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The Effects of Electricity Boiler on Integrated CCHP-Thermal-Heat Only Unit Commitment Problem Based on Hybrid GA Approach

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Abstract

Combined cooling, heat, and power (CCHP) units can be integrated with conventional separate cooling, heat, and power production units to meet demands. The goal of this study is to develop and examine a hybrid GA-heuristic optimization algorithm for solving the unit commitment problem for integrated CCHP-thermal-heat only system with considerations for electricity boiler. When environmental emission cost and valve-point effects are considered, the utilization of CCHP units in an integrated CCHP-thermal-heat system results in environmental emission and total cost reduction by and 38.37 and 0.03% respectively.. Also, using electricity boiler, environmental emission and total cost reduction of 0.53 and 0.03 are reached, respectively.

Keywords: Combined cooling, heat and power, Unit commitment, Environmental emission, Electricity boiler

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1. Introduction

Proper utilization of combined cooling, heat, and power (CCHP) systems requires considerations for a range of technical, economic, and environmental emission issues for the purpose of optimal operation planning and scheduling [1-3]. When integrated to meet cooling, heat, and power demands, CCHP units are used for providing cooling (absorption chillers), heat, and power simultaneously, thermal units are utilized to meet cooling (compression chillers) and power generation, and heat only units are used for supplying the heat needed beyond that available from CCHP units. Also, CCHP units can be integrated with thermal and heat only units for delivering cooling, heat, and power as well as providing spinning reserve for power, which constitutes unit commitment (UC) problem [4]. However, for thermal units, opening steam valves of the large steam turbine for increasing the power output leads to a non-convex fuel cost function [5-6] that must be accounted for in the UC problem formulation.

In the literature, there are limited studies that focus on solving UC problem for CCHP systems.

Optimal dispatch strategy for integrated energy systems with CCHP and wind power is presented in [7]. In that study, the objective function of the optimization model is to minimize the total operation cost of integrated energy systems and, the model is transformed into mixed integer linear programming formulation to improve the computation efficiency. Numerical case studies conducted demonstrate the lower operation cost of the proposed model facilitating wind power integration.

In [8], a new operation strategy, based on the variational electric cooling to cooling load ratio, for the CCHP system with unlimited and limited power generation unit capacity is investigated. In [9, 10], a stochastic multi-objective optimization model to optimize the CCHP operation strategy for different climate conditions is proposed. The probability constraints are added into the stochastic model to guarantee the optimized CCHP operation strategy is reliable to satisfy the stochastic energy demand.

Several studies about scheduling of CCHP-based microgrids are presented in [11-18].

An online economic optimal operation of CCHP and photovoltaic systems is proposed in [19, 20]. In those studies, a test system consists of a CCHP, a photovoltaic system, an auxiliary boiler, an absorption chillers, a heat storage tank, and utility grids are included.

A multi-objective optimization problem for CCHP system is discussed in [21]. The main objective of that study is to minimize simultaneously the amount of fuel utilization and pollutants emission from CCHP system. A value-based planning method for CCHP placement based on the energy hub concept is proposed in [22]. The proposed method takes the benefits and costs of CCHP placement into account and determines the optimal sizing and operation for energy hub elements.

The multi-objective optimization dispatch of CCHP based on the principle of equal emission is presented in [23]. In [24], an optimal operating strategy for CCHP in multi-energy carrier system is proposed.

A simple model for CCHP based hybrid power system scheduling for energy resources is presented in [25]. That research points an effective operation strategy which ensure a clean and energy efficient power scheduling by exploiting available energy resources effectively.

It is noted that in all previous studies [8-25], the effects of integration of CCHP units with other units, the feasibility region constraint of CCHP units, electricity boiler, and valve point effects for steam turbines of thermal units are not studied. Also, to accurate modeling of UC problem, related constraints such as minimum up/down times (*MUT*/*MDT*) must be considered.

The goal of this study is to develop and examine a hybrid Genetic algorithm (GA)-heuristic optimization algorithm for solving the unit commitment problem for integrated CCHP-thermal-heat only system with considerations for electricity boiler.

The organization of this study is as follows. Section 2 introduces the UC problem formulation for integrated CCHP-thermal-heat only system and, Section 3 explains the heuristic optimization algorithm proposed in this study. In Section 4, the parametric values and data are presented and, simulation results are analyzed. Finally, in Section 5, conclusion and recommendations are given.

