Ant Colony Search Algorithm For Solving Multi Area Unit Commitment Problem With Import And Export Constraints

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Abstract

This paper presents a new approach to solve the multi area unit commitment problem (MAUCP) using a Ant Colony Search Algorithm (ACSA). The objective of this paper is to determine the optimal or a near optimal commitment schedule for generating units located in multiple areas that are interconnected via tie lines. The Ant Colony Search Algorithm is used to solve multi area unit commitment problem, allocated generation for each area and find the operating cost of generation for each hour. Joint operation of generation resources can result in significant operational cost savings. Power transfer between the areas through the tie lines depends upon the operating cost of generation at each hour and tie line transfer limits. The tie line transfer limits were considered as a set of constraints during optimization process to ensure the system security and reliability. The overall algorithm can be implemented on an IBM PC, which can process a fairly large system in a reasonable period of time. Case study of four areas with different load pattern, each containing 26 units connected via tie lines has been taken for analysis. Numerical results showed comparing the operating cost using Ant Colony Search method with conventional evolutionary programming (EP) and dynamic programming (DP) method. Experimental results shows that the application of this Ant Colony Search method have the potential to solve multi area unit commitment problem with lesser computation time.

Keywords

Ant Colony Search Algorithm (ACSA), Dynamic Programming (DP), Evolutionary Programming (EP), Multi Area Unit Commitment Problem (MAUCP).

Nomenclature

$F(P_{g_i}^k)$	Production cost of unit i in area K
$P_{g_i}^k$	Power generation of unit i in area K
a_i^k, b_i^k, c_i^k	Cost function parameters of unit i in area K
$X_{i,j}^{off}$	Time duration for which unit i have been off at jth hour.
$P_{i,j}^k$	Power generation of unit i in area K at jth hour
$I_{i,j}^k$	Commitment state (1 for ON, 0 for OFF)
$Pg_{i,j}^k$	Power generation of unit i in area K at jth hour
D_j^k	Total system demand of area K at jth hour
R_j^k	Spinning reserve of area K at jth hour
E_j^k	Total export power to area K at jth hour
$Pj_{\max}^k$	Maximum power generation in area K at jth hour
$Pj_{\min}^k$	Minimum power generation in area K at jth hour
T_i^{on}	Minimum up time of unit i
T_i^{off}	Minimum down time of unit i
$Lj_{\max}^k$	Maximum total import power in area K at jth hour
W_j	Net power exchange with outside system
λ_{sys}	Marginal cost of supplying the last incremental energy to meet entire system demand.
$Pg_{i\max}^k$	Maximum power generation at area K at ith hour
$Pg_{i\min}^k$	Minimum power generation at area k at ith hour

1. **Introduction**

In multi area, several generation areas are interconnected by tie lines, the objective is to achieve the most economic generation to meet out the local demand without violating tie-line capacity limits constraints [1]. The main goal of this paper is to develop a multi area generation scheduling scheme that can provide proper unit commitment in each area and effectively preserve the tie line constraints.

In an interconnected multi area system, joint operation of generation resources can result in significant operational cost savings [2]. It is possible by transmitting power from a utility, which had cheaper sources of generation to another utility having costlier generation sources. The total reduction in system cost shared by the participating utilities [3].

The exchange of energy between two utilities having significant difference in their marginal operating costs. The utility with the higher operating cost receives power from the utility with low operating cost. This arrangement usually on an hour to hour basis and is conducted by the two system operators.

In the competitive environment, customer request for high service reliability and lower electricity prices. Thus, it is an important to maximize own profit with high reliability and minimize overall operating cost [4].

Multi Area unit commitment was studied by dynamic programming and was optimised with local demands with a simple priority list scheme on a personal computer with a reasonable execution time [5]. Even though the simplicity and execution speed are well suited for the iterative process, the commitment schedule may be far from the optimal, especially when massive unit on/off transitions are encountered. The tie-line constraint checking also ignores the network topology, resulting in failure to provide a feasible generation schedule solution [5]. The transportation model could not be used effectively in tie line constraints, as the quadratic fuel cost function and exponential form of start up cost were used in this study.

An Evolutionary algorithm is used for obtaining the initial solution which is fast and reliable [6]. Evolutionary Programming (EP) is capable of determining the global or near global solution [7]. It is based on the basic genetic operation of human chromosomes. It operates with the stochastic mechanics, which combine offspring creation based on the performance of current trial solutions and competition and selection based on the successive generations, from a considerably robust scheme for large scale real valued combinational optimization. In this work, the parents are obtained from a predefined set of solution (i.e., each and every solution is adjusted to meet the requirements). In addition, the selection process is done using evolutionary strategy [8]-[10].

For the last few years, the algorithms inspired by the observation of natural phenomena to help solving complex combinatorial problems have been increasing interest. In this study, a new Ant Colony Search Algorithm (ACSA), which was derived by the observation of the behaviors of ant colonies, is proposed [11]. In analyzing the behaviors of real ants, it was found that the ants are capable of finding shortest path from food sources to the nest without using visual cues. In the application of this method to UC problem, the initial population of colony can be first randomly generated within the search space of problem. Then, the fitness of ants is individually assessed based on their corresponding objective function. With the selection of trial, the ant dispatch can be activated based on the level of pheromone and the distance of selected trial in order to find the best tour or the shortest path.

