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# PSO algorithms for combined heat and power dispatch problem considering renewable energy sources

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**Abstract**
In this research, the modified version of the conventional combined heat and power economic load dispatch (CHPED) is successfully solved by incorporating the presence of renewable energy sources (RES). In the study, four modified versions of the original particle swarm optimization (PSO) are used. Among these methods, the performance of PSO with a constriction factor, an inertia weight, and a Cauchy (TVIW-CD-PSO) is completely superior to the other remaining methods. Besides, the presence of RES has been proven to be highly effective for reaching the main target of the considered problem.

**Keywords:** CHPED, TVIW-CD-PSO, PSOs

## 1. Introduction

Currently, the world relies heavily on thermal generating sources. Electricity is generated from the combustion of fossil fuel types such as coal, oil, and natural gases. However, the operating performance of thermal generating sources in general is quite low when compared with others. During the operation of thermal power plants, an enormous volume of heat is wasted. Therefore, to enhance the operational performance of these plants, heat from thermal power plants should be considered. Previous studies indicated that using combined heat and power economic load dispatch (CHPED) is considered a feasible solution to reach the target. Instead of ignoring the wasted heat in conventional thermal power plants, this amount of heat is transmitted for use in residential areas and other industrial processes. The CHPED problem has drawn the attention of many researchers. Therefore, a great number of computing methods are suggested to determine the solutions.

Typical methods can be listed, such as Harmony search method (HSM) and two other improved versions based on HSM [1-3], Two-layer computing method (TLCM) [4], Genetic mechanism-based method (GMBM) and its modified versions [5-7], Teaching – Learning based method (TLBM) [8], Sequential quadratic programing method (SQPM) [9], Duplex programing method (DPM) [10], Bee swarm optimization method [11], the modified Ant social searching method (MASS) [12], the Evolutionary programing method (EPM) [13], Mesh dynamic navigation method (MSNM) [14], the Straightforward searching method (SSM) [15], Artificial immune method (AIM) [16], Lagrange relaxation with dynamic substitute factor-based gradient [17]. All methods mentioned are meta-heuristic methods, except for the conventional computing method in [17]. Recently, renewable energy sources (RES) such as wind and solar are being used with the aim of reducing pollution from thermal power plants and the depletion of traditional resources. RES are being applied to some engineering problems, such as economic load dispatch [18, 19], optimal power flow [20, 21].

In this research, the conventional CHPED problem is modified by integrating a renewable energy source (RES-CHPED). The main task of RES-CHPED is to reduce the fuel cost of thermal plants as much as possible. In addition, four methods are reapplied to solve the RES-CHPED problem. They are particle swarm optimization (PSO) [22], PSO with coefficient factor (CF-PSO) [23], PSO with inertia weight (IW-PSO) [24], and PSO with a constriction factor, an inertia weight, and a Cauchy (TVIW-CD-PSO) [25].

In summary, the main contributions of the research can be listed below:

- Apply successfully three different modified versions of PSO and PSO to solve the RES-CHPED problem
- Prove the outstanding performance of TVIW-PSO-CD among other methods
- Solve the new RES-CHPED problem considering the presence of RES

## 2. Problem formula

### 2.1 Objective function

In the RES-CHPED problem, the volume of heat and power produced by all generators is optimally assigned so that the total fuel cost (*TFC*) is as low as possible. The typical system consists of $N_e$ electricity generators, $N_h$ heat generators and $N_{cg}$ combined generator. The objective function of such problem is described below:

$$TFC = \sum_{x=1}^{N_e} FC_{ex}(P_{ex}) + \sum_{y=1}^{N_h} FC_{hy}(H_{hy}) + \sum_{z=1}^{N_{cg}} FC_{cgz}(P_{cgz}, H_{cgz}) \quad (1)$$

In this Eq. (1), $FC_e$, $FC_h$, and $FC_{cg}$ are respectively fuel cost of generating electricity, heat and combined electricity and heat. Their formulation is presented as follow

$$FC_{ex} = \varepsilon_{ex} + \theta_{ex} P_{ex} + \sigma_{ex} P_{ex}^2;\ x = 1, \ldots, N_e \quad (2)$$