2. Problem Formulation

A) Assumptions

In this study, the following assumptions are considered:

- The CCHP and thermal units provide cooling demand through absorption and compression chillers, respectively.
- The CCHP, electricity boiler, and heat only units provide heat demand.
- The power is generated by CCHP and thermal units.
- Spinning reserve is considered only for power demand.
- The input power of electricity boiler is provided by thermal and CCHP units.

B) Thermal units

For thermal units, the objective function is,

$$\min\{TC_{THE}\} \tag{1}$$

Where

$$TC_{THE} = FC_{THE} + SC_{THE} + EMC_{THE} \tag{2}$$

$$FC_{THE} = \sum_{t=1}^{T}\sum_{i=1}^{N}\{f(P(i,t))I(i,t)\} \tag{3}$$

$$\begin{aligned} f(P(i,t)) &= a_i P^2(i,t) + b_i P(i,t) + c_i \\ &+ \left| d_i \sin\left(e_i(P_{\min}(i) - P(i,t))\right)\right| \end{aligned} \tag{4}$$

where the last term in Eq. (4) represents the valve-point effects modeled as a non-convex term.

$$SC_{THE} = \sum_{i=1}^{N}\{SUC(i,t)I(i,t)(1-I(i,t-1))\} \tag{5}$$

$$SUC(i,t) = \begin{cases} HSC(i) & T^{OFF}(i,t) \le CST(i) + MDT(i) \\ CSC(i) & T^{OFF}(i,t) > CST(i) + MDT(i) \end{cases} \tag{6}$$

$$I(i,0) = IS(i) \tag{7}$$

Note that $IS(i) > 0$ if thermal unit i has been ON before first time period and, $IS(i) < 0$ if thermal unit i^{th} has been OFF before first time period.

The objective function for thermal units given by Eq. (1) is subject to the following constraints,

- Generation capacity

$$P_{\min}(i)I(i,t) \le P(i,t) \le P_{\max}(i) \tag{8}$$

- Minimum up time'

$$T^{ON}(i,t) \ge MUT(i) \tag{9}$$

- Minimum down time

$$T^{OFF}(i,t) \ge MDT(i) \tag{10}$$

C) CCHP units

For CCHP units, the objective function is,

$$\min\{TC_{CCHP}\} \tag{11}$$

Where

$$TC_{CCHP} = FC_{CCHP} + SC_{CCHP} + EMC_{CCHP} \tag{12}$$

$$FC_{CCHP} = \sum_{t=1}^{T}\sum_{j=1}^{M}\{f(P(j,t),H(j,t))I(j,t)\} \tag{13}$$

$$\begin{aligned} f(P(j,t),H(j,t)) &= \zeta_j P^2(j,t) + \beta_j P(j,t) + \alpha_j \\ &+ \lambda_j H^2(j,t) + \gamma_j H(j,t) + \phi_j P(j,t)H(j,t) \end{aligned} \tag{14}$$

$$SC_{CCHP} = \sum_{j=1}^{M} \{SUC(j,t) I(j,t)(1 - I(j,t-1))\} \quad (15)$$

$$SUC(j,t) = \begin{cases} HSC(j) & T^{OFF}(j,t) \le CST(j) + MDT(j) \\ CSC(j) & T^{OFF}(j,t) > CST(j) + MDT(j) \end{cases} \quad (16)$$

$$I(j,0) = IS(j) \quad (17)$$

If spinning reserve cost is considered, FC_{CCHP} is modified as

$$FC_{CCHP} = (1-re)\sum_{t=1}^{T}\sum_{j=1}^{M}\{f(P(j,t),H(j,t))I(j,t)\} + re\sum_{t=1}^{T}\sum_{j=1}^{M}\{f(P(j,t)+R(j,t),H(j,t))I(j,t)\} \quad (18)$$

The objective function for CCHP units given by Eq. (12) is subject to the following constraints,

– Generation capacity

$$P_{\min}(j)I(j,t) \le P(j,t) \le P_{\max}(j) \quad (19)$$

$$H_{\min}(j)I(j,t) \le H(j,t) \le H_{\max}(j) \quad (20)$$

– Minimum up time

$$T^{ON}(j,t) \ge MUT(j) \quad (21)$$

– Minimum down time

$$T^{OFF}(j,t) \ge MDT(j) \quad (22)$$

3. Power-heat Feasible Operating Region

Each CCHP unit has a power-heat feasible operation region shown in Fig. 1, which can be presented as a set of linear inequality constraints.