2. Problem Formulation

The cost curve of each thermal unit is in quadratic form [1]

$$F({Pg_i}^k) = a_i^k ({Pg_i}^k)^2 + b_i^k ({Pg_i}^k) + c_i^k \text{ Rs/hr} \qquad (1)$$

k = 1 … N_A

The incremental production cost is therefore

$$\lambda = 2a_i^k {Pg_i}^k + b_i^k \qquad (2)$$

(or)

$${Pg_i}^k = \lambda - b_i^k / 2a_i^k \qquad (3)$$

The startup cost of each thermal unit is an exponential function of the time that the unit has been off

$$S(X_{i,j}^{off}) = A_i + B_i(1 - e^{x_{i,j}^{\frac{off}{\tau_i}}}) \qquad (4)$$

The objective function for the multi-area unit commitment is to minimize the entire power pool generation cost as follows [1].

$$\min_{I,P} \sum_{k=1}^{N_A} \sum_{j=1}^{t} \sum_{i=1}^{N_k} \left[\begin{array}{l} I_{i,j}^k F_j^k (P_{i,j}^k + \\ I_{i,j}(1-I_{i,j-1}) S_i (X_{i,j-1}^{off})) \end{array} \right] \tag{5}$$

To decompose the problem in above equation (5), it is rewritten as

$$\min \sum_{j=1}^{t} \left[F(P_{g_{i,j}}) \right] \tag{6}$$

$$F\left(P_{g_{i,j}}\right) = \sum_{k=1}^{N_A} F^k\left(P_{g_{i,j}}^k\right) \tag{7}$$

Subject to the constraints of equations (9), (11) and (14–18). Each $F^k\left(P_{g_{i,j}}^k\right)$ for K=1 ……NA is represented in the form of schedule table, which is the solution of mixed variable optimization problem

$$\min_{I,P} \sum_i \left[I_{i,j}^k F_i^k \left(P_{i,j}^k\right) + I_{i,j}\left(1 - I_{i,j-1}\right)\left(S_i\left(X_{i,j}^{off}\right)\right)\right] \tag{8}$$

Subject to following constraints are met for optimization.

1) System power balance constraint

$$\sum_k P_{g_j}^k = \sum_k D_j^k \tag{9}$$

Sum of real power generated by each thermal unit must be sufficient enough to meet the sum of total demand of each area while neglecting transmission losses.

2) Spinning reserve constraint in each area

$$\sum_i P_{g_{i,j\max}}^k \geq D_j^k + R_j^k + E_j^k - L_j^k \tag{10}$$

3) Generation limits of each unit

$$P_{j_{\max}}^k \leq P_{i,j}^k \leq P_{j_{\min}}^k \tag{11}$$

i=1…..N$_k$, j=1….t, k=1…N$_A$

4) Thermal units generally have minimum up time T$_{on}$ and down time T$_{off}$ constraints, therefore

$$\left(X_{i,j-1}^{on} - T_i^{on}\right) * \left(I_{i,j-1} - I_{i,j}\right) \geq 0 \tag{12}$$

$$\left(X_{i,j-1}^{off} - T_i^{off}\right) * \left(I_{i,j} - I_{i,j-1}\right) \geq 0 \tag{13}$$

5) In each area, power generation limits caused by tie line constraints are as follows

Upper limits

$$\sum_i P_{g_{i,j}}^k \leq D_j^k + E_{j_{\max}}^k \tag{14}$$

Lower limits

$$\sum_i P_{g_{i,j}}^k \geq D_j^k - L_{j_{\max}}^k \tag{15}$$

Import/Export balance

$$\sum_i E_j^k - \sum_k L_j^k + W_j = 0 \tag{16}$$

6) Area generation limits

$$\sum_i P_{g_{i,j}}^k \leq \sum_i P_{g_{i\max}}^k - R_j^k \text{ ; k=1…. N}_A \quad \text{j=1…….t} \tag{17}$$

$$\sum_i P_{g_{i,j}}^k \geq \sum_i P_{g_i \min}^k \text{ ; k=1…. N}_A \quad \text{j=1…….t} \tag{18}$$

The objective is to select λ_{sys} at every hour to minimize the operation cost.

$$P_{g_j}^k = D_j^k + E_j^k - L_j^k \tag{19}$$

where
$$P_{g_j}^k = \sum_{i=1}^{N_k} P_{g_{i,j}}^k \tag{20}$$

Since the local demand D_j^k is determined in accordance with the economic dispatch within the pool, changes of $P_{g_j}^k$ will cause the spinning reserve constraints of equations (10) to change accordingly and redefine equation (8). Units may operate in one of the following modes when commitment schedule and unit generation limits are encountered [16].

a) Coordinate mode : The output of unit i is determined by the system incremental cost

$$\lambda_{\min,i} \le \lambda_{sys} \le \lambda_{\max,i} \qquad (21)$$

b) Minimum mode : Unit i generation is at its minimum level

$$\lambda_{\min,i} \rangle \lambda_{sys} \qquad (22)$$

c) Maximum mode : unit i generation is at its maximum level

$$\lambda_{\max,i} \langle \lambda_{sys} \qquad (23)$$

d) Shut down mode : unit i is not in operation, $P_i = 0$

Besides limitations on individual unit generations, in a multi- area system, the tie-line constraints in equations (12), (13) and (15) are to be preserved. The operation of each area could be generalized into one of the modes as follows.

