Original Research Article

Artificial gorilla troop optimization for optimization operation of a complicated hydrothermal system

Abstract —This study implements a novel meta-heuristic method called artificial gorilla troop optimization (AGTO) to handle the short-term fixed-head hydrothermal scheduling problem (ST-HTS). In the study, the constraints of reservoir and the fuel function of total generating electricity cost for thermal power plants are taken into account. AGTO is a newly published method and the main inspiration is based on the living practice of gorilla in nature. While tested by the hydrothermal power system, AGTO have demonstrated its striking performance to other state-of-the-art meta-heuristic algorithms and other popular algorithms. In this study, AGTO is implemented alongside with improved particle swarm optimization (IPSO) and tunicate swarm algorithm (TSA) for assessing the raw performance. The results obtained by these methods see that AGTO is a highly effective computing method for an engineering problem such ST-HTS besides IPSO and TSA in all compared criteria.

Keywords-- Artificial gorilla troop optimization; fixed head; fuel cost; hydrothermal scheduling; reservoir volume constraint.

1. Introduction

Nowadays, thermal power plant and hydroelectric power plant are the main generating sources that cover a major part of power demand. The main the materials to run thermal generating sources such as oil, coal, nature gas and so on are dramatically increased over cost due to the over exploitation [1]. In addition, the potential reserves of these kind of fuels are limited and soon, they will be empty under current consumption rate. On contrary, the main source to run at most hydroelectric power plant is water – one of most abundant material in the earth. The target in this circumstance is to reduce operating cost caused by thermal generating sources and alleviate the damage to the environment [2]. For achieving that target, the optimization of discharged water from the reservoir in the combined system with thermal and hydroelectric power plant is considered as the most favorable options. The more water is discharged, the more pressure on running thermal power plant is reduced. However, the amount of water circulate in the reservoir of hydroelectric power plant must satisfied all relevant constraints that will be

clarified in the next section [3].

Deterministic and meta-heuristic methods are commonly applied to solve the considered problem. The first method is mainly the combination of Gradient search [3] and the Newton-Raphson distribution while second method is meta-heuristic algorithm such as Simulated annealing algorithm (SA) [1], Evolutionary programing algorithms (EPA) [4], Genetic algorithm (GA) [5], modified EPA (MEPA) [6-8], improved EPA (IEPA) [7], PSO [9], the enhanced Bacterial Foraging algorithm (EBFA) [10], modified PSO (MPSO) [11-13], Clonal picking algorithm (CPA) [14], improved modified EPA (IMEPA) [15], and improved PSO (IPSO) [16]. In the midst of these mentioned methods, GS is the method with lowest efficiency because of its own characteristic that is only applied for the conventional problem in which the generation model is described by a piecewise linear [4]. The efficiency of Newton-Raphson is better than GS. But the common drawback of these methods is highly relied on applying Jacobi matrices and the size of considered system. On the other hand, meta-heuristic algorithms are broadly applied to deal with short term hydrothermal scheduling problem with incorporating water storage level constraint of reservoir. In fact, SA is not utilized that much by researcher because its time-consuming characteristic. PSO and EP are more efficient and reliable in term of optimal solution and convergence degree while compared to SA and GA. The EPA in [4, 6] implemented Gauss random variable to produce the offspring and extending operator. But in [7,8,15] enhanced versions of EPA are proposed using Gauss or Cauchy expression for creating the number of offspring. In the [12-13] the modified versions of PSO are shown alongside with the use of the weigh factor and constriction operator. Besides, a new modified on both velocity and position update are also applied in these studies. These modifications have shortened the computing time and improved the quality of optimal solutions. But the results reported from the studies have violated the lower limitation of discharged water constraint. In the [16], another modified version of PSO called FIPSO is proposed accompany with a new velocity update mechanism. The results reached by the method is quite impressive while compared with other previous studies but again violation of a lower limitation is detected. Therefore, this method is not really a powerful and reliable computing tool for the considered problem. In [10], the author has suggested the IBFA to cope with the problem. But the reported solutions pointed out that the amount of water is used larger than the initial assumption. In general, modified algorithms have reached better optimal solutions than original ones [17] but they needed more settings of control parameter and more

computation steps due to the applied modifications [18].