These constraints address the joint characteristic technology of power-heat in CCHP units.

$$x_k P(j,t) + y_k H(j,t) \le z_k \quad (23)$$

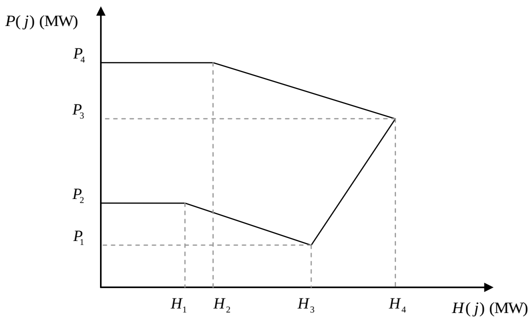

Fig. 1. Power-heat feasible operating region of CCHP units [1].

A) Heat only units

For heat only units, the objective function is,

$$\min\{TC_{HTO}\} \quad (24)$$

$$TC_{HTO} = FC_{HTO} + SC_{HTO} + EMC_{HTO} \quad (25)$$

$$FC_{HTO} = \sum_{t=1}^{T}\sum_{l=1}^{L}\{f(H(l,t))I(l,t)\} \quad (26)$$

$$f(H(l,t)) = \rho_l H^2(l,t) + \mu_l H(l,t) + \sigma_l \quad (27)$$

$$SC_{HTO} = \sum_{l=1}^{L}\{SUC(l,t)I(l,t)(1 - I(l,t-1))\} \quad (28)$$

$$SUC(l,t) = \begin{cases} HSC(l) & T^{OFF}(l,t) \le CST(l) + MDT(l) \\ CSC(l) & T^{OFF}(l,t) > CST(l) + MDT(l) \end{cases} \quad (29)$$

$$I(l,0) = IS(l) \quad (30)$$

The objective function for heat only units given by Eq. (25) is subject to the following constraints,

– Generation capacity

$$H_{\min}(l)I(l,t) \le H(l,t) \le H_{\max}(l) \quad (31)$$

– Minimum up time

$$T^{ON}(l,t) \ge MUT(l) \quad (32)$$

– Minimum down time

$$T^{OFF}(l,t) \ge MDT(l) \quad (33)$$

B) Electricity boiler

Electricity boiler consumes electric power to generate heat energy when heat load cannot be met entirely by the CHP units and the heat storage tank. The cost function of electricity boiler is

$$\min\{TC_{EB}\} \quad (34)$$

$$TC_{EB} = \sum_{t=1}^{T} P_e(t)\left\{\sum_{k=1}^{K} P(k,t)\right\} \quad (35)$$

$$H(k,t) = \eta_k P(k,t) \quad (36)$$

$$P_{\min}(k) \le P(k,t) \le P_{\max}(k) \quad (37)$$

It is noted that $P(k,t)$ could also met by thermal and CCHP units.

C) Integrated CCHP-thermal-heat only-electricity boiler

When CCHP, thermal, and heat only units are operated as one integrated system, the objective function is,

$$\min\{TC_{INT}\} \quad (38)$$

$$TC_{INT} = TC_{THE} + TC_{CCHP} + TC_{HTO} + TC_{EB} \quad (39)$$

The objective function of UC problem given by Eq. (35) is subject to the following constraints,

System cooling, heat, and power balances

– Cooling balance

$$C_{ac}(t) + C_{cc}(t) = C_D(t) \quad (40)$$

$$C_{cc}(t) = COP_{cc}\sum_{i=1}^{N} P_{cc}(i,t) \quad (41)$$

$$C_{ac}(t) = COP_{ac}\sum_{j=1}^{M} H_{ac}(j,t) \quad (42)$$

– Heat balance

$$\sum_{j=1}^{M} H(j,t) = \sum_{j=1}^{M} H_{hd}(j,t) + \sum_{j=1}^{M} H_{ac}(j,t) \quad (43)$$

$$\sum_{j=1}^{M} H_{hd}(j,t) + \sum_{l=1}^{L} H(l,t) + H(k,t) = H_D(t) \quad (44)$$

