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Review of Integrated Thermal Energy Storage with Cogeneration System

Jaspal Singh[1], Ms.Maninder[2], Mr. Inderjit Singh[3]
M.Tech Scholar (EE)[1] ,A.P (EE)[2,3]
SBSSTC Ferozepur

ABSTRACT:

The use of Combined Heat and Power (CHP) with an overall effectiveness from 70 to 90% is one of the most effective solutions to minimize the energy utilization. Mainly caused by interdependence of the power as well as heat in these systems, the optimal operation of CHP systems is a composite optimization issue that requires powerful solutions. This paper discourse the optimal day-ahead scheduling of CHP units with Thermal Storage Systems (TSSs). Fundamentally, the optimal scheduling of CHP units problemis a complex optimization problem with innumerable stochastic besides deterministic variables. The initial stage models behavior of operating parameters and to minimizes the operation costs or price meantime the second stage examine the system's Thermal Storage Systems scenarios. The fruitfulness of the proposed algorithm has been examined. This paper illustrates Firefly algorithm (FA) to probe CHPED with Thermal Storage Systems with bounded feasible operating region. The main prospective of this technique is that it proper the fairness between local and global search. A comparative investigation of the FA with (RCGA), (NSGAII), (SPEA2) is introduced.

Key words: Thermal Storage Systems (TSSs), TSS Modelling, Cost Function,CHP Unit Firefly Algorithm (FA).

1. INTRODUCTION

Thermal energy storage (**TES**) is obtained with various different technologies. Depending on the particular technology, it permits extra thermal energy to be stored and used hours, days, or months later, at scales ranging from individual process, building, multiuser-building, district, town, or region. Examples of utilization are the balancing of energy demand between daytime and nighttime, storing summer heat for winter heating, or winter cold for summer air conditioning. Storage media include water or ice-slush tanks, masses of native earth or bedrock executed with heat exchangers by means of boreholes, deep aquifers contained between impermeable strata; shallow, lined pits filled with gravel and water and insulated at the top.

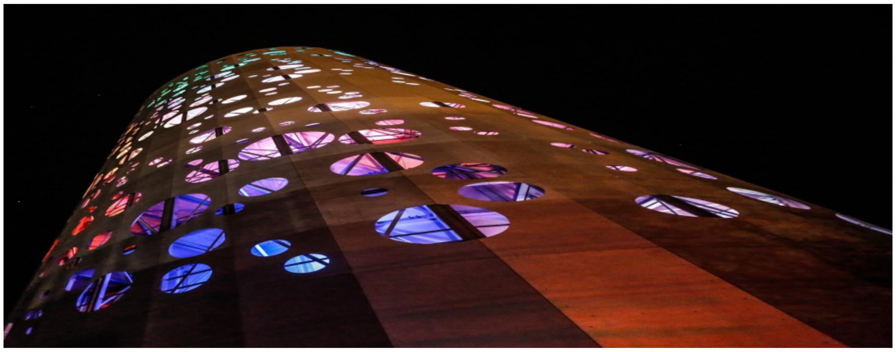

Figure 1.1

A fleeting inspection into the energy storage approach currently available for the integration of oscillating renewable energy was execute [1,2]. These incorporate Pumped Hydroelectric Energy Storage (PHES), „Underground Pumped Hydroelectric Energy Storage (UPHES), Battery Energy Storage (BES), Flow Battery Energy Storage (FBES), Compressed Air Energy Storage (CAES), Flywheel Energy Storage (FES), Thermal Energy Storage (TES), Supercapacitor Energy Storage (SCES), Superconducting Magnetic Energy Storage (SMES), Hydrogen Energy Storage System (HESS) and Electric Vehicles (EVs).It is challenge to achieve reliable and inexpensive electricity in mature energy market. The exhaustion of fossil fuel reserves and advancement in technology development i.e. thermal energy storage and CHP unit is to reduced emission and fuel cost.