In this paper, Artificial gorilla troops optimizer [19] will be applied to solve the problem of hydrothermal scheduling problem. In addition, other metaheuristic algorithms such as improved particle swarm optimization (IPSO) [20] and tunicate swarm algorithm (TSA) [21] are also implemented for comparison.

2. Problem Formulation

Supposed that, a hydrothermal power system includes T thermal power plants H hydroelectric power plant. The whole schedule is separated into K subintervals and each subinterval last l hour. The main goal is to shorten the total generating electricity cost TGEC of thermal power plant as much as possible and satisfy all relevant constraints

The main objective function featured by the considered problem is formulated as below [20]:

$$\text{Minimize } TGEC = \sum_{k=1}^{K} \sum_{t=1}^{T} l \left| \begin{array}{l} a_{1t} + b_{1t} PG_{T,l} + c_{1t} PG_{T,l}^2 \\ + \left| d_{1t} \times \sin\left(e_{1t} \times \left(PG_{T,l}^{min} - PG_{T,l}\right)\right)\right| \end{array} \right| \tag{1}$$

where a_{1t}, b_{1t}, c_{1t}, d_{1t}, e_{1t} are respectively the fuel consumption factors given by thermal power plant t.

Besides, there are important constraints that must be all satisfied in the whole computing process as follow:

- Power balance constraint: this means, the amount of power generated by the supply side must be equal to the sum of power consumed by load and power loss caused by transmission lines [21]:

$$\sum_{t=1}^{T} PG_{t,k} + \sum_{h=1}^{H} PH_{h,k} - PL_k - PD_k = 0 \tag{2}$$

where the value of power losses caused by transmission lines are determined by applying Kron's thesis as below [17]:

$$PL_k = \sum_{t=1}^{T+H} \sum_{h=1}^{T+H} PG_{t,k} B_{th} PH_{h,k} + \sum_{t=1}^{T+H} B_{0t} PG_{t,k} + B_{00} \tag{3}$$

where PD_k and PL_k are respectively the amount of power required by demand side and value of power loss in transmission process in subinterval k

- The constraint of discharged water level: The volume of water for discharging of a particular hydro power plant j at m^{th} subinterval is calculated as below

$$DW_{h,k} = l \times pd_{h,k} \tag{4}$$

where $pd_{h,k}$ is the proportion of discharged water from the reservoir and its determination is as follows

$$pd_{h,k} = a_{2h} + b_{2h} PH_{h,k} + c_{2h} PH_{h,k}^2 \tag{5}$$

- The constraints of remained water level in reservoir: This constraint is described by the equation (6) below:

$$VR_{h,k-1} - VR_{h,k} + PW_{h,k} - DW_{h,k} - SW_{h,k} = 0 \tag{6}$$

where $VR_{h,k}$, $PW_{h,k}$ and $SW_{h,k}$ are respectively the capacity of reservoir, the volume of pumped-in water and the amount of water dropped out while reservoir is full capacity of hydroelectric power plant h in subinterval k

- The constraint about the water storage in reservoir: This constraint mainly focuses on the water level at the beginning and the ending of the whole schedule. The description of the constraint is shown as follows:

$$VR_{h,0} = V_{h,beg}; \quad VR_{h,K} = V_{h,end} \tag{7}$$

- The constraint of water storage in reservoir: This is the operation constraints of hydroelectric power plant. These constraints are featured by the limitations of water storage in reservoir as described in equation (8) below:

$$VR_{h,min} \leq VR_{h,k} \leq VR_{h,max}; h=1,2,...,H; k=1,2,...,K \tag{8}$$

where $V_{j,max}$ and $V_{j,min}$ are respectively the lowest and the highest water storage in reservoir for hydroelectric power plant h

- The constraint about discharged water proportion: Similar to the constraint in equation (8), the discharged water proportion for a particular hydroelectric power plant must be located inside the allowed range of the lowest and the highest value

$$pd_{h,min} \leq pd_{h,k} \leq q_{h,max}; \quad h=1,2,...,H; k=1,2,...,K \tag{9}$$

where $pd_{h,max}$ and $pd_{h,max}$ are respectively the lowest and the highest discharged water proportion given by hydroelectric plant h