– Power balance

$$\sum_{i=1}^{N} P(i,t) = \sum_{i=1}^{N} P_{ed}(i,t) + \sum_{i=1}^{N} P_{cc}(i,t) \quad (45)$$

$$\sum_{i=1}^{N} P_{ed}(i,t) + \sum_{j=1}^{M} P(j,t) = P_D(t) \quad (46)$$

System power spinning reserve inequality

$$\sum_{i=1}^{N} R(i,t) + \sum_{j=1}^{M} R(j,t) \geq R(t) \quad (47)$$

Units constraints

All units' constraints (Eqs. (9)-(11), (20)-(23), (32)-(34), and (37)-(38)) must be met.

D) Environmental emission

The operation of integrated CCHP-thermal-heat only system is always accompanied by the release of several environmental pollutants and, the CO_2 emissions by units at hour *t* are given by

$$EMS(P(i,t)) = \gamma_{ei} P^2(i,t) + \beta_{ei} P(i,t) + \alpha_{ei} \quad (48)$$

$$EMS(P(j,t)) = \gamma_{ej} P^2(j,t) + \beta_{ej} P(j,t) + \alpha_{ej} \quad (49)$$

$$EMS(H(l,t)) = \gamma_{el} H^2(l,t) + \beta_{el} H(l,t) + \alpha_{el} \quad (50)$$

and environmental emission associated costs are:

$$EMC_{THE} = EMP \sum_{t=1}^{T} \sum_{i=1}^{N} EMS(P(i,t)) \quad (51)$$

$$EMC_{CCHP} = EMP \sum_{t=1}^{T} \sum_{j=1}^{M} EMS(P(j,t)) \quad (52)$$

$$EMC_{HTO} = EMP \sum_{t=1}^{T} \sum_{l=1}^{L} EMS(H(l,t)) \quad (53)$$

4. Optimization Methodology

In this section, the heuristic optimization algorithm developed for optimal scheduling of integrated CCHP-thermal-heat only system for minimizing environmental emission and total cost is presented.

Cost reduction and impressive low execution time can be achieved by utilizing the described heuristic optimization algorithm, as the maximization of proposed fitness function (*FF*) in this study finds the optimal output power of a unit [1]. After calculating the optimal output power of units using GA discussed in [26-28], the units are sorted according to their best *FF*s and, the committed units are then determined when all constraints such as generation capacity, *MUT*, and *MDT* are satisfied. This heuristic optimization algorithm is successfully applied to solve CHP PBUC [1] and, here it is modified to solve UC for integrated CCHP-thermal-heat only system.

To solve the UC problem for integrated CCHP-thermal-heat only system, three alternatives (UC for power demand and UC for heat demand under two conditions) are proposed as detailed in Fig. 2.

It is noted that electricity boiler is utilized when the cost of power input is less than the cost of corresponding heat (75% of power input).

