A Modified ANT Colony Algorithm for Solving the Unit Commitment Problem

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Unit Commitment Problem

- Find the optimal utilization of generative units to minimize the full action cost subject to problem constraints like daily load demand curve and generator unit properties like spinning reserve, minimum start/ stop time, start-up cost by hot/ cold method, Shut down cost, maximum/ minimum production limit, Ramp Up/ Down Limits etc.
- A nonlinear optimization with huge size.
- Some methods include exhaustive enumeration method, priority list, dynamic programming, Lagrange method, least square method and ant colony algorithm.

ANT Colony Algorithm

- At each stage, the ant chooses to move from one Unit to another according to some rules:

1) It must visit each Unit exactly once.
2) An inefficient Unit has less chance of being chosen.
3) The more intense the pheromone trail laid out on an edge between two Units, the greater the probability that that edge will be chosen.
4) Having completed its journey, the ant deposits more pheromones on all edges it traversed, if the journey is cheap.
5) After each iteration, trails of pheromones evaporate.

- The overall result is that when one ant finds a optimal path, other ants are more likely to follow that path, and positive feedback eventually leads to many ants following a single path.

Cost Function

Components of Cost of a Generator in Hour t:

- **Generation Cost:** Production Cost of Unit * Production Amount of Unit $= F_i \ P_i^t$
- **Cold/ Hot Start Cost:** ST_i^t
- **Shut Down Cost:** SD_i^t

$$minimize \ F\left(U_i^t, P_i^t\right) = \sum_{t=1}^{24} \sum_{i=1}^{n} F_i \ P_i^t + ST_i^t + SD_i^t$$

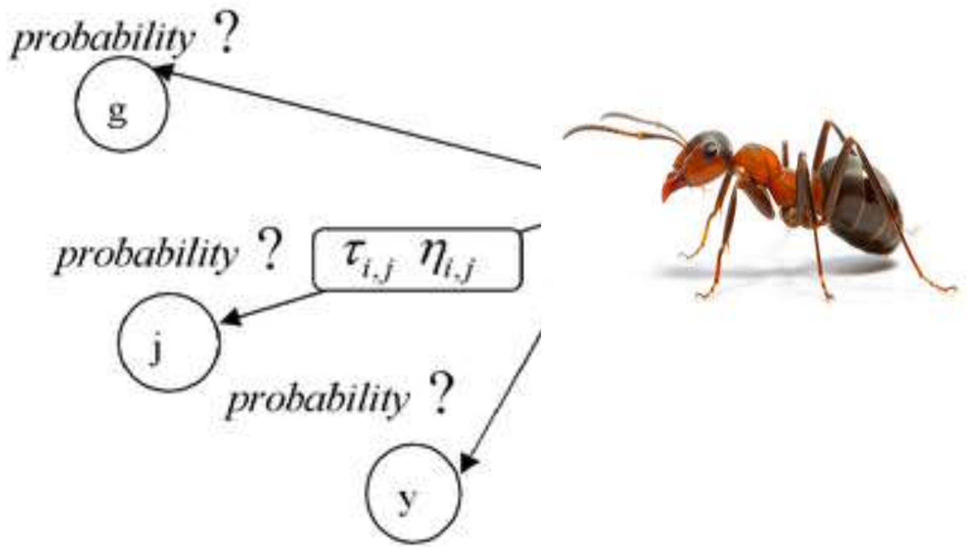
Constraints

Constraint	Formula
Power balance constraint: Power Supplied = Power Demanded.	$\sum_{i=1}^{n} P_i^t U_i^t = P_D^t$
Spinning reserve constraint: Maximum Generation ≥ Load Demand + Spinning Reserve.	$\sum_{i=1}^{n} P_{i,max}^t U_i^t \geq P_D^t + R^t$
Generator limit constraint: Feasible Power is Generated within generation and ramp up/ down limits.	$max(P_i^{t-1} - DR_i, P_{i,min}^t) \leq P_i^t \leq \min(P_i^{t-1} + UR_i, P_{i,max}^t)$
Start Up Cost: Hot Start Cost or Cold Start Cost.	$ST_i^t = \begin{cases} HSC_i & if\ T_{i,off} \leq T_{i,cold} \\ CSC_i & otherwise \end{cases}$
Shut down cost: Only applicable if unit changes state from 1 to 0.	$SD_i^t = \begin{cases} SD_i & if\ U_i^{t-1} = 1\ and\ U_i^t = 0 \\ 0 & otherwise \end{cases}$