Where $P_e$ is the amount of electricity produced by electricity generators; $\varepsilon_e$, $\theta_e$ and $\sigma_e$ are fuel consumption coefficients

$$FC_{ex} = \varepsilon_{ex} + \theta_{ex} P_{ex} + \sigma_{ex} P_{ex}^2;\ x = 1, \ldots, N_e \quad (3)$$

Where $H_h$ is the amount of heat generated by heat generators; $\varepsilon_h$, $\theta_h$ and $\sigma_h$ are fuel consumption coefficients

$$F_{cgz}(P_{cgz}, H_{cgz}) = \alpha_{cgz} + \beta_{cgz} P_{cgz} + \gamma_{cgz} P_{cgz}^2 + \tau_{cgz} + \omega_{cgz} H_{cgz} + \varphi_{cgz} H_{cgz}^2;\ z = 1, \ldots, N_{cg} \quad (4)$$

where $P_{cg}$ and $H_{cg}$ are respectively the amount of electricity and heat produced by combined generator; $\alpha_{cg}$, $\beta_{cg}$, $\gamma_{cg}$, $\tau_{cg}$, $\omega_{cg}$ and $\varphi_{cg}$ are fuel usage coefficients

### 2.2 Constraints

The constraints of such problem are detailed below.

#### 2.2.1 The equality constraints

- **Power equality constraint**

$$P_{DM} + P_{Ls} - \sum_{x=1}^{N_e} P_{ex} - \sum_{z=1}^{N_{cg}} P_{cgz} - P_{RES} = 0 \quad (5)$$

Where $P_{DM}$ is load demand; $P_{RES}$ is power output of RES plant; $P_{Ls}$ is power loss and it is determined by using the equation (6) below:

$$P_{Ls} = \sum_{a=1}^{N_e+N_{cg}} \sum_{b=1}^{N_e+N_{cg}} P_a B_{ab} P_b + \sum_{a=1}^{N_e+N_{cg}} B_{0a} P_a + B_{00} \quad (6)$$

In the equation (6) above $P_a$ and $P_b$ are respectively the amount of power bumped into bus *a* and bus *b*; $B_{ab}$, $B_{0a}$ and $B_{0a}$ is loss factor given from loss matrix

- **Heat equality constraints**

Similar to the power equality constraints, the heat constraint is the relationship between the generation side and the demand side ($H_D$). In order to secure the operation of the entire system, the amount of heat from the generation side must meet the demand side. The constraint is presented below.

$$H_D - \sum_{y=1}^{N_h} H_{hy} - \sum_{z=1}^{N_{cg}} H_{cgz} = 0 \quad (7)$$

#### 2.2.2 The inequality constraints

The electric power and heat power must satisfy their limits as follow:

- **The operation boundary of electricity generator**

$$P_{ex,min} \leq P_{ex} \leq P_{ex,max} \quad (8)$$

- **The operation boundaries of heat generator**

$$H_{hy,min} \leq H_{hy} \leq H_{hy,max} \quad (9)$$

- **The operation boundaries of combined generator**

$$P_{cgz,min} \leq P_{cgz} \leq P_{cgz,max} \quad (10)$$

$$H_{cgz,min} \leq H_{cgz} \leq H_{cgz,max} \quad (11)$$

- **The operation boundaries of RES**

$$0 \leq P_{RES} \leq P_{RES,max} \quad (12)$$

In addition to the inequality constraints, the electric power and heat constraints must be within the zone as presented in figure 1.