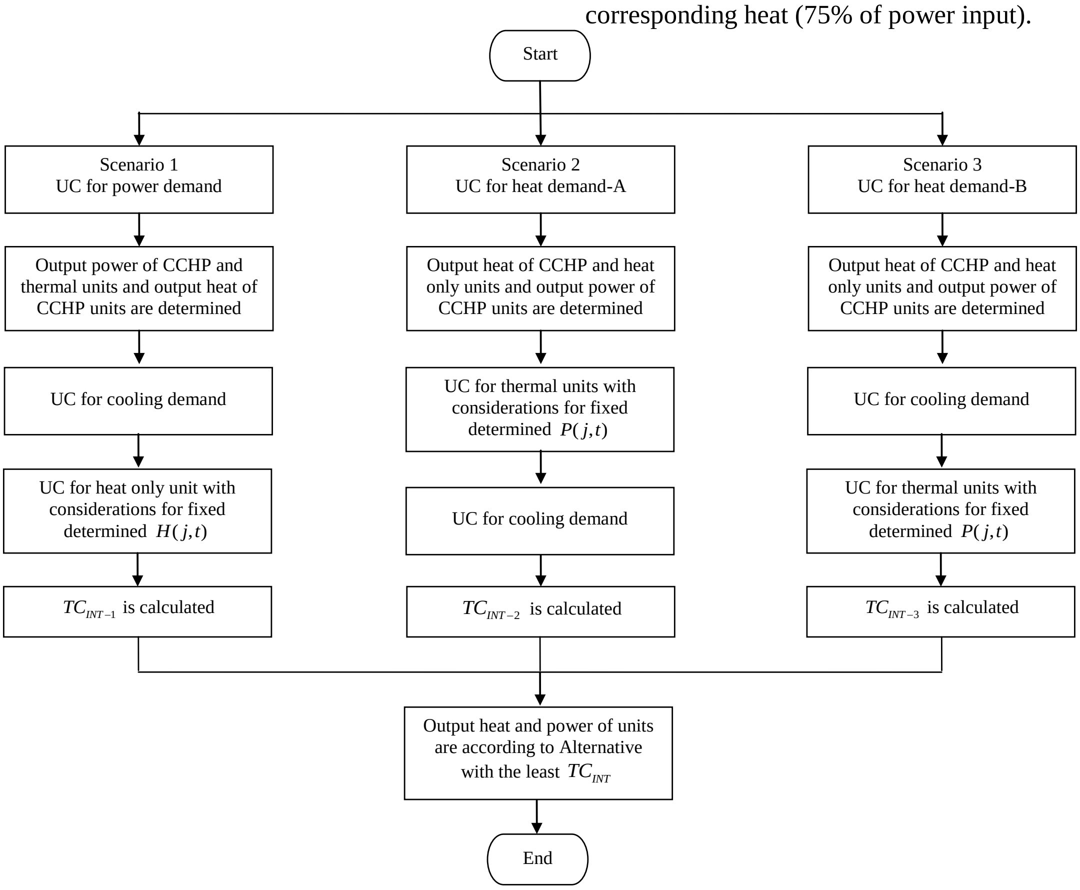

Fig. 2. Optimization algorithm flowchart of UC problem for integrated CCHP-thermal-heat only system at hour t.

5. Simulation Results

The simulation results are presented to examine the environmental emission reductions and total cost achieved based on the heuristic optimization algorithm proposed in this study.

A) Data needed

- Thermal units: Ten thermal units with characteristics data from [6] are used.
- CCHP units: Two CCHP units with data from [4] are used.
- Heat only unit: One heat only unit with data from [4] is used.
- Chillers: Absorption $(COP_{ac} = 1.2)$ and compression chillers $(COP_{cc} = 3)$ data are from [6].
- Power system demand: The needed data for power system demand is based on [1] for simulation. It is noted that spinning reserve limit is considered at 10% of power demand [29-33].
- Heat system demand: The needed data for heat demand is based on [4].
- Cooling system demand: The needed data for heat demand is based on [4].
- Electricity boiler: The needed data for electricity boiler is available in [6] when the efficiency is 75%.

B) Results and discussion

In this case, cooling, heat, and power demands are satisfied by integrated CCHP-thermal-heat only system. Environmental emission cost is considered $(EMP = 26.6 \text{ \$/TOC})$ [1].

The effects of CCHP units:

It is determined from Table I that, the utilization of CCHP units reduces environmental emission and total cost in comparison with separated thermal and heat only units by 38.37 and 0.03% , respectively.

The effects of electricity boiler:

In this section, electricity boiler is considered.

It is concluded from Table II that the utilization of electricity boiler can simultaneously reduce environmental emission and total cost by 0.53 and 0.03%, respectively.

The input power and output heat of electricity boiler are presented in Table 3.

Optimal output (power+cooling) for integrated CCHP-thermal-heat only system is shown in Table 4., where cooling demand is met by thermal units using compression chillers and, CCHP and thermal units are responsible for satisfying power demand.

Table.1.
Results for UC problem for operation of integrated CCHP-thermal-heat only system when 2 CCHP units are utilized with considerations for environmental emission cost.

Operation	*TC ($)*	*TC (%)*	*EMS (TOC)*	*EMS (%)*
Without CCHP	1,323,734	-	50,986	-
With CCHP	1,323,330	0.03	31,421	38.37

Table.2.
Results for UC problem for operation of integrated CCHP-thermal-heat only system when electricity boiler is utilized.

