F(s)$ represents LFs step down, and α describes the scale factor which can be obtained as given below:

$$\alpha=\omega_m/t^2 \tag{24}$$

where, ω_m describes the max walk step.

The model of Lévy flight is given below:

$$F(s)=\frac{(\gamma-1)\tilde{A}(\gamma-1)\sin\left(\frac{\pi}{2}(\gamma-1)\right)}{\pi\tau^{\alpha}} \tag{25}$$

where, τ>0, $\gamma=1.5$, and $\tilde{A}(i)$ determines the gamma function.

The fly behavior of the moths with long distance from the light source into it that has been formulated as follows:

$$x_i^{t+1}=\delta\left(x_i^t+\rho\left(x_{best}^t-x_i^t\right)\right) \tag{26}$$

where, δ describes a scale factor, ρ represents the acceleration factor, and x_{best}^t is the best moth of the current iteration (t).

In some cases, the moths fly towards a position far from the light source which is modeled as follows:

$$x_i^{t+1}=\delta\left(x_i^t+\frac{1}{\rho}\left(x_{best}^t-x_i^t\right)\right) \tag{27}$$

Fig. (2) shows the rectilinear flight of the moths during the above two updating conditions where, x_i is the start point (original position), x_{best}

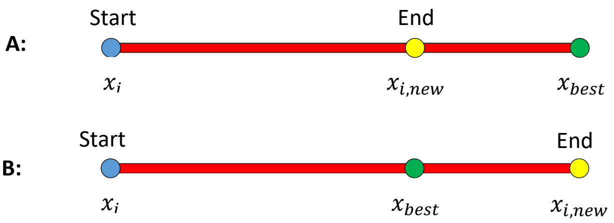


Fig. 2. The rectilinear flight of the moth with x_{best} at right-hand side (A) and the middle hand side (B)

shows the end point (best position), and $x_{i,new}$ is the light source (updated position) for the i^{th}moth, respectively.

In MSA, the scale factor, δ is a random value for improving the population diversity and to adjust the algorithm convergence rate. During the random selection of the δ, it sometimes makes premature convergence. There are several procedures for solving this problem. The most widely used method is the Lévy flight (LF) mechanism [39]. The LF mechanism as a random walk procedure is utilized for proper controlling of the local search. The LV mechanism is modeled as follows:

$$F(w) \approx \frac{1}{w^{1+\tau}} \tag{28}$$

$$w = \frac{A}{\sqrt[\upsilon]{|B|}} \tag{29}$$

$$\sigma^2 = \left\{ \frac{\tilde{A}(1+\upsilon)}{\upsilon \tilde{A}((1+\upsilon)/2)} \frac{\sin(\pi\upsilon/2)}{2^{(1+\upsilon)/2}} \right\}^{\frac{2}{\upsilon}} \tag{30}$$

where, $\upsilon \grave{o} [0,2]$ describes the LV index (here, $\upsilon = 3/2$ [40]), $A, B \sim N(0, \sigma^2)$, $\tilde{A}(.)$ is Gamma function, w is the step size.

Based on the LV mechanism, the formulation can be updated as follows:

$$x_i^{t+1} = \ddot{a}\left(x_i^t + \rho\left(x_{best}^t - x_i^t\right) \times \mathrm{F}(\ddot{a})\right) \tag{31}$$

$$x_i^{t+1} = \ddot{a}\left(x_i^t + \frac{1}{\rho}\left(x_{best}^t - x_i^t\right) \times \mathrm{F}(\ddot{a})\right) \tag{32}$$

Another improvement of this paper is to utilize the Chaos theory to develop the $\ddot{a}$ value. A general formulation for the chaotic procedure can be as below:

$$CM_{i+1}^j = f\left(CM_i^j\right), \quad j = 1, 2, \ldots, m \tag{33}$$

here, m is the dimension of map and $f\left(CM_i^j\right)$ is the chaotic model's generator function.