The main objectives of the paper are:

1) Combined heat and power economic dispatch with scheduling of thermal storage system using continuous and binary particle swarm optimization.
2) The minimization of fuel cost of thermal, CHP and heat generating units with scheduling of thermal energy storage units to fulfill the load demand and satisfying inequality constraints.
3) The simulation is carried out on test system consisting of CHP, thermal, heat and heat storage units for different load. Optimization technique based on swarm intelligent algorithm is used for optimization the problem and simulation results have been computed in FORTRAN 90.

2. OVERVIEW

Vitality stockpiling advancements are significant parts in most vitality frameworks and could be a vital apparatus in accomplishing a low-carbon future. These advancements take into account the decoupling of vitality free market activity, generally providing a profitable asset to framework administrators. There are numerous situations where vitality stockpiling organization is focused or close aggressive in the present vitality framework. In any case, administrative and economic situations are habitually poorly prepared to remunerate capacity for the suite of administrations that it can give. Moreover, a few innovations are still excessively costly relative, making it impossible to other contending advancements (e.g. adaptable age and new transmission lines in power frameworks). One of the key objectives of this new roadmap is to comprehend and communicate the value of energy storage to energy system stakeholders. This will contain concepts that discourse the current status of deployment and predicted evolution in the context of current and future energy system requires by using a “systems perspective” as compared to looking at storage technologies in isolation.

3. Energy Technology Perspectives 2014 vision for electricity storage

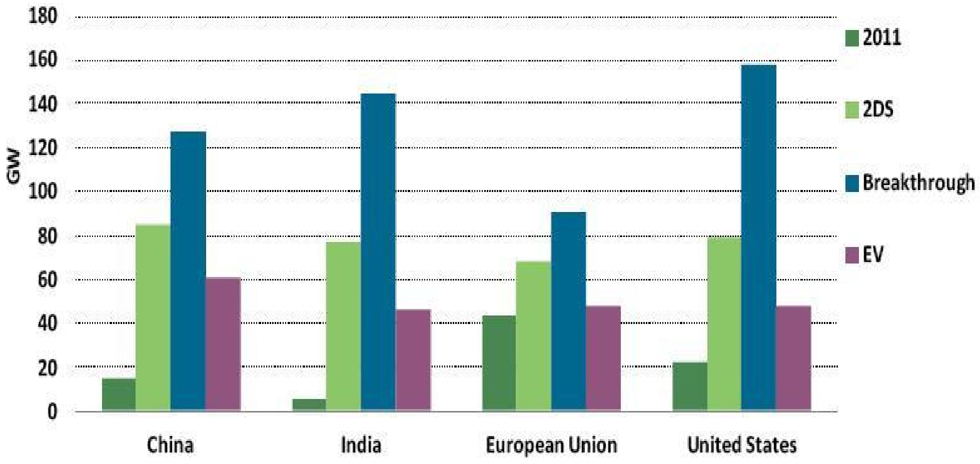

Figure 1.2

Three frameworks for electricity storage deployment The ETP 2DS scenario distributeas a reference case, governing the capacity expansion of power generation technologies at this moment to 2050 to meet low-carbon intentions. The pliability or flexibility of the resulting system is then investigated using a linear dispatch model where the overall price of operating the electrical system is dwindled by determining the dispatch of generation as well as by storage technologies during every hour in a given year. This approach allows a detailed assessment of the storage requirement within the power generation fleet from the 2DS under a span of conditions with other technologies competitive to provide the similar services. Full detail on the modeling and scenario expectation can be found in Annex B. The 2DS assume the cost of advancements providing frequently capacity for arbitrage applications in 2050 will be that of the base cost and cost of the innovation giving this administration these days: PSH. In the 'leap forward' situation, forceful drops in particular vitality (per MWh) likewise control limit (per MW) stockpiling costs encourage a raising sending of capacity.