Operation	*TC ($)*	*TC (%)*	*EMS (TOC)*	*EMS (%)*
Without electricity boiler	1,323,330	-	31,421	-
With electricity boiler	1,322,900	0.03	31,254	0.53

In Table V, Optimal output (heat+cooling) for integrated CCHP-thermal-heat only system is presented. It is shown that cooling demand is met by CCHP units using absorption chillers and, CCHP and heat only units are responsible for satisfying heat demand.

Table.3.
Power input and heat output of electricity boiler

Hr	*Electricity boiler (MW)*		*Hr*	*Electricity boiler (MW)*	
	Power input	*Heat output*		*Power input*	*Heat output*
1	0	0.0	13	10	7.5
2	0	0.0	14	0	0.0
3	40	30.0	15	0	0.0
4	40	30.0	16	50	37.5
5	5	3.8	17	30	22.5
6	50	37.5	18	0	0.0
7	50	37.5	19	10	7.5
8	50	37.5	20	25	18.8
9	0	0.0	21	0	0.0
10	40	30.0	22	40	30.0
11	40	30.0	23	50	37.5
12	0	0.0	24	50	37.5

As discussed in section III, GA is used to find $P^*(i,t)$. For example, the GA convergence curves for thermal unit 2 at hr 12. ($P^*(2,12) = 246$) is shown in Fig. 3.

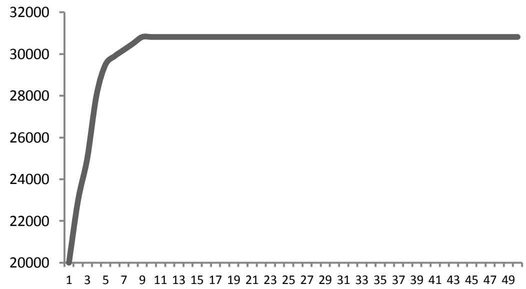

Fig. 3. Topology of the smart large consumer

Table.4.
Optimal output (power+cooling) for integrated CCHP-thermal-heat only system with considerations for environmental emission and electricity boiler