The utilization of the chaos mechanism can be utilized as a secondary mechanism to develop the system speed and convergence [41, 42]. Therefore, in this study, the sinusoidal chaotic map has been used to provide the MSA operation in respect of convergence as follows:

$$\begin{gathered} p_0 \in [0,1], a \in (0,4] \\ \ddot{a}_{k+1} = a\ddot{a}_k^2 \sin\left(\pi \ddot{a}_k\right), \end{gathered} \tag{34}$$

here, k represents the iteration number.

4. THE SYSTEM OPTIMIZATION PROCEDURE BASED ON BMSA

The major target here is to suggest an optimized structure for this system to achieve better results compared with the RF system. To do so, a maximization problem for economical and environmental terms of the system has been considered. Due to the minimization nature of the MSA, we used the inverse model of the function such that by minimizing it, the economical and environmental terms have been maximized. The inverse function is given below:

$$\min cf = \frac{1}{\omega_1 \times ATCS + \omega_2 \times PES + \omega_3 \times CDER} \tag{35}$$

where, ω_1, ω_2, and ω_3 represents the weights of YOCS, PES, and CDER.

The BMSA has been used to lessen the defined objective function (F_O). Fig. (2) indicates the optimum diagram of this system based on BMSA.

The total number of parameters for different components in the employed CCHP system has been illustrated in Table 1.

Table 2 illustrates the cost of initializing the units' components in the suggested system.

By considering the assumptions above, the optimized configuration of the CCHP system based on BMSA was simulated. Therefore, the fitness function has been computed. At the process

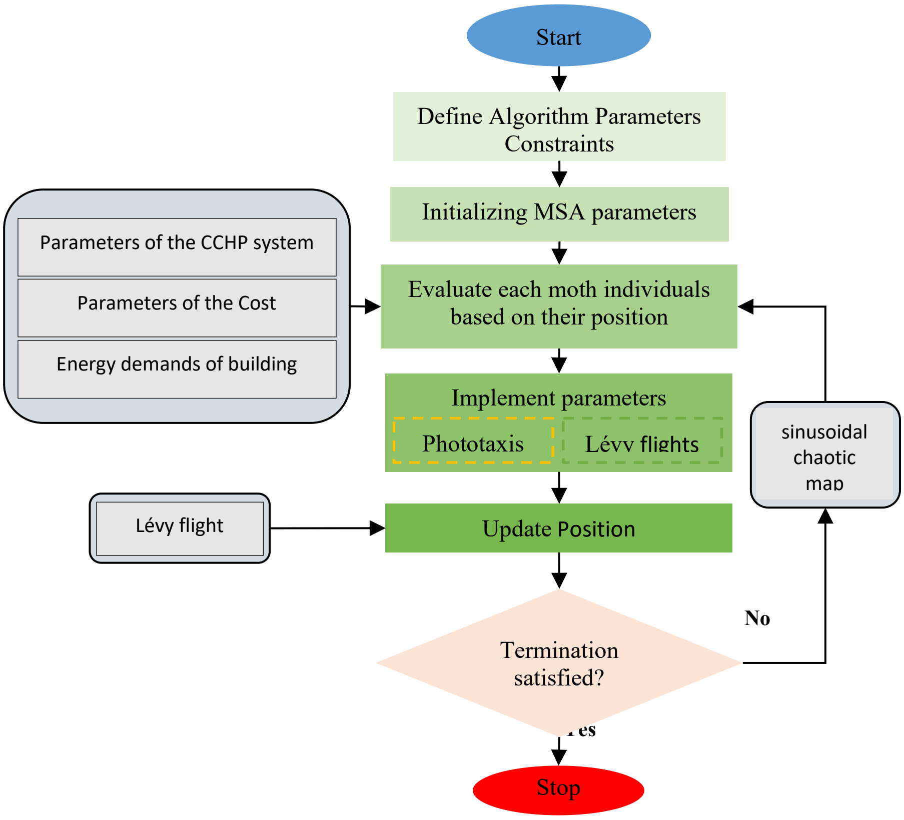


Fig. 3. The workflow of the suggested BMSA

Table 1. The total number of parameters employed in the system configuration and separation generation system