(i) Area coordinate mode

$$\lambda^k = \lambda_{sys}$$

$$D_j^k - L_{\max}^k \le \sum_i P_{g_{i,j}}^k \le D_j^k + E_{\max}^k \qquad (24)$$

(or)

$$-L_{\max}^k \le \sum_i P_{g_{i,j}}^k - D_j^k \le E_{\max}^k \qquad (25)$$

(ii) Limited export mode

When the generating cost in one area is lower than the cost in the remaining areas of the system, that area may generate its upper limits according to equations (14) or (17) therefore

$$\lambda^k \langle \lambda_{sys} \qquad (26)$$

For area k, area λ^k is the optimal equal incremental cost which satisfies the generation requirement.

(iii) Limited import mode

An area may reach its lower generation limit according to equation (15) or (18) in this case because of higher generation cost

$$\lambda_{\min}^k \rangle \lambda_{sys} \qquad (27)$$

3. Tie Line Constraints

To illustrate the tie-line flow in a multi-area system, the four area system given in Fig.1 is studied.

An economically efficient area may generate more power than the local demand, and the excessive power will be exported to other areas through the tie-lines [1]. For example assume area 1 has the excessive power the tie line flows would have directions from area1 to other areas, and the maximum power generation for area1 would be the local demand in area1 plus the sum of all the tie-line capacities connected to area1.

If we fix the area 1 generation to its maximum level than the maximum power generation in area 2 could be calculated in a similar way to area 1. Since tie line C_{12} imports power at its maximum capacity, this amount should be subtracted from the generation limit of area 2. According to power balance equation (9) some areas must have a power generation deficiency and requires generation imports. The minimum generation limits in these areas is the local demand minus all the connected tie-line capacities. If any of these tie-lines is connected to an area with higher deficiencies, then the power flow directions should be reserved.

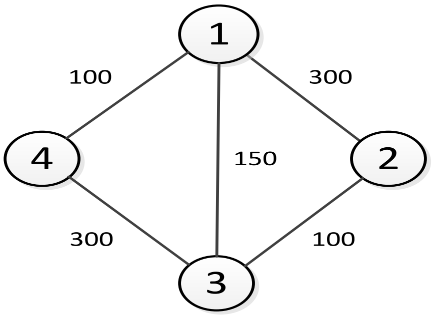
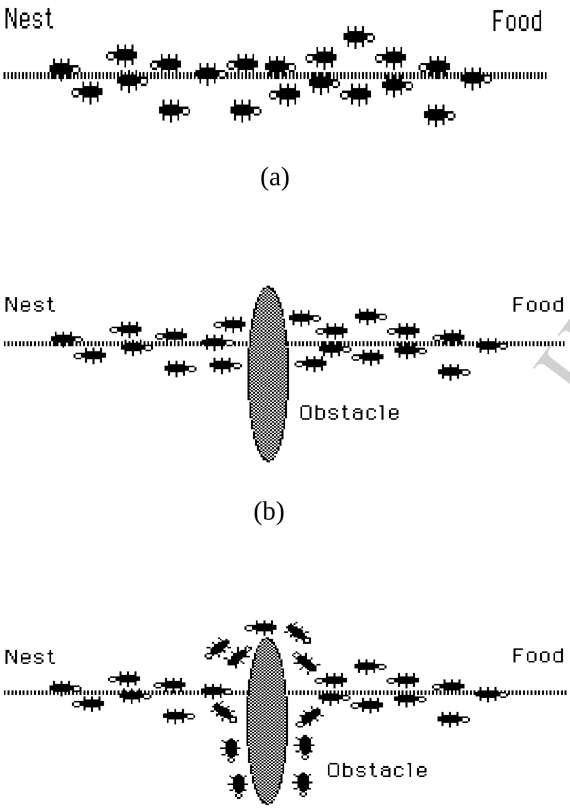


Figure 1. Multi-area connection and tie-line limitations

4. ACSA Paradigm

4.1. Behavior of Ants

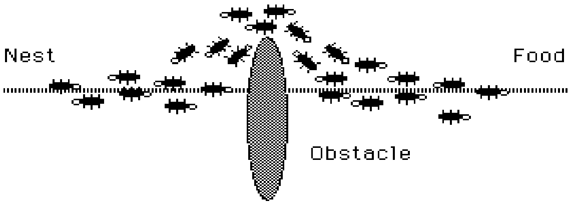
Ant colony search (ACS) studies are inspired from the behavior of ants colonies that are used to solve function or combinatorial optimization problems. Currently, most work has been done in the direction of applying ACS to combinatorial optimization. The first ACS system was introduced by Marco Dorigo [12] and was called "ant system". Ant colony search algorithm, to some extent; mimic the behavior of real ants. As is well known, real ants are capable of finding the shortest path from food sources to the nest without using visual cues. They are also capable of adapting to changes in the environment. Pheromone trails, which ants use to communicate information among individuals regarding path and to decide where to go. Ants deposit a certain amount of pheromone while walking, and each ant probabilistically prefers to follow a direction rich in pheromone rather than a poorer one. The behavior of ant is given in fig. 2.