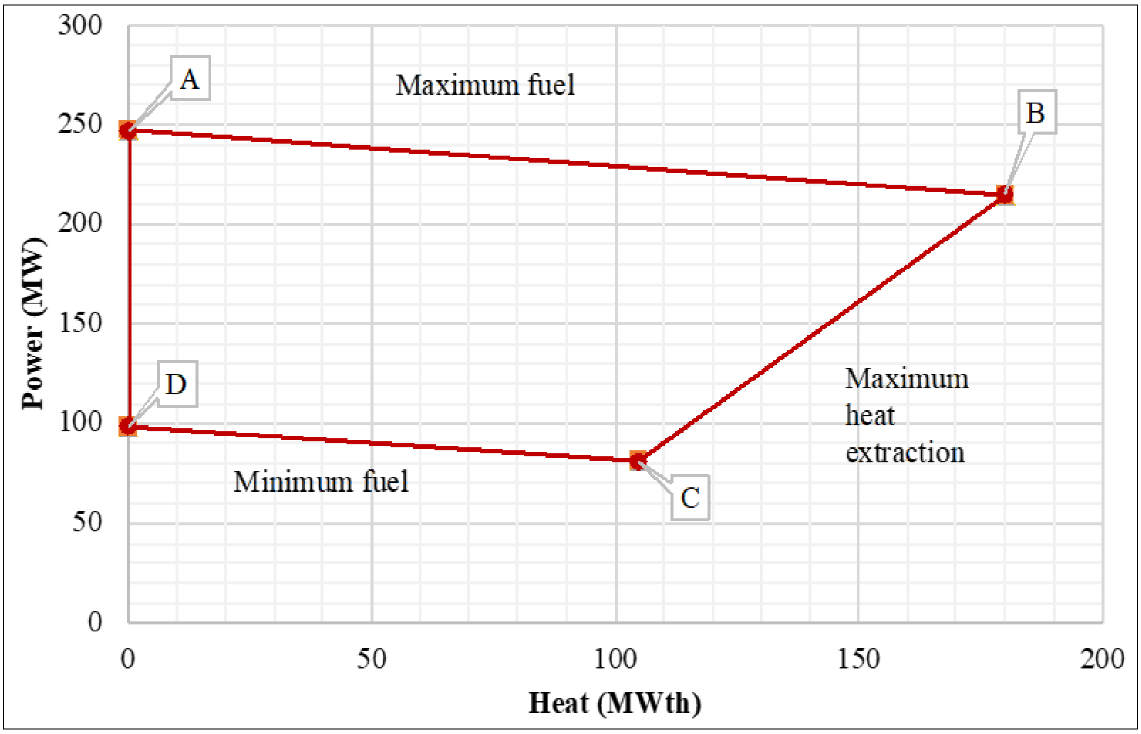


**Fig 1:** Heat and power characteristics form combined generator

**3. Methods**

**3.1 The particle swarm optimization (PSO)**

Particle swarm optimization is a meta-heuristic method developed by Kenedy and Eberhart to cope with a wide range of optimization problems. The main inspiration for PSO came from mimicking the foraging behavior of school fish, bird swarms, or other groups of animals in nature. Each member of the group is distinguished by a position and a velocity. The update mechanism of PSO is sequentially described by the following equations.

$$Vt_i^{new} = Vt_i + af_1 \times Rn \times \left(Pt_{Best,i} - Pt_i\right) + af_2 \times Rn\left(Pt_{G\_best} - Pt_i\right) \quad (13)$$

$$Pt_i^{new} = Pt_i + Vt_i^{new} \quad (14)$$

Where, s$Vt_i^{new}$ and $Vt_i$ are respectively the new velocity and the old velocity of the *ith* individual; $af_1$ and $af_2$ are the accelerate coefficients, *Rn* is the random value between 0 and 1. $Pt_{Best,i}$ is the best position of the *ith* individual. $Pt_{G\_best}$ is the best position of all individuals in group.

### 3.2 PSO with constriction factor

CF-PSO was a new version of PSO which was formed by using constriction factor (CF) in update velocity equation [19]. The equation is stated by

$$Vt_i^{new} = CF \times \left(Vt_i + af_1 \times RN \times \left(Pt_{Best,i} - Pt_i\right) + af_2 \times RN\left(Pt_{G_{best}} - Pt_i\right)\right) \quad (15)$$

**Where**

$$CF = \frac{2}{\left|2 - (af_1 + af_2) - \sqrt{(af_1 + af_2)^2 + 4 \times (af_1 + af_2)}\right|} \quad (16)$$

### 3.3 PSO with inertia weight (IW-PSO)

By adding inertia weight (IW) in the update of the velocity mechanism, the study [20] successfully built up a new modified version based on the original PSO called IW-PSO. The new velocity update process is presented by.

$$Vt_i^{new} = (IW \times Vt_i + af_1 \times RN \times \left(Pt_{Best,i} - P_i\right) + af_2 \times RN\left(Pt_{G_{best}} - Pt_i\right)) \quad (17)$$

**Where**

$$IW = IW_{max} \times \frac{IW_{max} - IW_{min}}{IW_{max}} \times IT \quad (18)$$

Where, IT is the current iteration of the computing process.