Parameter	Value
The performance of the Boiler (η_b)	0.75
The operation of the waste HRS (η_{hr})	0.75
The efficiency of the Heating coil (η_{hc})	0.75
The operation of the PGU of CCHP system (η_e)	0.50
The effectiveness of the PGU of separation generation system (η_{ge}^{p})	0.45
Transmission performance of the Grid (η_G)	0.96
CO₂ emission ($\mu_{Co_2,f}$)	215
Conversion factor (g/k Wh)($\mu_{Co_2,e}$)	968
COP of Electric chiller (COP_{ec})	2.8
COP of Absorption chiller (COP_{ch})	0.8

of optimization, the performance procedure has been studied and the annual energy charge has been obtained by the general relationship among the system's general energy balance, system performance characteristics, and the load demands. After considering the above assumptions and applying the limitations to an optimal section of system parameters, the search operation starts

Table 2. The initial cost of the units' elements in the suggested system

Facility	Price ($/kW)
Prime mover	720.5
Electric chiller	145.3
Natural gas	0.031
Boiler	37.2
Absorption chiller	175.5
Heating coil	32.1
Electricity (23:00–6:00)	0.065
Electricity (7:00–22:00)	0.22

and continues for evaluating a satisfying optimal criterion.

5. SIMULATION RESULTS

The simulation for achieving the optimal volume of the proposed CCHP plant and the EC to CL ratio is applied to a residential building in Yazd.

The floor area of the building is 6300 m^2 and the average height of ceiling equals 3.5 m. we consider 25°C as the desired temperature of the building. Furthermore, the variations of the daily electric power demand were considered lower than the daily HL and CL. It is also assumed that the demand electricity is well fixed with higher heating and cooling load amounts. MatlabR2017b software has been utilized for hourly energy load approximating. Fig. (4) shows the building's daily loads in Yazd.

It is observed that the peak amount of the HL (Q_H) is at a lower level than the highest amount of the CL (Q_C); this is because of the hot weather of Yazd which can be proof to increase the energy demand (E) in the autumn and spring for the configured CHP system.

For achieving the best optimal configuration for the simulation, we need to design the optimization algorithm parameters in their best way to improve the system convergence. This is why we proposed a balanced version of the MSA based on LV and Sinusoidal chaotic mapping to decrease the