(a)

(b)

(c)



(d)

Figure 2: Behavior of ants : (a) Real ants follows a path between nest and food source. (b) An obstacle appears on the path: ants choose whether to turn left or right with equal probability. (c) Pheromone is deposited more quickly on the shorter path. (d) All ants have chosen the shorter path.

4.2 Ant colony search Algorithm

4.2.1. ACS State Transition Rule

In ACS the state transition rule is as follows: An ant positioned on node chooses the city S to move by applying the given rule, if q ≤ qo

Where

q is a random number uniformly distributed in (0…..1)

q_0 is a parameter (0≤qo≤1)

S is random variable selected according to the probability distribution given in (28)

The state transition rule used by ant system, called a random – proportional rule, is given by Eq(8), which gives the probability with which ant k in city r chooses to move to the city s.

$$p_k(r,s)=\begin{cases}\dfrac{[\tau(r,s)].[\eta(r,s)]^{\beta}}{\sum_{u\varepsilon J_k(r)}[\tau(r,u)].[\eta(r,u)]^{\beta}}(r) & \text{if} s\varepsilon J_k(\text{ r}) \\ 0 \quad \text{otherwise} & \end{cases} \qquad (28)$$

Where

τ – is the pheromone

$J_k(r)$ – is the set of cities that remain to be visited by ant k positioned on city r (to make the solution feasible)

β – is a parameter, which determines the relative importance of pheromone versus distance (β>o)

η – 1/δ is the inverse of the distance δ(r,s)

4.2.2.ACS Global Updating Rule

Global updating is performed after all ants have completed their tours. The pheromone level is updated by applying the global updating rule of equation (29).

$$\tau(r,s) \leftarrow (1-\alpha)\tau(r,s) + \alpha\, \Delta\tau(r,s) \qquad (29)$$

where

$$\Delta\tau(r,s) = \begin{cases} (L_{gb})^{-1} & \text{if}(r,s)\varepsilon \text{ global-best-tour} \\ 0 \quad \text{otherwise} & \end{cases}$$

α – is the pheromone decay parameter
Lgb – is the length of the globally best tour from the beginning of trial

4.2.3. ACS Local Updating Rule

While building a solution of the MAUCP, ants visit edges and change their pheromone level by applying the local updating rule of equation (30)

$$\tau(r,s) \leftarrow (1-\rho)\tau(r,s) + \rho\ \Delta\tau\,(r,s) \qquad (30)$$

where
ρ – is a heuristically defined coefficient
τo - is the initial pheromone level

4.2.4. ACS Parameter Setting

In this program of the following sections the numeric parameters, except when indicated differently, are set to the following values: β=2, qo= 0.9, α=ρ=0.1.

4.3. Ant Colony Search General Algorithm

To solve MAUCP by ACSA, the search space of generation scheduling problem is established using multi-process decision making concept. The main computations are discussed below.

Step 1 : Ant Generation

In the first step, the colonies of ants are first generated. Ants are positioned on initial state while the initial pheromone value of τ_0 is also given at this step. Based on the concept multi state process, the search space of thermal generation scheduling problem can be established. All the possible permutations constitute this search space. Each stage contains several states, while the order of state selected at each stage can be combined as an achievable tour that is deemed a feasible solution to the problem.

Step 2 : Assessment of Fitness

In this step, the fitness of all ants is assessed based on the corresponding objective function, which can be expressed as following:

$$f(\mu) = \sum tc\left(s_{\mu(i)}, s_{\mu(i+1)}\right) \qquad (31)$$

Where
$tc(s_i,s_j)$ is the transition cost between state s_i and s_j
μ(i) for i=1….n defines a permutation
With the evaluated fitness of the corresponding ants, the pheromone can be added to the particular direction in which the ants have selected.

Step 3: Ant Dispatch

In this step, the ants are dispatched based on the level of pheromone and distance. Each ant chooses the next state to move taking into account of τ_{ij} and η_{ij} values. When the value of τ_{ij} gets larger, there has been a lot of traffic on this edge; hence it is more desirable to reach the optimal solution. When the value of η_{ij} increases, it represents that the closer state should be chosen with a higher probability.

Step 4: Convergence

The computation process continues until the number of iterations reaches the predefined maximum threshold, of the iteration counter without improving the best objective function reaches the maximum allowable value. All the tour visited by ants in each iteration should be evaluated. If a better path found in the process, it will be saved for later reference. The best path selected among all iterations implies the optimal scheduling solution to the problem.

Algorithm for ACSA for SCUC

Step 1 : Ant generation
Step 2 : Assessment of fitness
Step 3 : Ant dispatch
Step 4 : Update pheromone by applying local updating rule

Step 5 : Check for all ants are completed their tours.
If No go to step 3
Step 6 : Apply Global pheromone update rule

Step 7 : Check for convergence. If No go to step 2

5. Ant colony search algorithm for MAUCP

ACSA is conducted to solve MAUCP by following sequence of operations.