Figure 7: Electricity storage capacity for daily electricity storage by region in 2011 and 2050 for *ETP 2014* scenarios

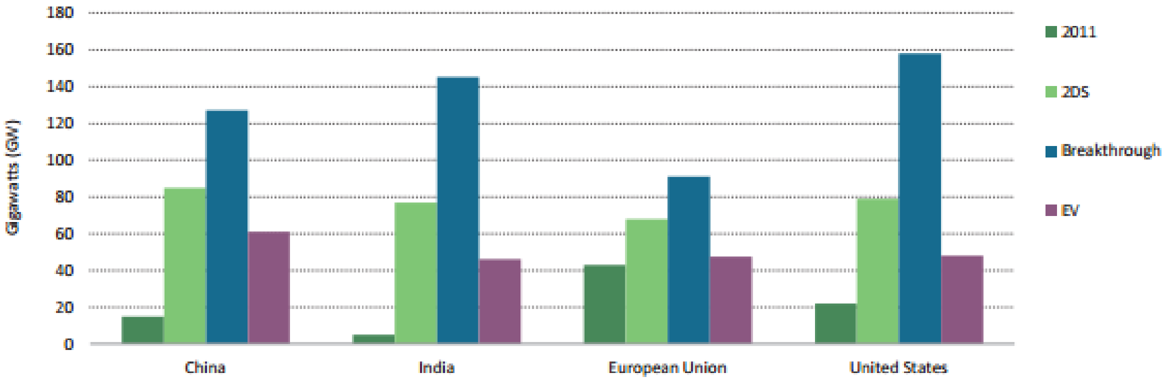

Figure 1.3

4. Thermal storage system (TSS) modeling

Thermal storage system (TSS) modeling and constraints are presented in this section. The constraints of thermal storage system include the limits of thermal storage which is like an ESS constraints.

- Thermal storage limits in each period:

$$H_{storage}(t) = HCAP_{storage} \ \forall\, t \tag{1}$$

Thermal storage maximal discharge limits:

$$HD_{storage}(t) \leq (0.4 \times HCAP_{storage}) \times X(t) \ \forall\, t,\ X \in \{0,1\} \tag{2}$$

Thermal storage maximal charge limits:

$$HC_{storage}(t) \leq (HCAP_{storage}) \times Y(t) \ \forall\, t,\ Y \in \{0,1\} \tag{3}$$

The thermal storage cannot charge and discharge at the same

time in each time slice:

$$X(t) + Y(t) \leq 1 \ \forall\, t,\ Y \ and \ X \in \{0,1\} \tag{4}$$

Thermal storage maximal discharge limits in each period “t’’, considering the battery state storage in period t-1:

$$HD_{storage}(t) - H_{storage}(t-1) \leq 0 \ \forall\, t \tag{5}$$

Thermal storage maximal charge limits in each period ‘‘t’’, considering the battery state storage in period t-1:

$$HC_{storage}(t) - H_{storage}(t-1) \leq HCAP_{storage} \ \forall\, t \tag{6}$$

State balance of the thermal storage:

$$H_{storage}(t) = H_{storage}(t-1) - HD_{storage}(t) + HC_{storage}(t-1) \ \forall\, t \tag{7}$$

Initial state of the thermal storage:

$$HD_{storage}(t=0) \leq (0.4 \times HCAP_{storage}) \ \forall\, t \tag{8}$$

Thermal power balance:

$$HE_{Demand}(t) = H_{g}(t) - HD_{storage}(t) - HC_{storage}(t) \ \forall\, t \tag{9}$$

5. Cost Function

The problem in the proposed case includes conventional power units, conventional heat units and cogeneration units. Convex input-output operational curves for conventional power and heat only units are considered which indicate their cost functions will be convex too. Thus, given problem have combined heat and power units with convex quadratic cost functions. The cost function for each unit individually can be obtained by multiplying input-output curve with fuel cost burned in that unit. Thus, cost function can be represented as the sum of cost functions for all the units separately as given below:

$$C_b(H_b) = \alpha_b + \beta_b H_b + \gamma_b H_b^2 \qquad (13)$$

$$C_e(P_e) = \alpha_e + \beta_e P_e + \gamma_e P_e^2 \qquad (14)$$

$$C_{chp}(P_{chp}, H_{chp}) = \alpha_{chp} + \beta_{chp} P_{chp} + \lambda_{chp} P_{chp}^2 + \delta_{chp} H_{chp} + \psi_{chp} H_{chp}^2 + \xi_{chp} P_{chp} H_{chp} \qquad (15)$$

$$F(X) = \sum_{e=1}^{E} C_e(P_e) + \sum_{chp=1}^{CHP} C_{chp}(P_{chp}, H_{chp}) + \sum_{b=1}^{B} C_b(H_b) \qquad (16)$$

where,

e, b, chp are the indices of power only units, heat only units and combined heat and power units respectively and E, B, CHP are the number of conventional power units, conventional heat units and combined heat and power units.

6. COMBINED HEAT AND POWER UNIT

CHP unit is an emerging technology and used in an effective manner for an economic operation. The generation of heat and power from running CHP plants based on gas turbine and the steam turbine are following the feasible region of operation (FOR). The interdependence of power and heat is illustrated in Fig. 1.The feasible limits of the heat and power generation from CHP plants are given as:

$$\underline{G_j}(H_j)U_{t,j} \le G_{t,j} \le \overline{G_j}(H_j)U_{t,j} \qquad t\forall T, j\forall Nc \qquad (17)$$

$$\underline{H_j}(G_j)U_{t,j} \le H_{t,j} \le \overline{H_j}(G_j)U_{t,j} \qquad t\forall T, j\forall Nc \qquad (18)$$

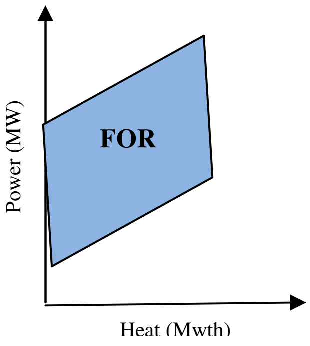

Figure 1: Feasible operating region for generation of heat and power.

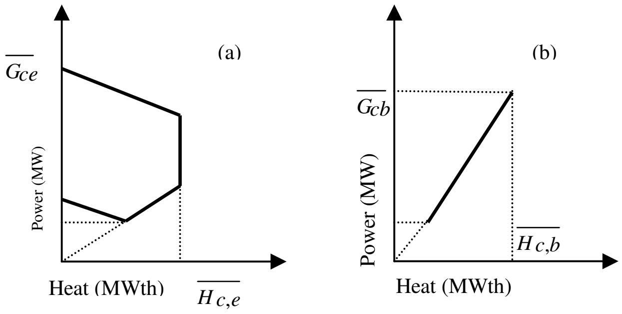

Figure 2: The operating mode of CHP unit(a) Extraction mode and (b) Back-pressure mode.

The modelling of dual-mode CHP plant is according to backpressure and extraction mode. The graphical representation of power and heat (GH)-charts [4] for dual-mode CHP units is illustrated in Fig. 2. The maximum power generated by the extraction mode is typically two to three times the power generated by the backpressure mode, whereas the maximum heat generation is greater as compared to extraction mode and it is illustrated in Fig. 2(a) and 2(b). This CHP plant has reached to the maximum generation output in less than 30 minutes. Moreover, large scale combined-cycle units are world leading with regard to lower capital costs, high efficiencies, and short start-up times. The mathematical formulation of back-pressure and extraction mode is given below:

A. Back-pressure mode: The generation of G_j and H_j during back-pressure mode is characterized by a fixed ratio of G_j and H_j, which is expressed as:

$$G_{t,j} = R_j^b H_{t,j} \qquad t\forall T, j\forall Nc \qquad (19)$$

The heat and power generation is restricted by minimum and extreme limit, which is followed as:

$$\underline{G_j^b} = R_j^b \underline{H_j^b} \qquad t\forall T, j\forall Nc \qquad (20)$$

$$\overline{G_j^b} = R_j^b \overline{H_j^b} \qquad t\forall T, j\forall Nc \qquad (21)$$