### 3.4 PSO with time-varying inertia weigh and Cauchy

The study [21] added a constriction factor (*CF*), an inertia weight (*IW*), and a Cauchy (*CD*) into the original PSO to form the TVIW-CD-PSO in the hopes of improving performance. The update of the new velocity of the method is depicted below:

$$Vt_i^{new} = CF \times (IW \times Vt_i + af_1 \times RN \times CD \times \left(Pt_{Best,i} - Pt_i\right) + af_2 \times RN \times (Pt_{Gbest,i} - Pt_i)) \quad (19)$$

**Where**

$$CD = \left|tan\left(\frac{\pi}{4} \times (RN - \frac{1}{2})\right)\right| \quad (20)$$

### 4. Results

In this section, the PSO method and three modified versions of PSO are applied to determine the optimal solution to the RES-CHPED problem. All methods are run with the same population of 50 and a maximum iteration of 200. In addition, each method is implemented with 50 independent runs. Data for the system is taken from a study [19]. Power demand and heat demand are 220 MW and 125 MW, respectively. In addition, a PV with a 50MW capacity is integrated with the original system. The entire work is carried out on a personal computer with a 2.6 GHz central processing unit (CPU) and 8 GB of random-access memory (RAM).

Figure 2 displays the cost value given by four methods after completing 50 independent runs. The PSO, CF-PSO, IW-PSO, and TVIW-CD-PSO methods are represented by the black, blue, pink, and red lines, respectively. It is easy to recognize that TVIW-CD-PSO is superior to others. Specifically, the results given by this method are strongly stable and the fluctuation of fitness value after each run is very small.

The convergence curves for the best run of four methods are described in Figure 3. As seen in the figure, the convergence curve of TVIW-CD-PSO is the earliest one. TVIW-CD-PSO only requires approximately 40 iterations to determine the best fitness value, while the other methods cannot be obtained. In addition, the PSO is the worst method among the four applied methods. At the end of the iteration, the fitness value of PSO is still far away from the best one.