Hr	Unit Output (MW)											
	Thermal (Power + Cooling)										CCHP	
	1	2	3	4	5	6	7	8	9	10	1	2
1	227.00+0.00	222.00+0.33	185.00+27.67	120.00+0.33	171.00+1.67	111.0+11.67	00.00+00.00	00.00+00.00	0.00+0.00	0.00+0.00	000.00	000.00
2	234.00+0.00	229.00+0.00	202.00+37.33	131.00+0.00	181.00+0.00	133.00+0.00	00.00+00.00	00.00+00.00	0.00+0.00	0.00+0.00	000.00	000.00
3	227.00+32.5	222.0+32.83	185.00+64.17	120.0+32.83	173.00+0.00	116.00+6.67	00.00+00.00	85.00+00.33	0.00+0.00	0.00+0.00	000.00	000.00
4	231.00+0.00	226.00+0.00	193.00+31.00	126.00+0.00	177.00+0.00	81.00+00.00	00.00+00.00	00.00+47.00	0.00+0.00	0.00+0.00	215.00	109.50
5	229.00+0.00	224.00+0.00	190.00+37.33	124.00+0.00	175.00+0.00	126.00+0.00	00.00+00.00	87.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
6	231.00+0.00	226.00+0.00	195.00+39.33	127.00+0.00	178.00+0.00	128.00+0.00	130.00+0.00	88.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
7	239.00+0.00	233.00+0.00	213.00+41.67	140.00+0.00	188.00+0.00	140.00+0.00	130.00+0.00	94.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
8	242.00+0.00	235.00+0.00	219.00+36.00	193.00+0.00	192.00+0.00	144.0+16.00	130.00+0.00	96.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
9	243.00+0.00	236.00+0.00	223.00+48.33	300.00+0.00	224.00+0.00	146.0+14.00	130.00+0.00	97.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
10	246.00+42.0	238.00+0.00	330.00+10.33	300.00+0.00	243.00+0.00	160.00+0.00	130.00+0.00	100.0+20.33	0.00+0.00	0.00+0.00	215.00	109.50
11	282.00+21.3	246.00+51.3	340.00+00.00	300.00+0.00	243.00+0.00	160.00+0.00	130.00+0.00	120.00+0.00	0.00+0.00	0.00+0.00	215.00	109.50
12	356.00+23.0	246.00+59.3	340.00+00.00	300.00+0.00	243.00+0.00	160.00+0.00	130.00+0.00	120.00+0.00	0.00+0.00	0.00+0.00	215.00	109.50
13	246.00+57.3	238.00+5.67	330.00+10.33	300.00+0.00	243.00+0.00	160.00+0.00	130.00+0.00	100.0+20.33	0.00+0.00	0.00+0.00	215.00	109.50
14	243.00+0.00	236.00+0.00	223.00+90.00	300.00+0.00	224.00+0.00	146.0+14.00	130.00+0.00	97.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
15	242.00+0.00	235.00+0.00	219.00+77.67	193.00+0.00	192.00+9.33	144.0+16.00	130.00+0.00	96.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
16	227.00+0.00	222.00+0.33	185.0+102.67	120.00+0.33	173.00+0.00	122.00+0.67	130.00+0.00	51.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
17	221.00+5.67	168.00+45.3	185.00+00.33	110.0+10.33	167.00+5.67	98.00+24.67	127.00+2.67	80.00+05.33	0.00+0.00	0.00+0.00	215.00	109.50
18	231.00+0.00	226.00+0.00	195.00+83.33	127.00+0.00	178.00+0.00	128.00+0.00	130.00+0.00	88.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
19	242.00+0.00	235.00+0.00	219.00+56.67	193.00+0.00	192.00+0.00	144.0+16.00	130.00+0.00	96.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
20	246.00+42.0	238.00+0.00	330.00+10.33	300.00+0.00	243.00+0.00	160.00+0.00	130.00+0.00	100.0+20.33	0.00+0.00	0.00+0.00	215.00	109.50
21	243.00+0.00	236.00+0.00	223.00+38.00	300.00+0.00	224.00+0.00	146.0+14.00	130.00+0.00	97.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
22	231.00+0.00	226.00+0.00	195.00+41.67	127.00+0.00	178.00+0.00	128.00+0.00	130.00+0.00	88.00+00.00	0.00+0.00	0.00+0.00	215.00	109.50
23	227.00+0.00	223.00+0.00	187.00+29.67	121.00+0.00	174.00+0.00	124.00+0.00	130.00+0.00	85.00+00.33	0.00+0.00	0.00+0.00	000.00	061.00
24	227.00+0.00	223.00+0.00	187.00+31.00	121.00+0.00	173.00+0.00	123.00+0.00	130.00+0.00	0.00+00.000	0.00+0.00	0.00+0.00	000.00	000.00

Table.5.
Optimal output (heat+cooling) for integrated CCHP-thermal-heat only system with considerations for environmental emission and electricity boiler

Hr	Unit output MW			Hr	Unit output MW		
	Heat only	CCHP heat+cooling			Heat only	CCHP heat+cooling	
		1	2			1	2
1	401	0.00+0.00	0.00+0.00	13	179	160+00.00	135+0.00
2	407	0.00+0.00	0.00+0.00	14	177	158+00.00	135+0.00
3	417	0.00+0.00	0.00+0.00	15	172	155+12.00	135+0.00
4	158	138+10.00	135+0.00	16	163	145+00.00	135+0.00
5	160	143+00.00	135+0.00	17	160	143+00.00	135+0.00
6	166	149+00.00	135+0.00	18	166	149+10.00	135+0.00
7	169	151+00.00	135+0.00	19	172	155+10.00	135+0.00
8	172	155+00.00	135+0.00	20	179	160+10.00	135+0.00
9	178	159+00.00	135+0.00	21	176	157+10.00	135+0.00
10	179	160+00.00	135+0.00	22	166	148+10.00	135+0.00
11	181	162+00.00	135+0.00	23	355	0.00+00.00	75+18.33
12	183	165+11.00	135+0.00	24	414	0.00+00.00	0.00+0.00

6. Conclusions and Recommendations

A hybrid GA-heuristic optimization algorithm for solving the UC problem with integrated CCHP-thermal-heat only system with considerations for electricity boiler is developed. It is shown that with considerations for electricity boiler, integrated CCHP-thermal-heat only system can simultaneously reduce environmental emission and total cost, as compared with separated operation of thermal and heat only units. For future works, the application of the heuristic optimization algorithm developed in this study for solving UC problem with integration of CCHP and renewable energy resources is suggested.

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