The fuel consumption of CHP unit is a linear function of the heat and power output and it is expressed as:

$$F(G_{t,j}H_{t,j}U_{t,j}) = \psi_j^q H_{t,j}U_{t,j} + \psi_j^p G_{t,j}U_{t,j} \quad t\forall T, j\forall Nc \qquad (22)$$

The fuel consumption from the CHP unit is follow Eq. 6 and limit on fuel consumption is given as:

$$\underline{F_j^b} U_{t,j} \le F_{t,j} \le \overline{F_j^b} U_{t,j} \qquad t\forall T, j\forall Nc \qquad (23)$$

The fuel consumption of CHP unit must satisfy the ramping up and down limit at each subinterval, which is expressed as:

$$RFD_j \le F_{t,j} - F_{(t-1),j} \le RFU_j \qquad t\forall T,\ j\forall Nc \qquad (24)$$

***B.* Extraction mode:** This operating mode of cogeneration unit provides more flexibility than back-pressure mode by relaxing the back-pressure constraints and the ratio of G_j and H_j is discussed as:

$$G_{t,j} \ge R^{e}_{j} H_{t,j} \qquad t\forall T,\ j\forall Nc \qquad (25)$$

Flexibility is increased due to variable ratio of G_j and H_j. Hence, it is useful for power sector to modify H_j and G_j output to meet the demand.

$$\underline{G}^{e}_{j} = R^{b}_{j} \underline{H}^{e}_{j} \qquad t\forall T,\ j\forall Nc \qquad (26)$$

$$\overline{G}^{e}_{j} = R^{b}_{j} \overline{H}^{e}_{j} \qquad t\forall T,\ j\forall Nc \qquad (27)$$

$$\underline{F}^{e}_{j} U_{t,j} \le F_{t,j} \le \overline{F}^{e}_{j} U_{t,j} \qquad t\forall T,\ j\forall Nc \qquad (28)$$

In this paper, this dual-mode CHP unit is investigated in the combined system. CHP unit operating in the extraction and backpressure mode is given a valuable solution at a time when the penetration level of heat demand of the system is higher or lower, regarding of current conditions. Moreover, the benefit of this model is to take care of the fuel consumption limit of the CHP unit. This realistic model is helpful for utility planner to known well qualified decisions before participating in the market. The CHP model, enabling short start up regarding the generation output is leading to more flexibility in production planning. The main idea of this paper is to obtain energy generation from the CHP units in such a way that GENCO's profit is maximized for the schedule horizon while satisfying all constraints.

7. FIREFLY ALGORITHM

Firefly algorithm has been effectively carryout to explain distinctive power frameworks difficulties. Economic dispatch issue has been settled utilizing firefly calculation and its answer gives predominant outcome then other optimization calculation. In, firefly algorithm has been utilized in recurrence control in combined cycle gas turbine control plant for improvement of controller picks up. FA is one of the ongoing swarm intelligence techniques created by Yang [3,2] in 2008 and is a sort of stochastic, nature-propelled, meta-heuristiccalculation that can be connected for taking care of the hardest optimization issues (additionally NPdifficult issues). This algorithm has a place with stochastic calculations. This implies it utilizes a kind a sort of randomization via looking for an arrangement of arrangements. It is motivated by the flashing lights of fireflies in nature. Heuristic signifies 'to find' or 'to find arrangements by experimentation'.

FireflyAlgorithm

Objective functionf(x),x=(x1. . .xd)

```
Initializeapopulationoffirefliesxi (i=1,2 . . .n)
Definelightabsorptioncoefficient
While(t<MaxGeneration)
    fori=1:nallnfireflies
        Forj=1:iallnfireflies
            LightintensityIiatxiisdeterminedbyf(xi)
            If(Ij>Ii)
                Movefireflyitowardsjinallddimensions
            Endif
            Attractiveness varieswithdistancerviaexp [-$\gamma r^2$]
            Evaluatenewsolutionsandupdatelightintensity
        Endforj
    Endfori
    Rankthefirefliesandfindthecurrentbest
Endwhile
Postprocessresultsandvisualization
```

8. RESULTS

The results are obtained by implemented the algorithm by using FORTRAN-90 on personal computer (1.66 GHz, Pentium-IV, with 512 MB RAM PC). The algorithms are operated for 100 individuals and 200 iterations for setting of HFA control parameters. In this paper, best, worst and mean results of applying algorithms for different trial along with their computation time are presented. The presented method applied to the different test system to show the effectiveness of the proposed method. After many trails of proposed method parameter set.