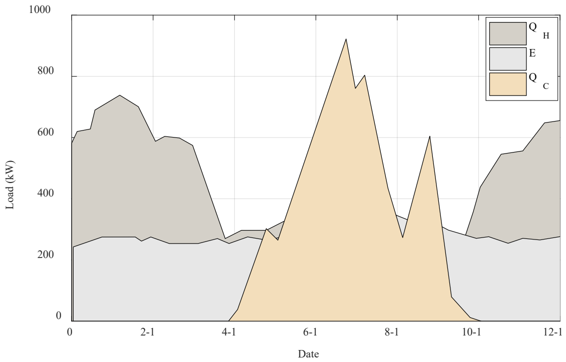


Fig. 4. The results of daily load

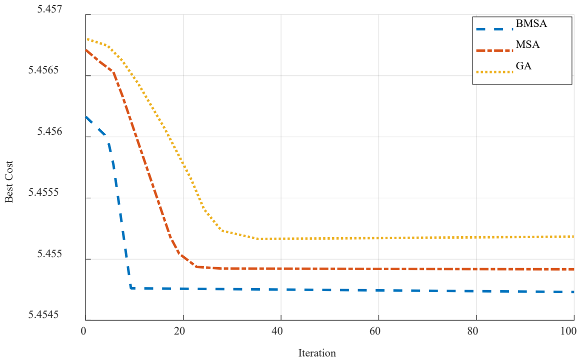


Fig. 5. The simulation achievements of the optimized system by different methods

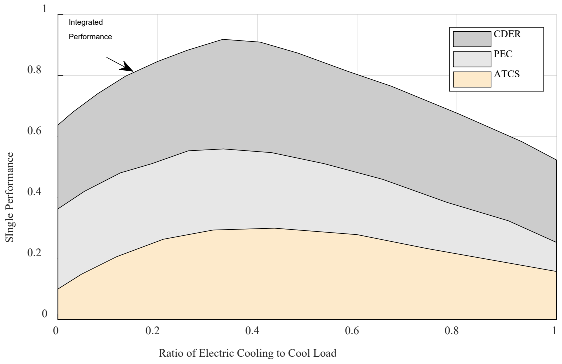


Fig. 6. The PES, YOCS, CDER of the efficiencies of the system for scenario 1

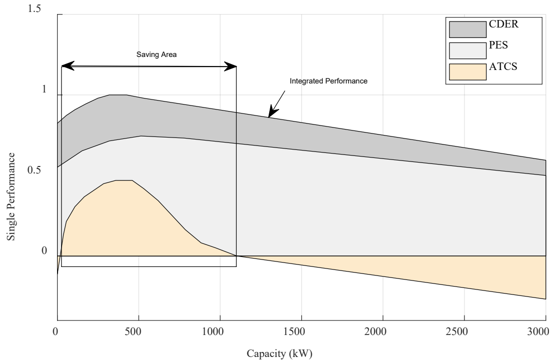
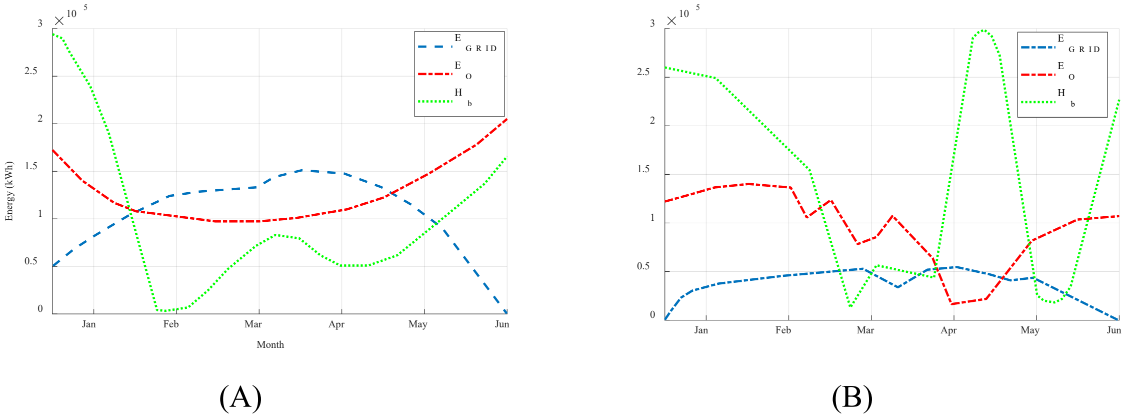


Fig. 7. The PES, CDER, and YOCS of the efficiencies of the system for scenario 2



(A)

(B)

Fig. 8. The monthly supplementary heat, received energy from the grid, and surplus power of CCHP systems for (A) Scenario1 and (B) Scenario 2

premature convergence of the optimizer.

By implementing the optimized procedure on the system, the optimum amounts of volume for a ratio of EC to CL and power generating unit have been obtained as $\left[R_{cl}, F_{max}\right]=\left[0.75,670\right]$.