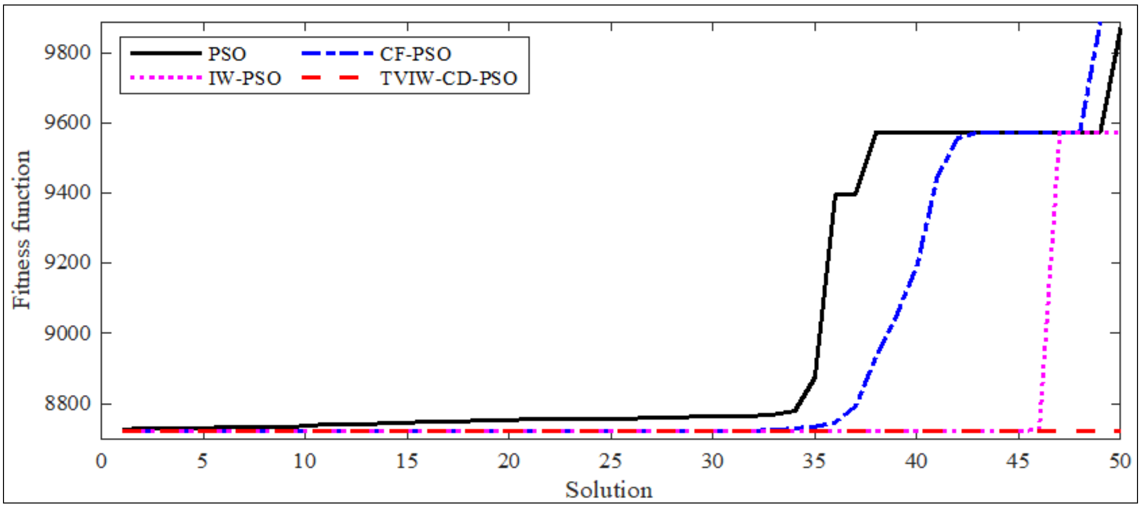


**Fig 2:** Cost of 50 runs sorted from the lowest to highest

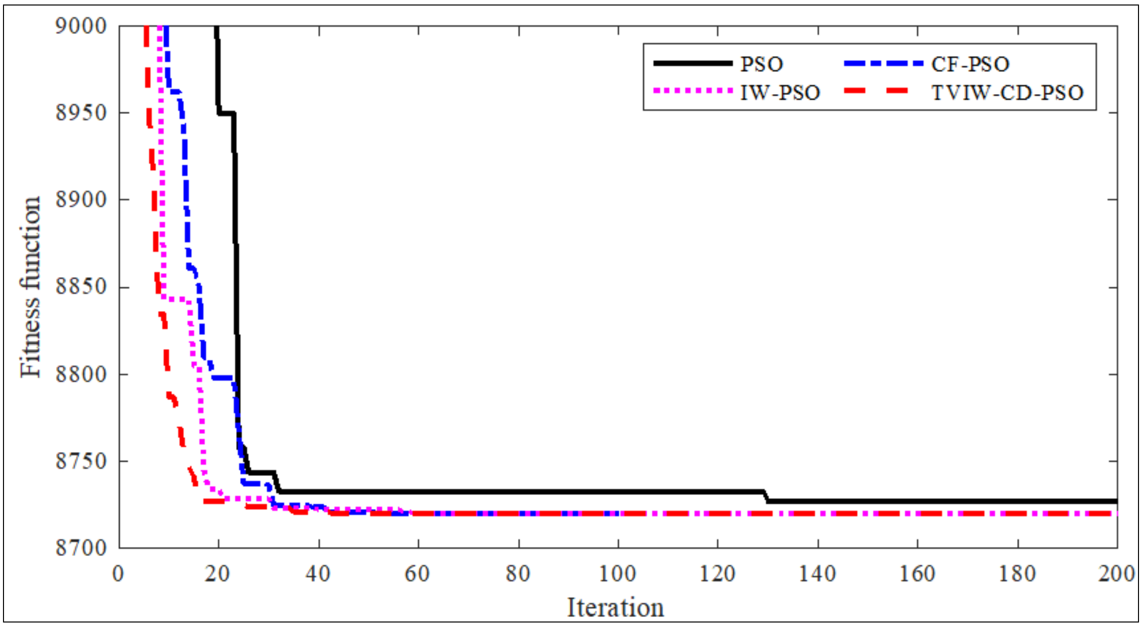


**Fig 3:** The best convergence characteristics of four methods

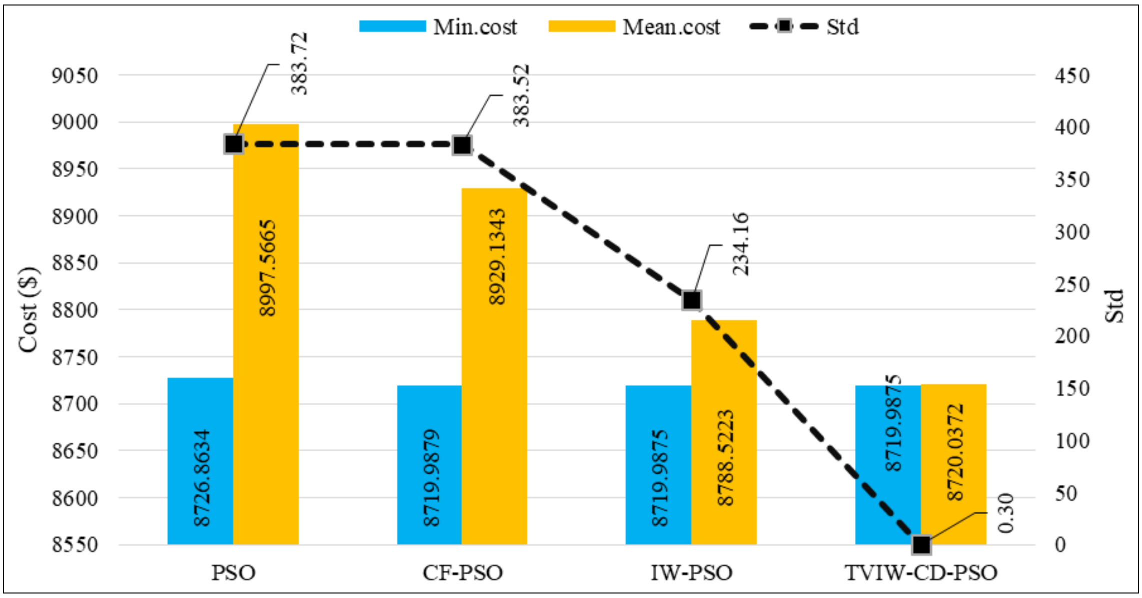


**Fig 4:** Comparison of min cost, mean cost and Std of four methods

The minimum cost (Min. cost), the mean cost (Mean. cost) and the standard deviation (Std) from four methods are respectively shown in Figure 4. The results obtained by PSO were the worst, while those of TVIW-CD-PSO were the best.

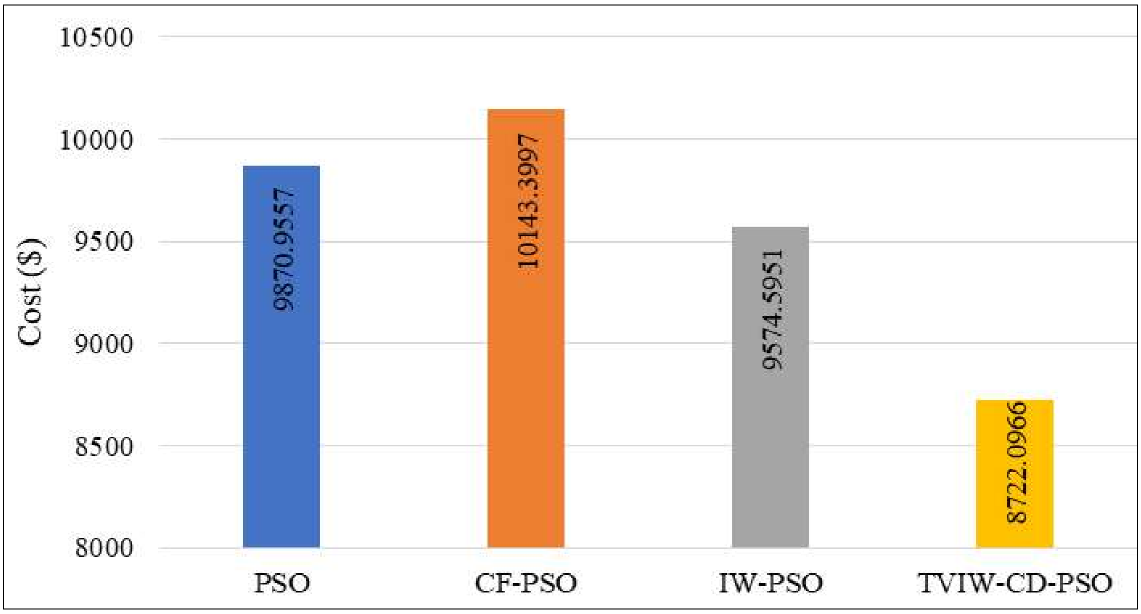


**Fig 5:** Comparison of max. cost and Std of four methods

The Min. cost, Mean. cost, and Std of TVIW-CD-PSO are $8719.9575, $8997.5665, and 0.03, respectively, whereas those of PSO are $8726.8634, $8997.5665, and 383.72

When taking a look at the maximum cost values (Max. cost) obtained by four methods, the smallest one is from TVIW-CD-PSO, and the largest one is owned by the CF-PSO. In particular, in Figure 5, the Max. cost given by TVIW-CD-PSO is only $5722.0966 while the similar value reached by CF-PSO is up to $10143.3997.

## 5. Conclusion

In this research, the new RES-CHPED was successfully solved by the PSO method and its modified versions. Among these methods, TVIW-CD-PSO showed its exceptional performance while evaluating the obtained results in all aspects. Besides, all the constraints of RES-CHPED are satisfied. The conclusion is that TVIW-CD-PSO is a powerful and stable computing method for solving the RES-CHPED problem.

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