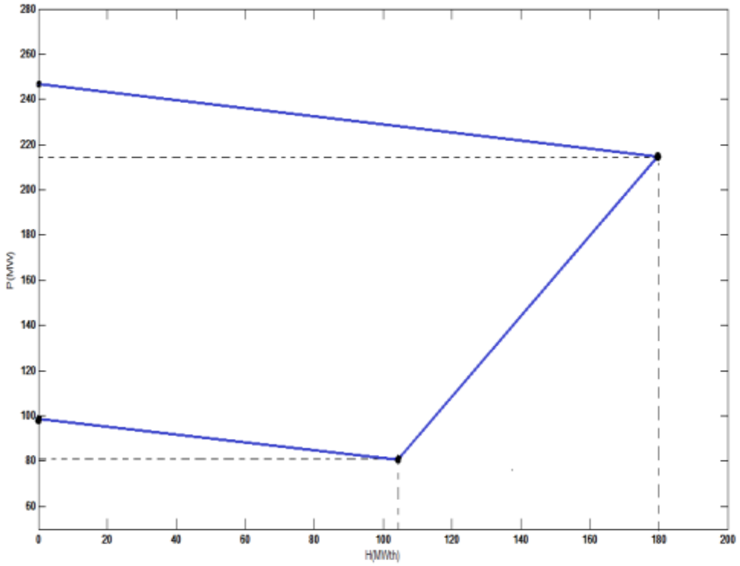

Fig 2: Feasible operating region of units (5 of test system 1), (14 and 16 of test system 2) and (28, 30, 34 and 36 of test system 3)

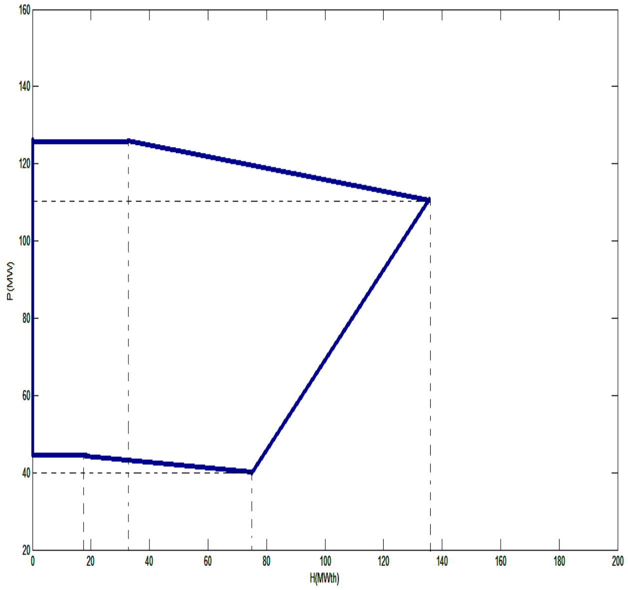

Fig 3: Feasible operating region of units (6 of test system 1), (15 and 17 of test system 2) and (27, 29, 33 and 35 of test system 3)