1. Initialize area A=1.
2. Read unit data, tie-line data, load demand profile and number of iterations to be carried out.
3. Find initial feasible solution.
4. Colonies of ants are generated and ants are positioned with initial phermone value of τ_0.
5. Calculate the fuel cost and start up cost of each power plant at each ant position.
6. Calculate total production cost.
7. Calculate the fitness function of all ants.
8. Update ant position based on τ_{ij} and η_{ij} values.
9. Update phermone by applying local updating rule.
10. Check for all ants completed their tour. IF No go to step 8. Otherwise go to next step.
11. Apply global phermone update rule.
12. Check for N number of areas completed. If yes go to step 2, else go to step 14.
13. Export power from lower operating cost areas to higher operating cost area by following tie-line constraints.
14. Print the commitment schedule of N areas and tie- line flows

5.1. Repair mechanism

A repair mechanism to restore the feasibility of the constraints is applied and described as follows

- Pick at random one of the OFF units at one of the violated hours.
- Apply the rules in section 4.2 to switch the selected units from OFF to ON keeping the feasibility of the down time constraints.
- Check for the reserve constraints at this hour. Otherwise repeat the process at the same hour for another unit.

5.2. Making Offspring Feasible

While solving the constrained optimization problem, there are various techniques to repair an infeasible solution [8] [11]. In this paper, we have chosen the technique, which evolves only the feasible solutions. That is, the schedule which satisfies the set of constraints as mentioned earlier. Here, in this paper, the selection routine is involved as “curling force” to estimate the feasible schedules. Before the best solution is selected by evolutionary strategy, the trial is made to correct the unwanted mutations.

5.3. Implementation

Software program were developed using MATLAB software package, and the test problem was simulated for ten independent trials using Ant Colony Search Algorithm (ACSA). The training and identification part as implemented in the ACSA technique is employed here and considered as a process involving random recommitment, constraint verification, and offspring creation.

6. Numerical Results

The test system consists of four areas, and each area has 26 thermal generating units [1]. Units have quadratic cost functions, and exponential start up cost functions. Table 1 lists generating unit characteristics like the minimum up/down times, initial conditions and generation limits of units in every area. Table 2 to Table 5 lists the cost functions of units given in the four area [1], where variables a_i, b_i and c_i are defined in equation 1. A_i, B_i and C_i are defined in equation 4. Load demand profile for each area is different and is given in Fig. 3. The hourly operating cost of four areas by Dynamic Programming (DP), Evolutionary Programming (EP) and Ant Colony Search Algorithm (ACSA) method is given in Table 6 to Table 8 respectively. The total operating cost in pu comparison between DP, EP and ACSA method is shown in Table 9. Comparison of total operating cost in each area by DP, EP and ACSA method is shown in Fig. 4. The proposed algorithm quickly reaches smallest total operating cost compared to DP and EP method, which indicates that the proposed algorithm could determine the appropriate schedule within a reasonable computation time. It is noted that cost in one iteration may be lower than that of the previous iteration, indicating that our optimization rules always comply with the equal incremental cost criterion for dispatching power generation among thermal units. The tie-line flow pattern at 11 am and 4 pm are shown in Fig. 5 and Fig. 6 respectively.