- The constraint of generator operation: the amount of power produced by thermal power plant and hydroelectric plant must be inside the safety limitations [18]:

$$PG_{t,min} \leq PG_{t,k} \leq PG_{t,max}; \ t=1,2,...,T; k=1,2,...,K \quad (10)$$

$$PH_{h,min} \leq PH_{h,k} \leq PH_{h,max}; h=1,2,...,H; k=1,2,...,K \quad (11)$$

where $PG_{t,max}$, $PG_{t,min}$ and $PH_{h,max}$, $PH_{h,min}$ are respectively the lowest and highest power produced by thermal power plant t and hydro power plant h

3. The Calculation Of Slack Thermal Unit And Slack Hydro Units

We assumed that the amount of power produced by all thermal power plants excluding the one connected with the slack bus and the amount of water remained in reservoirs at the end of subintervals are clarified

The amount of discharged water in l hours is determined by equation (12) below:

$$VR_{h,k-1} - VR_{h,k} + PW_{h,k} - DW_{h,k} - SW_{h,k} = 0 \quad (12)$$

The amount of discharged water $DW_{h,k}$ is firstly determined by equation (4) after that, the amount of power produced by hydroelectric power plant $PH_{h,k}$ is achieved by equation (5)

The amount of power produced by the thermal power plant connected with slack bus is obtained by equation (13) as below [22-23]:

$$PG_{1,k} = PD_{D,k} + PL_k - \sum_{t=2}^{T} PG_{t,k} - \sum_{h=1}^{H} PH_{h,k} \quad (13)$$

4. Artificial Gorilla Troop Optimization (AGTO)

The Artificial gorilla troop optimization is a nature inspired metaheuristic algorithm AGTO. The algorithm is proposed at the end of 2021 by Abdollahzahed. By simulating the living practice of Gorilla troop, AGTO has proved its efficiency while compared with other state-of-the-art meta-heuristic algorithms such as TSA, GWO, SCA, MVO, WOA, GSA and MFO. AGTO was then applied successfully for two other optimization problems in [24-25]. The main difference between meta-heuristic algorithms is their update mechanism for new solutions. This

mechanism in AGTO is divided into two stages including *Local based forward* and *Global based forward*. Both stages will be described in the next subsection below:

Stage 1: Local based forward

$$G_{new} = \begin{cases} (ub - lb) \times \theta_1 + lb, & rdn < \tau \\ (\theta_2 - M) \times G_{rds} + N \times K, & rdn \geq 0.5 \\ G - N \times [N \times (G - G_{rds}) + \theta_3 \times (G - G_{rds})], & rdn < 0.5 \end{cases} \quad (14)$$

Where, G_{new} is the new location of the gorilla at the next iteration; G is the current location of the gorilla; ub and lb are respectively the upper and the lower boundaries of the search space; θ_1, θ_2 and θ_3 are random value produced in the interval of 0 and 1. τ is the given operator and its value varies between 0 and 1. G_{rds} is the random gorilla picked up from the entire population; M, N and K are respectively determined by equations (15), (17) and (18) below:

$$M = Q \times \left(1 - \frac{h}{H}\right), \quad (15)$$

With

$$Q = \cos(2 \times \theta_4) + 1 \quad (16)$$

$$N = M \times l \quad (17)$$

$$K = RD \times X \quad (18)$$

In the equations (15) to (18) above, Q is the amplifying operator; h is the current iteration and H is the maximum quantity of iterations; θ_4 is the random value in the interval of 0 and 1; N is the control operator, l is a random value produced between -1 and 1; RD is the random value generated in -M and M

Stage 2: Global based forward

$$G_{new} = \begin{cases} K \times I \times (G - SB) + G, & M \geq \varepsilon \\ SB - (SB \times IF - G \times IF) \times VT, & M < \varepsilon \end{cases} \quad (19)$$

In the equation 19 above, SB is the silverback gorilla location, ε is the reference parameter set before the entire computing process takes place. I is the synthesis term, IF is the impact term and VT is the violation term. These terms are determined by equation (20), (22) and (23) below:

$$I = \left(\left| \frac{1}{Pop} \sum_{i=1}^{Pop} G_i \right|^{\alpha} \right)^{\frac{1}{\alpha}} \tag{20}$$

with,

$$\alpha = 2^K \tag{21}$$

$$IF = 2 \times \theta_5 - 1 \tag{22}$$

$$VT = \rho \times RF \tag{23}$$

And RF is determined by

$$RF = \begin{cases} U_1, & rdn \geq 0.5 \\ U_2, & rdn < 0.5 \end{cases} \tag{24}$$