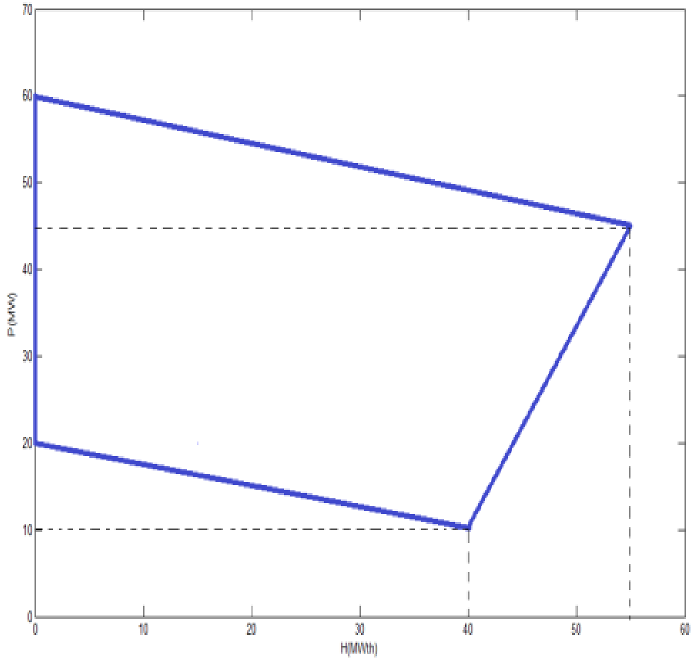

Fig 4: Feasible operating region of units (18 of test system 2) and (31 and 37 of test system 3)

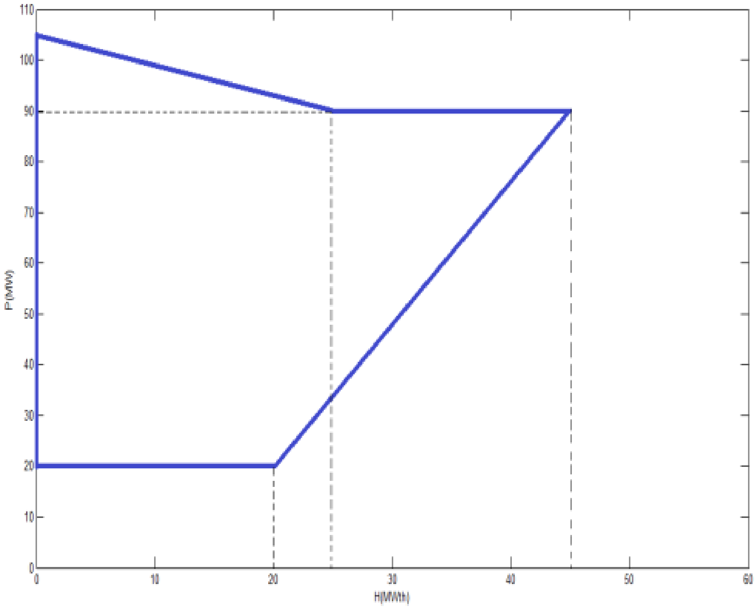

Fig 5: Feasible operating region of units (19 of test system 2) and (32 and 38 of test system 3)

Parameter settings

Initialization is good in FA than pso. Hcso is better Many trails or run of program on different value of population and society. Also changing the value of acceration coefficient (C1, C2 , C3, C4, C5). By varying the value of society or increasing beyond range result in diteration of result. For proper exploration and explotation (ns) value setting is important. No of iteration is set. Interia weight is set .9 - .4. In this proposed algorithm based on HFA is carried out to solve CHPED. To find the stable and optimal solution, program is run for different value of C_1 , $C_{2,}$ $C_{3,}$ C_4, w^{max}, w^{min}, ITmax and C factor The control parameter of FA and HFA are decided by number of trails performed to set different values to achieve optimum solution. For different value of swarm size , society, acceleration coefficients best result obtained from the parameter given below(table 1). after 30 trails For the complex problem like CHP including the transmission losses and complex equality and inequality constraints with changes the swarm size above or below 60 result in worst solution. Trails on different the acceleration coefficients optimum solution set as parameter(table 1). For HFA search factor() and constriction factor are decided.