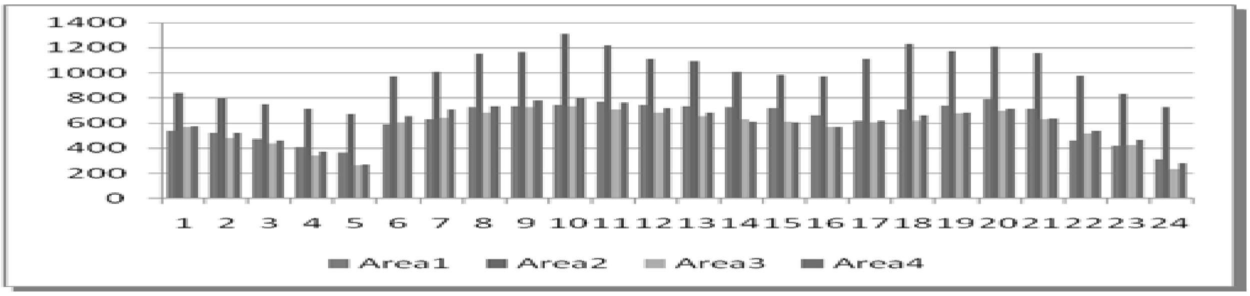


Figure 3. Load demand profile in each area

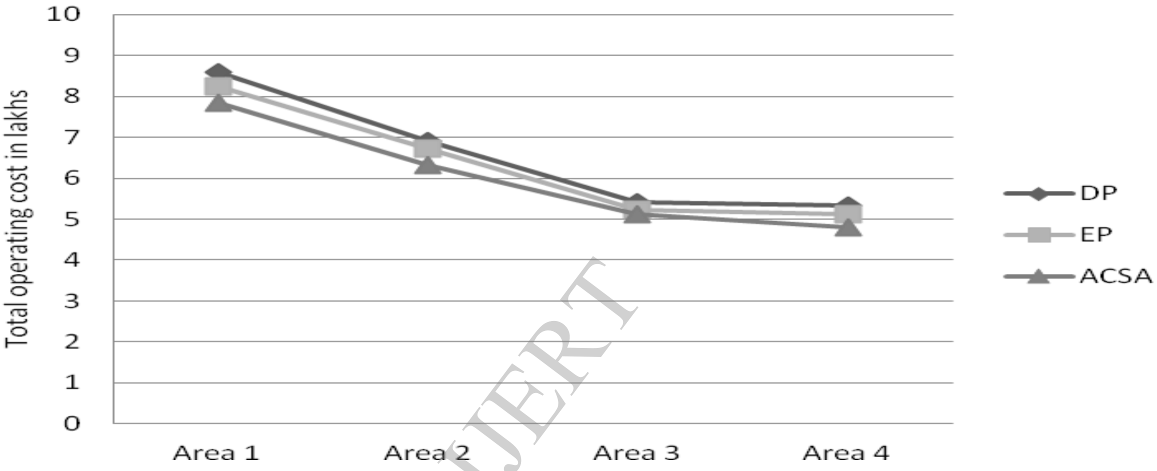


Figure 4. Comparison of Total Operating cost by DP, EP and ACSA method

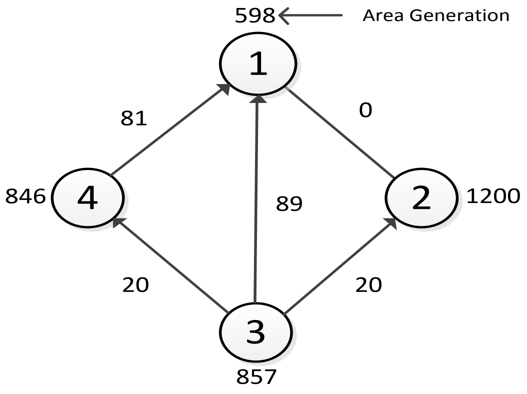


Figure 5. Tie line flow pattern at 11 am

Table 1. Generating unit characteristics

Unit No.	**Minimum up time(hour)**	**Minimum down time (hour)**	**Initial condition (hour)**	**Minimum Generation(MW)**	**Maximum Generation (MW)**
1	0	0	-1	2.40	12
2	0	0	-1	2.40	12
3	0	0	-1	2.40	12
4	0	0	-1	2.40	12
5	0	0	-1	2.40	12
6	0	0	-1	4.00	20
7	0	0	-1	4.00	20
8	0	0	-1	4.00	20
9	0	0	-1	4.00	20
10	0	-2	3	15.20	76
11	3	-2	3	15.20	76
12	3	-2	3	15.20	76
13	3	-2	3	15.20	76
14	3	-2	-3	25.00	100
15	4	-2	-3	25.00	100
16	4	-2	-3	25.00	100
17	4	-3	5	54.25	155
18	4	-3	5	54.25	155
19	5	-3	5	54.25	155
20	5	-3	5	54.25	155
21	5	-4	-4	68.95	197
22	5	-4	-4	68.95	197
23	5	-4	-4	68.95	197
24	8	-5	10	140.00	350
25	8	-5	10	140.00	350
26	8	-5	10	140.00	350

Table 2. Cost functions for generating units in area 1

Unit No.	**Gen. cost co-effi. $a(\$/\mathrm{MW}^2)$**	**Gen. cost co-effi. $b(\$/\mathrm{MW})$**	**Gen. cost co-effi. $c\ (\$)$**	**Start up Cost co-effi.A($)**	**Start up Cost co-effi.B($)**	**Start up time constant τ**
1	24.360	25.237	0.0120	0	0	1
2	24.379	25.255	0.0121	0	0	1
3	24.395	25.273	0.0125	0	0	1
4	24.420	25.299	0.0129	0	0	1
5	24.434	25.321	0.0130	0	0	1
6	117.121	37.000	0.0060	20	20	2
7	117.239	37.132	0.0062	20	20	2
8	117.358	37.307	0.0064	20	20	2
9	117.481	37.490	0.0066	20	20	2
10	81.000	13.322	0.0046	50	50	3
11	81.028	13.244	0.0047	50	50	3
12	81.104	13.300	0.0049	50	50	3
13	81.176	13.350	0.0052	50	50	3
14	217.000	18.000	0.0042	70	70	4
15	217.100	18.100	0.0044	70	70	4
16	217.200	18.200	0.0047	70	70	4
17	142.035	10.394	0.0043	150	150	6
18	142.229	10.515	0.0045	150	150	6
19	142.418	10.637	0.0047	150	150	6
20	143.497	10.708	0.0048	150	150	6
21	256.101	22.000	0.0025	200	200	8
22	257.649	22.100	0.0026	200	200	8
23	258.176	22.200	0.0026	200	200	8
24	175.057	10.462	0.0016	300	200	8
25	305.036	7.486	0.0019	500	500	10
26	306.910	7.493	0.0019	500	500	10