5. Numerical Results and Discussion

In this section, Artificial gorilla troops optimizer [19] will be applied to solve the hydrothermal scheduling problem. In addition, other metaheuristic algorithms such as improved particle swarm optimization (IPSO) [20] and tunicate swarm algorithm (TSA) [21] are also implemented for comparison. The real efficiency of the applied methods is assessed by implementing on one testing configurations of power system. The system consists of one thermal power plant and one hydroelectric power plant scheduled in six periods. Note that, the fuel consumption caused by thermal power plant in the system is approximately described by a second order function. The time length of whole schedule lasts three days and schedule is broken into 12 subintervals. The whole work is carried out in a personal computer with 1.8 Ghz CPU and 4GB of RAM. Matlab is the main environment for coding and running these algorithms.

The settings of parameters are plotted in Figure 1 for the implementation of three algorithms. For a fair comparison, the population size and maximum quantity of iteration for three methods are respectively set by 20 and 100. Besides, each method is operated with 30 independent runs
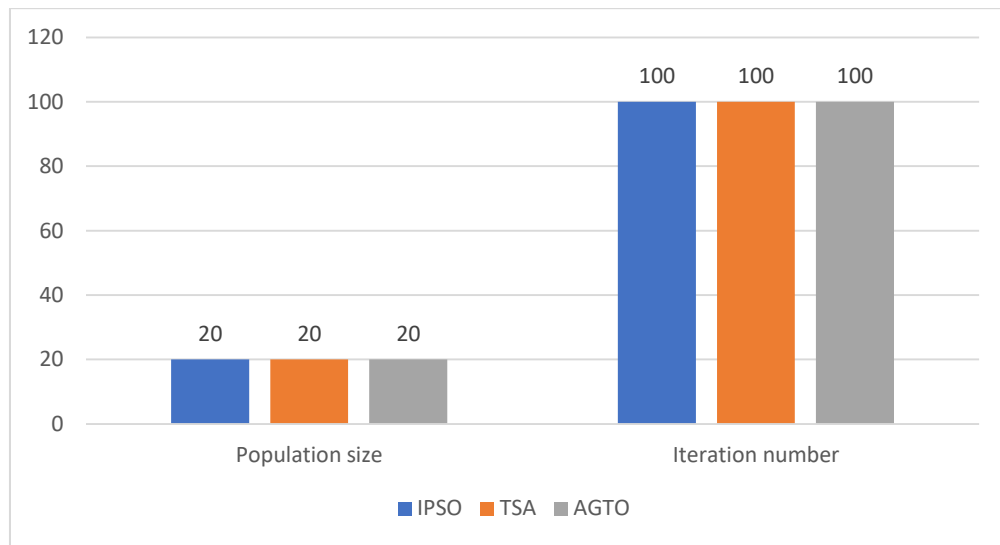
for the best solution.

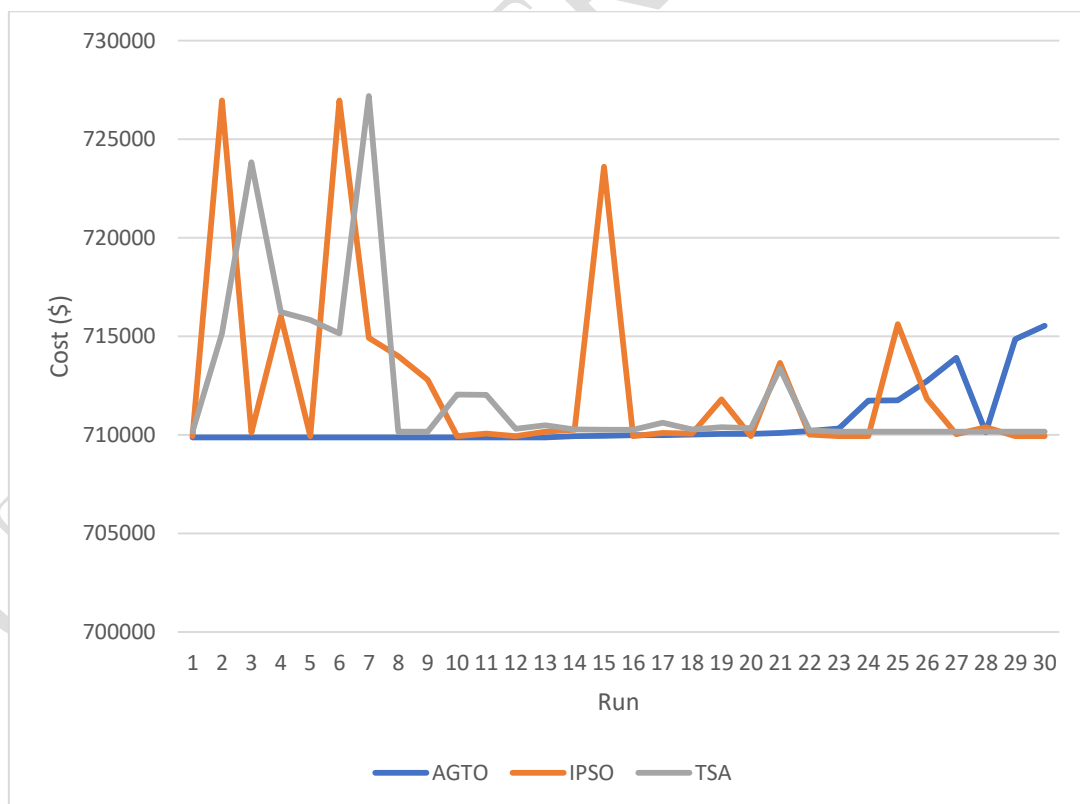Figure 1. Setting of population and iteration number