Table 1

Parameter setting of FA and HFA algorithms

Parameter	FA	HFA
Swarm size(M)	60	60
Number of society (N_s)	5	5
Inertia weight	$W_{max} = 0.9$, $w_{min} = 0.4$	$W_{max} = 0.9$, $w_{min} = 0.4$
Acceleration coefficients	$C_L = 2$, $C_{SL1} = 0.5$, $C_{SL2} = .5$, $C_{SM1} = 0.25$, $C_{SM2} = 0.75$,	$C_L = 2$, $C_{SL1} = 0.5$, $C_{SL2} = .5$, $C_{SM1} = 0.25$, $C_{SM2} = 0.75$
Acceleration coefficients for HCSO		$C_{SL1} = 2.05$, $C_{SL2} = 2.05$, $C_{SM1} = 2.05$, $C_{SM2} = 2.05$

Test system 1:

The test system consists of 7 units in which four are power generation units, two units are cogeneration units and one is heat unit. For two cogeneration units the feasible operating region is shown in Fig (----).The feasible operating reason equations for test systems 1 of cogeneration units are as follows:

Test system 1:

$1.781914894 \text{ x } h_5 - p_5 - 105.7446809 \leq 0$

$0.1777777784 \text{ x } h_5 + p_5 - 247.0 \leq 0$

$- 0.169847328 \text{ x } h_5 - p_5 + 98.8 \leq 0$

$1.158415842 \times h_6 - p_6 - 46.88118818 \leq 0$

$0.151162791 \times h_6 + p_6 – 130.6976744 \leq 0$

$-0.067681895 \times h_6 - p_6 + 45.07614213 \leq 0$

The parameters of test system 1 is shown in Table 1 which include the limits of power generation of conventional unit, heat and active power of cogeneration unit and heat production of heat unit and also shows the power and heat coefficient of conventional, cogeneration and heat units. The total demand of heat and power are 150MWth and 600MW respectively.Table 2. shows the result obtained by applying he proposed HCSO algorithm and their comparisons with PSO[], EP[], DE[], RCGE[], BCO[], CPSO[], TVAC-PSO[], TLBO[], OTLBO[] and FA[]. It is observed from Table 3. that the cost obtained by applying the proposed method HFA is much less than as compared to previously proposed best result of PSO(), EP(), DE(), RCGE(), BCO(), CPSO(), TVAC-PSO(), TLBO() and OTLBO().

9. CONCLUSIONS

This paper proposes a new technique HCSO for solving CHPED problems. All the complications present in CHPED problems can be handled effectively by HCSO. The results clearly illustrate its effectiveness. Proposed technique HCSO is not only cost efficient but also it gives better results in terms of best fuel cost, computational time and power loss. A new hybrid civilized swarm optimization approach is developed by embedding constriction based particle swarm with society-civilization algorithm to solve complex combined heat and power economic dispatch. A set of CHPED problems are solved by CSO and HCSO algorithms. The PSO algorithms show poor performance, whereas the CSO is very effective in giving quality solutions consistently for CHPED problems with less computational time. The HCSO outperforms the previous approaches and has the following merits: efficient searching ability in the multi-minima environment; superior robustness than the previousmethods; lesscomputational effort; comparable performance with mathematical programming approach and applicability to large-scale systems. .Numerical results from the two test systems and comparative analysis with previous approaches indicate the following advantages of CSO and HCSO. Perfect balance between global and local search.Ability to produce highly optimal cost in more robust manner with less computational time than the previous approaches.A meta-heuristic algorithm i.e. firefly algorithm is used for solving the CHPED has been proposed. Complication of the CHPED problem is constraint handling process due to the mutual dependencies of heat and power and multi-demand system. The proposed method in this work efficiently search and exploit the optimal solutions in the suggested economic dispatch problem. Also, the FA effectively handles the feasible region constraints. The algorithm integrates has the merits of global search and local search. Euclidean distance based penalty factor is added to the objective function value for the purpose of well satisfaction and handling of constraints regarding feasible operating region. Numerical results indicate that the proposed algorithm is more advantageous and effective for solving the CHPED with thermal energy storage system problem than all other previous techniques especially in case of the application to large-scale systems.

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