Table 3. Cost functions for generating units in area 2

Unit No.	**Gen. cost co-effi.a($/MW^2)**	**Gen. cost co-effi.b($/MW)**	**Gen. cost co-effi.c ($)**	**Start up Cost co-effi.A($)**	**Start up Cost co-effi.B($)**	**Start up time constant (τ)**
1	24.389	25.547	0.0123	0	0	1
2	24.411	25.675	0.0125	0	0	1
3	24.638	25.803	0.0130	0	0	1
4	24.760	25.932	0.0134	0	0	1
5	24.488	26.061	0.0136	0	0	1
6	117.755	37.551	0.0059	20	20	2
7	118.108	37.664	0.0066	20	20	2
8	118.458	37.777	0.0066	20	20	2
9	118.821	37.890	0.0073	20	20	2
10	81.136	13.327	0.0047	50	50	3
11	81.298	13.354	0.0049	50	50	3
12	81.464	13.380	0.0051	50	50	3
13	81.626	13.407	0.0053	50	50	3
14	217.895	18.000	0.0043	70	70	4
15	218.355	18.100	0.0051	70	70	4
16	218.775	18.200	0.0049	70	70	4
17	142.735	10.695	0.0047	150	150	6
18	143.029	10.715	0.0047	150	150	6
19	143.318	10.737	0.0048	150	150	6
20	143.597	10.758	0.0049	150	150	6
21	259.131	23.000	0.0026	200	200	8
22	259.649	23.100	0.0026	200	200	8
23	260.176	23.200	0.0026	200	200	8
24	177.057	10.862	0.0015	300	200	8
25	310.002	7.492	0.0019	500	500	10
26	311.910	7.503	0.0019	500	500	10

Table 4. Cost functions for generating units in area 3

Unit No.	Gen. cost co-effi. a($/MW^2)	Gen. cost co-effi. b($/MW)	Gen. cost co-effi. c ($)	Start up Cost co-effi.A($)	Start up Cost co-effi.B($)	Start up time constant (τ)
1	24.451	26.547	0.0123	0	0	1
2	24.395	26.675	0.0125	0	0	1
3	24.738	26.803	0.0130	0	0	1
4	24.861	26.932	0.0134	0	0	1
5	24.988	27.061	0.0136	0	0	1
6	118.755	38.551	0.0069	20	20	2
7	119.108	38.664	0.0076	20	20	2
8	119.458	38.777	0.0076	20	20	2
9	119.821	38.890	0.0083	20	20	2
10	82.136	14.327	0.0047	50	50	3
11	82.298	14.354	0.0059	50	50	3
12	82.464	14.481	0.0061	50	50	3
13	82.626	14.407	0.0063	50	50	3
14	218.895	19.000	0.0053	70	70	4
15	219.355	19.100	0.0061	70	70	4
16	219.775	19.200	0.0059	70	70	4
17	143.735	11.695	0.0056	150	150	6
18	144.029	11.715	0.0057	150	150	6
19	144.318	11.737	0.0058	150	150	6
20	144.597	11.758	0.0059	150	150	6
21	259.131	24.000	0.0036	200	200	8
22	259.649	24.100	0.0036	200	200	8
23	260.176	24.200	0.0036	200	200	8
24	177.057	11.862	0.0015	300	200	8
25	310.002	7.692	0.0019	500	500	10
26	311.910	7.703	0.0019	500	500	10

Table 5. Cost functions for generating units in area 4

Unit No.	Gen. cost co-effi. a($/MW^2)	Gen. cost co-effi. b($/MW)	Gen. cost co-effi. c ($)	Start up Cost co-effi.A($)	Start up Cost co-effi.B($)	Start up time constant (τ)
1	24.389	25.202	0.0123	0	0	1
2	24.411	25.255	0.0125	0	0	1
3	24.638	25.273	0.0130	0	0	1
4	24.760	25.342	0.0134	0	0	1
5	24.888	25.366	0.0136	0	0	1
6	117.755	37.012	0.0059	20	20	2
7	118.108	37.055	0.0066	20	20	2
8	118.458	37.098	0.0066	20	20	2
9	118.821	37.156	0.0073	20	20	2
10	81.136	13.261	0.0047	50	50	3
11	81.298	13.278	0.0049	50	50	3
12	81.464	13.295	0.0051	50	50	3
13	81.626	13.309	0.0053	50	50	3
14	217.895	17.500	0.0043	70	70	4
15	218.355	17.600	0.0051	70	70	4
16	218.775	17.700	0.0049	70	70	4
17	142.735	10.210	0.0047	150	150	6
18	143.029	10.268	0.0047	150	150	6
19	143.318	10.307	0.0048	150	150	6
20	143.597	10.375	0.0049	150	150	6
21	259.131	22.500	0.0026	200	200	8
22	259.649	22.600	0.0026	200	200	8
23	260.176	22.700	0.0026	200	200	8
24	177.057	10.462	0.0015	300	200	8
25	310.002	7.492	0.0019	500	500	10
26	311.910	7.503	0.0019	500	500	10

Table 6. Hourly cost of each area by DP method

HOURS (24)	AREA-1 (26 unit)	AREA-2 (26 unit)	AREA-3 (26 unit)	AREA-4 (26 unit)
1	36394.904	24678.309	29112.227	22128.126
2	32398.748	23221.985	22898.975	19312.818
3	31714.449	23121.988	23694.843	19163.999
4	31723.462	18350.520	26238.838	18774.766
5	32023.452	18364.520	25612.969	19065.740
6	35712.469	19012.524	23593.510	19715.542
7	38904.904	28196.592	21832.636	24921.278
8	39680.722	34467.091	20119.855	21974.690
9	41896.216	34791.559	19316.373	21367.342
10	37900.709	32945.357	22168.596	24306.437
11	37917.621	32869.634	20322.082	23391.572
12	37958.864	32865.094	20984.893	21272.693
13	33762.144	34214.477	18212.821	26541.176
14	33613.449	37582.461	17814.931	25892.619
15	31918.347	33706.661	17895.408	23704.434
16	37482.917	33472.179	22519.578	25306.943
17	37416.541	33621.180	23718.580	25778.726
18	36267.023	39914.137	27489.760	19513.752
19	36216.023	39893.695	23899.842	22287.661
20	36249.123	32892.034	21933.391	16016.417
21	38230.836	31482.461	19897.539	20245.248
22	30217.685	14517.871	21107.431	21796.720
23	32112.343	18698.415	19989.213	22319.124
24	30219.685	14516.872	19742.613	18318.498