Figure 2. Cost from 30 runs obtained by three applied algorithms

In the Figure 2, the blue line displays cost values obtained by AGTO after 30 independent runs, whilst the orange and the gray line depict the same results reached by IPSO and TSA. In the first 23 runs, the cost values given by AGTO are completely stable than those of both IPSO and TSA. Clearly, the cost values reached by IPSO and TSA have showed a large fluctuation in this period. In last 7 runs, the cost values of AGTO are not stable anymore, they start to rise and fall in the small amplitude. On contrary, the similar values repored by both IPSO and AGTO have reduced its fluctuation for the last run
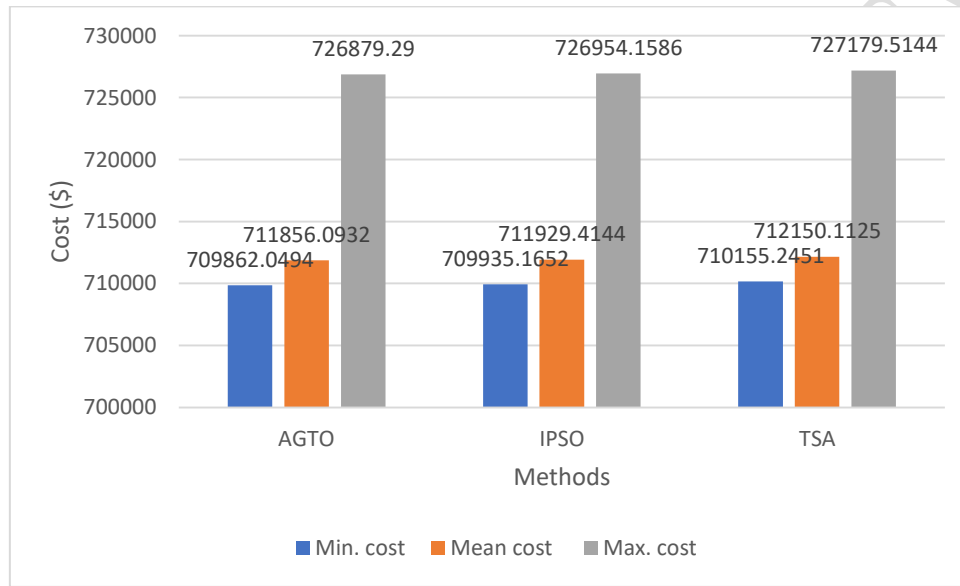