Therefore, the power generating unit volume in this system is 670 kW with 75% of the CL that is achieved from the electric and absorption chillers from the boiler or recovery system. The simulation achievements of the optimum cost for the suggested

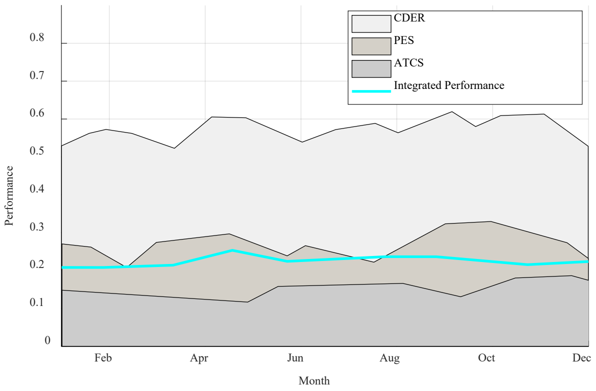


Fig. 9. The monthly efficiency analysis for the CCHP systems in Scenario1

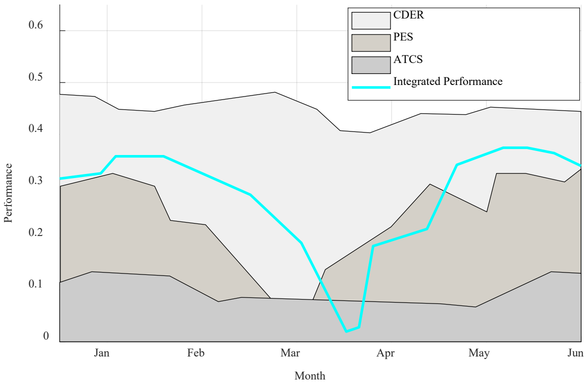


Fig. 10. The monthly efficiency analysis for the CCHP systems in Scenario2

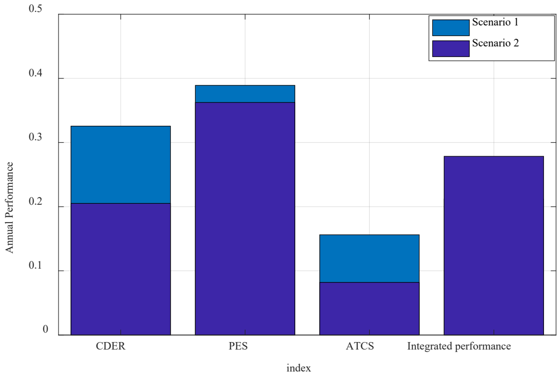


Fig. 11. The annual efficiency evaluation of the CDER, overall cost-saving, integrated performance, and first energy-saving of the two scenarios

BMSA-based structure were put in comparison with the standard MSA-based technique for representing its better efficiency and also with the GA-based algorithm as a very famous bio-inspired optimizer and are shown in Fig. (5).

The results from Fig. (5) showed that the best convergence is obtained by the suggested BMSA with only 10 iterations. The second method with good results is the standard MSA and the last algorithm with weaker values is GA which is received to its fixed value after 35 iterations that show the capability of the proposed MSA in finding the best solution with fast convergence.

Although different types of optimization algorithms can be also utilized for this objective, every single algorithm has some shortcomings. For example, GA as an efficient bio-inspired optimizer has slow convergence among various bio-inspired optimizers. There are some undefined variables in GA such as mutation and crossover ratio, fitness normalization/selection variables, and elitism percentage which should be tuned by lots of trials and errors. The main vantage of the presented procedure is that using it needs less number of parameters. Furthermore, the algorithm uses the LF and the sinusoidal procedures to enhance the convergence rate.

For further evaluation, two various scenarios were assumed to the system as in both scenarios, one parameter varies is a determined range and the other is held constant. The first scenario assumes that the system capacity is a constant amount of 670 kW while the EC to CL ratio has been assumed variant. Fig. 6 depicts the YOCS, CDER PES,of the efficiencies of the CCHP plant for scenario 1 by considering variant EC to CL ratio.

As can be observed from Fig. (6), the integrated performance gives a positive amount at the top of the graph. By enhancing the combined operation, the velocity has been reduced gradually and reaches to its peak value, 29.91% which accordingly enhances the amount of the R_{cl} at the volume amount lower than 0.75. in contrast, if the R_{cl} during the capacity amount is higher than 0.75, the combined effectiveness begins to reduce. It is observed that enhancing the value of the R_{cl} gives an embowed shape to the CDER, YOCS, and PES curves. Hence, the CDER parameter for the CCHP plant compared with RF gives the highest effective and the YOCS to the combined effectiveness has the lowest impact. Therefore, from the results, it can be said that applying the suggested optimization structure for this system decreases the CDE toward the RF and gives better performance for saving the primary energy.