Table 7. Hourly cost of each area by EP method

HOURS (24)	**AREA-1 (26 unit)**	**AREA-2 (26 unit)**	**AREA-3 (26 unit)**	**AREA-4 (26 unit)**
1	36967.398	23978.521	28416.216	21898.126
2	24332.916	22896.680	22740.900	19324.823
3	27998.167	23114.640	23667.246	19245.978
4	29612.861	18326.321	26117.837	18417.701
5	29363.621	18316.323	25472.429	18553.713
6	35721.176	18312.326	23869.510	19573.596
7	39617.164	28143.146	21845.592	24765.272
8	39328.856	38076.468	19905.851	21123.616
9	38549.734	34843.238	18245.373	21291.120
10	37219.318	32416.347	22163.591	24207.432
11	37184.469	31691.375	20612.082	23542.570
12	38316.472	31581.138	20979.893	21262.693
13	33116.354	34120.029	18127.822	26401.178
14	31630.279	37051.828	17124.939	25704.619
15	30466.627	33150.817	17878.473	23576.431
16	36281.163	32861.752	22306.578	25204.946
17	36894.174	32860.606	23648.580	25226.725
18	35696.310	39439.616	27612.752	19314.724
19	34975.326	39811.059	23799.842	22343.624
20	35766.320	32081.951	21834.391	15868.403
21	38622.479	29125.272	19798.539	20118.242
22	30614.829	15108.122	20985.432	21816.770
23	31483.724	18412.089	19896.273	22294.078
24	29540.211	15162.711	19716.613	18314.498

Table 8. Hourly cost of each area by ACSA method

HOURS (24)	**AREA-1 (26 unit)**	**AREA-2 (26 unit)**	**AREA-3 (26 unit)**	**AREA-4 (26 unit)**
1	34336.423	22618.345	28411.822	21921.265
2	24262.626	22458.681	22243.927	19427.375
3	27232.561	23006.322	22958.254	19224.418
4	29216.527	18168.468	25996.688	17884.585
5	28936.816	18831.753	25114.074	18503.871
6	35682.305	18131.933	23618.551	19367.459
7	39161.916	28214.713	20158.592	23247.172
8	38913.128	37866.544	19118.348	20751.954
9	38165.517	34595.109	17878.902	20129.412
10	36701.131	31341.347	21021.759	23988.243
11	36221.045	31260.137	20245.147	22754.326
12	37831.964	31058.831	20701.164	21123.106
13	32391.863	34650.702	18098.751	26324.891
14	31596.124	36715.018	16871.612	25216.106
15	30431.216	33681.628	17212.824	23175.934
16	35816.616	32162.904	22136.345	25047.745
17	36289.017	32238.516	23146.727	25526.217
18	35116.523	38149.046	27176.607	19643.724
19	34239.063	39780.612	23467.218	22934.162
20	35174.314	32163.595	21608.239	15238.124
21	38136.164	29212.972	19179.052	21294.524
22	30114.339	15212.172	20298.102	20918.107
23	31348.171	18041.106	19638.927	22396.343
24	29345.852	15426.107	19307.116	18231.542

Table 9. Comparison of total operating cost for 26 unit

System	**Method**	**Total Operating Cost (pu)**

		Area 1	**Area 2**	**Area 3**	**Area 4**
26 Unit	DP	1.00000	1.00000	1.00000	1.00000
	EP	0.97377	0.98783	0.98618	0.98926
	ACSA	0.95405	0.96260	0.97250	0.95407

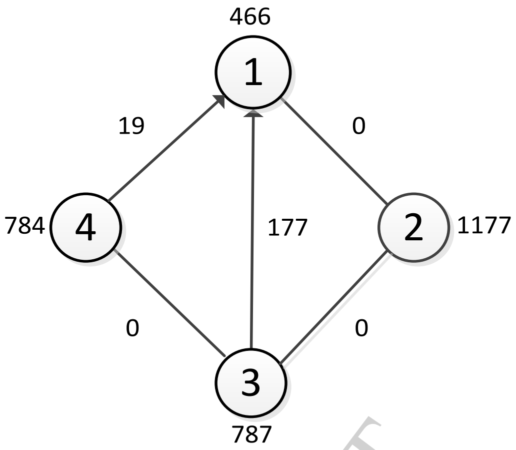


Figure 6. Tie line flow pattern at 4 pm

7. Conclusion

This paper presents ACSA method for solving multi area unit commitment problem with import and export constraints. In comparison with the results produced by the technique DP and EP method obviously proposed method displays satisfactory performance. Test results have demonstrated that the proposed method of solving multi area unit commitment problem with import and export constraints reduces the total operating cost of the plant. An effective tie-line constraint checking procedure is implemented in this paper. This method provides more accurate solution for multi area unit commitment problem with import and export constraints.

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