Figure 3. Cost summary of 30 runs obtained by three applied algorithms

Figure 3 reports the cost values obtained by three applied methods in term of minimum cost (Min.cost), mean cost (Mean cost) and maximum cost (Max.cost). Particularly, the Min.cost values are described by the blue bars while the Mean cost values and the Max.cost values are respectively represented by the orange bars and the grey bars. By observing the data, it easy to acknowledge that the results obtained by AGTO are completely superior to those of IPSO and TSA in all criterion. TSA is the method with the lowest efficiency. Specifically, the Min.cost given by AGTO is only $709862.0494 while the similar values reported by IPSO and TSA are up to $709935.1652 and $710155.2451, respectively. The comparison of Mean cost values also pointed out that AGTO have performed more effective than both IPSO and TSA. The statement can be clarified by looking at the particular value. While the Mean cost reached by AGTO is $711856.0932, the similar ones given by IPSO and TSA are $711929.4144 and $727179.5144,

respectively. Finally, the evaluation over the Max.cost values have proved the high performance of AGTO one more time. As proof, the Max.cost achieved by AGTO is again the lowest value among three applied methods.
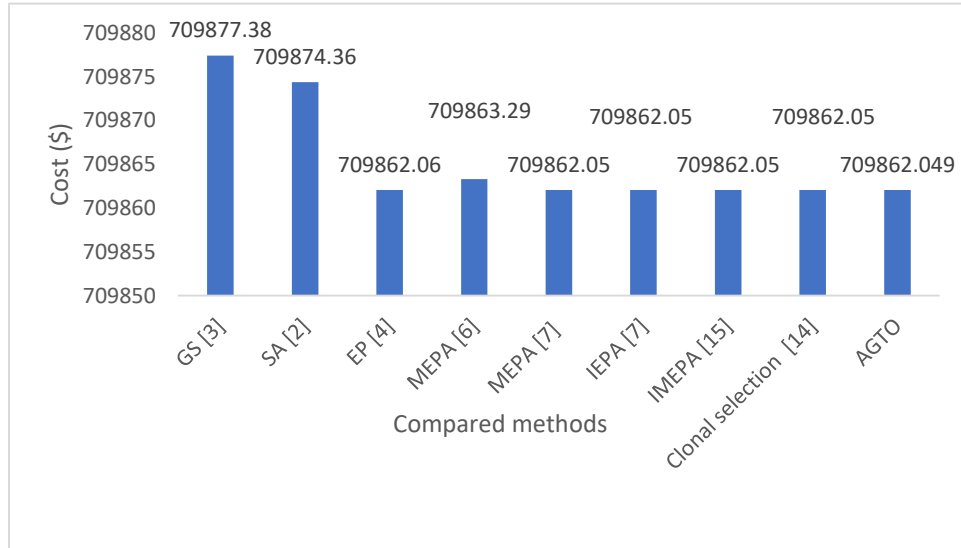

Figure 4. Cost comparison obtained by algorithms

While compared with previous methods as shown in Figure 4, the cost value obtained by AGTO is the best one among other remaining methods. Especially, the improving degree of AGTO over IPSO and TSA is huge. Particularly, the cost values reported by IPSO and TSA are up to $709877.38 and $709874.36, respectively while the similar value reached by AGTO is only $709862.049. By taking a simple calculation, the saved costs of AGTO over IPSO and TSA are respectively $15.331 and $12.331. These values equal to 0.0022% and 0.0017% of improved percentage.
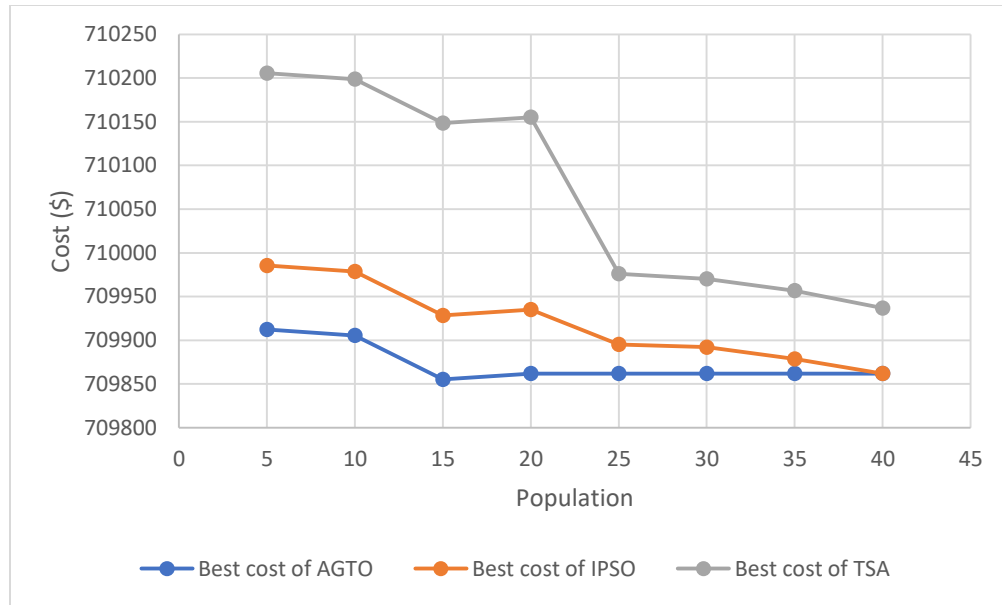
Figure 5. The best cost of applied method for different population and iteration number of 100