Scenario 2 is assumed as a condition with fixed value of $R_{cl} = 0.75$ while different values for the capacity. Fig. (7) shows the CDER. PES, YOCS, of the CCHP plant effectiveness for scenario 1 by considering variant EC to CL ratio.

The weighted combined effectiveness has been placed at the head of the diagram. The figure depicts that after achieving the maximum value by the combined operation with a upper amount of velocity, the velocity is decreased step by step to obtain the peak value at 400 kW and then it was reduced gradually by enhancing the volume of the power generating unit. It can be also seen that during the capacity value less than about 1103kW, both integrated and single performances are negative. This problem occurs because of the high amount of the parasitic electricity use of the designed CCHP plant in comparison with the reference system. It is seen that the value of the PES and CDER were enhanced and after meeting the maximum value, they were reduced due to enhancing the volume of the power generating unit. It is also shown that YOCS starts with an increase in its value, and after reaching the maximum value, it is reduced due to increasing of the system volume with hgiher than PES's and CDER's. Therefore, from Fig. (6), it can result that by capacity value more than 2500 kW, the yearly cost will not be stored by the system because of the additional CC. This case shows, but, CCHP plant stores the major power compared to the reference system, it cannot save enough cost for the users.

The results of both scenarios are shown that a suitable choice of the capacity for system is a significant section of increasing the system performance. Fig. (8-a) and Fig. (8-b) show the monthly obtained energy from the power grid, additional heat, and higher power of systems.

The simulation results showed that in scenario 2, the grid power (E_{grid}) has less value toward the optimum CCHP plant, while surplus heat from the boiler (H_b) has higher value toward the optimum CCHP plant in hot season. In addition, the additional electricity cannot be returned to the network which makes it exhausted. A good idea for utilizing the surplus power is to use it in the EC for the building cooling system that saves the primary energy. Fig. (9) and Fig. (10) show the analysis of system performance for both scenarios.

From Fig. (9) and Fig. (10) it is clear that the value of the PES and CDER except YOCS are near in both scenarios. In the hot season, due to the additional energy, to provide the cooling process, the primary electricity use of the optimal CCHP plant has been reduced. Thus, the annual cost and the CDE of the CCHP plant are reduced. Fig. (11) shows the annual performance of the primary energy saving, overall cost saving, combined operation of the 2 scenarios, and CDE reduction. It is clear that CDE has the most reduction in the CCHP system respectively along with yearly overall cost-saving and first energy-saving. The analysis shows that the yearly combined operation of the CCHP in scenario 1 equals 1.6% greater than scenario 2.

6. CONCLUSIONS

This study presented a new optimum structure of a CCHP for a building in Yazd. The method was implemented using a new meta-heuristic algorithm, called Balanced Moth Search optimizer. The technique has been an improved version of the Moth Search optimizer by LF and sinusoidal procedures to improve the convergence of the optimizer. The main purpose of the configuration was to develop the combined operation of the CCHP system. Simulation results indicated that the first energy-saving and the CO_2 emission decrease of the system save the restricted amount compared to reference system, while the yearly overall cost-saving decreased the ratio and volume. The CCHP configuration includes a combined cooling system to reduce the exhaust of additional electricity. Two various scenarios have also been assumed for more consideration. In scenario one a constant value (670 kW) was assumed to the capacity while the electric cooling (EC) to cool load (CL) ratio was assumed variant in a determined range and in the second scenario, an opponent condition with 0.75 constant EC to CL ratio were assumed. The final achievements of the presented technique were put in comparison with the standard Balanced Moth Search Algorithm and Genetic optimizer to indicate the method effectiveness.

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