The real performance of AGTO is evaluated more with different setting of control parameters such as population size and maximum quantity of iteration. Specifically, the evaluation is implemented in two separate tests. In the first test we fixed the maximum quantity of iteration at 100 and the population size is varied from 5 to 40. On contrary, the population size is anchored at 20 and the maximum quantity of iteration is allowed to change from 45 to 100 in the second test. The results for both tests are presented in Figure 5 and Figure 6, respectively. By observing the Figure 5, it easy to realize that, AGTO only requires 20 particles of polulation size for reaching the optimal performance while both IPSO and TSA must utilized 40 particles for reaching the same performance as AGTO. In the second test, for all setting of maximum quantity of iterations, the cost values obtained by AGTO are largely better than those of IPSO and TSA. Finally, AGTO takes 100 iterations for reaching the optimial results while both IPSO and TSA cannot perform the same.
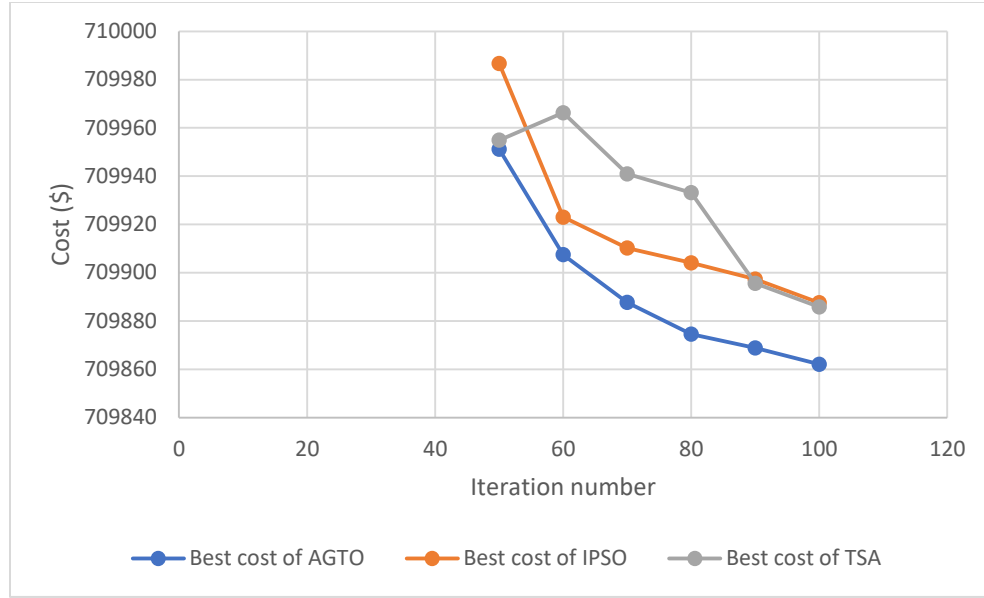
Figure 6. The best cost of applied method for different iteration number and population of 20

6. Conclusions

In this study, the novel meta-heuristic computing method called AGTO is successfully applied to determine the optimal solution for ST-HTS problem. In addition, the performance of AGTO is completely superior to both IPSO and TSA in all criteria including the Min.cost, Mean cost and Max.cost value. Besides, while tested with different setting of control parameters in two separate tests, ATGO still shows its outstanding feature by requiring less population size as well as maximum quantity of iteration than other applied methods. Moreover, the results also point out that, TSA is the method with the poorest efficiency among three applied methods. Finally, AGTO should be acknowledged a highly effective computing method to deal with the ST-HTS problem. Later, AGTO should be modified and improved more to enhance its performance for dealing a large-scale power system configuration of HTS problem. In that scenario, the complexity of the considered problem will reach a higher degree due to the increasing of both thermal and hydroelectric power plant as well as the quantity for related constraints.

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