Path Selection

- The Probability that the kth ant at i-th Unit will select j-th Unit is proportional to remaining pheromone amount τ_{ij} in i-j relocation path divided by i-j relocation path cost η_{ij}:

$$P_{ij}^{k}(t) = \frac{\dfrac{(\tau_{ij})^{\alpha}}{(\eta_{ij})^{\beta}}}{\sum_{1}^{k} \dfrac{(\tau_{ij})^{\alpha}}{(\eta_{ij})^{\beta}}}$$



$$\eta_{ij} = (\alpha_j (P_j)^2 + \beta_j P_j + \gamma_j) - (\alpha_i (P_i)^2 + \beta_i P_i + \gamma_i) + ST_j^t$$
$$+ SD_i^t + \lambda\Big(\sum_{i=1}^{n} P_i^t U_i^t - P_D^t\Big) + \nu_1\Big(P_D^t + R^t - \sum_{i=1}^{n} P_{i,max}^t U_i^t\Big) + \nu_2\big(P_j^t - \min(P_j^{t-1} + UR_j, P_{j,max}^t)\big) + \nu_3\big(\max(P_i^{t-1} - DR_i, P_{i,min}^t) - P_i^t\big)$$

Pheromone Matrix for each hour

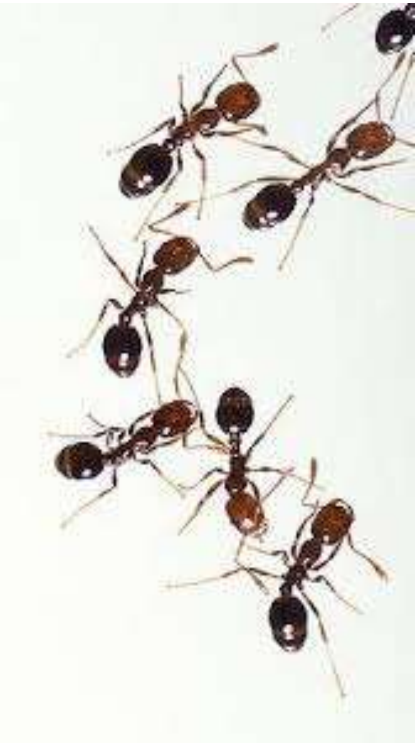
- Ant k deposits pheromone amount $\Delta\tau_{ij}$ in path i-j which depends on utility of the choice of Unit j.
- When all the ants have completed a solution, the trails are updated by:

$$\tau_{ij} = (1-\rho)\tau_{ij} + \sum_1^k \Delta\tau_{ij} \ \ \textit{where } \rho \textit{ is the pheromone evaporation rate}$$

Present i / **Next j**	**1**	**2**	**3**
1	0.95	0.75	0.35
2	0.05	0.15	0.00
3	0.00	0.10	0.65

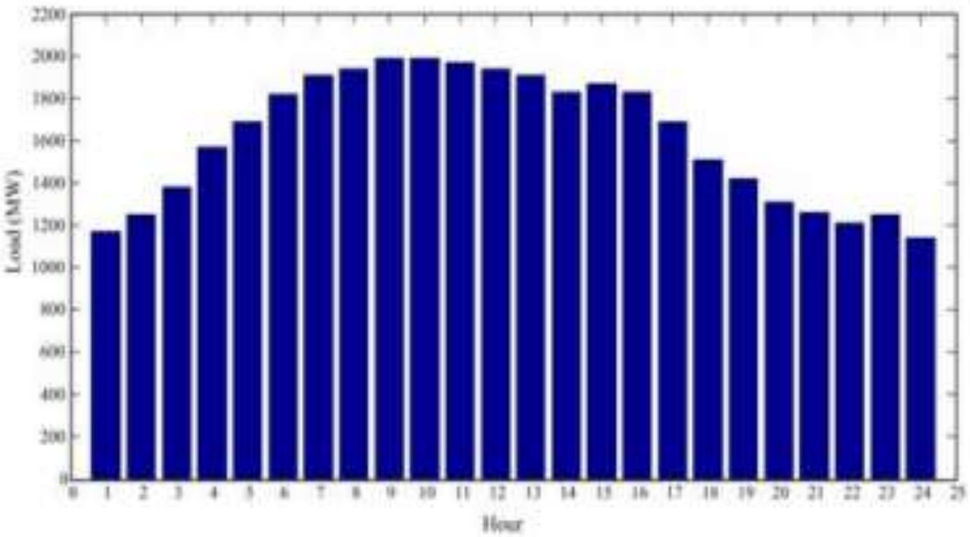
Stop Criterion

- If the number of ants passing a path gets more than a minimum amount, the solution is reached.
- Ants make optimal transitions and settle at most efficient Generation Units. The steady state Generation Units must be operated for optimal utilization of Power System in that Hour.
- The solution ensures that the load demand and all other constraints are met simultaneously while minimizing the cost function.



Results

- A modified version of ACO algorithm has been developed using MATLAB software for 10 Generator System with 200 ants and ρ=0.25.

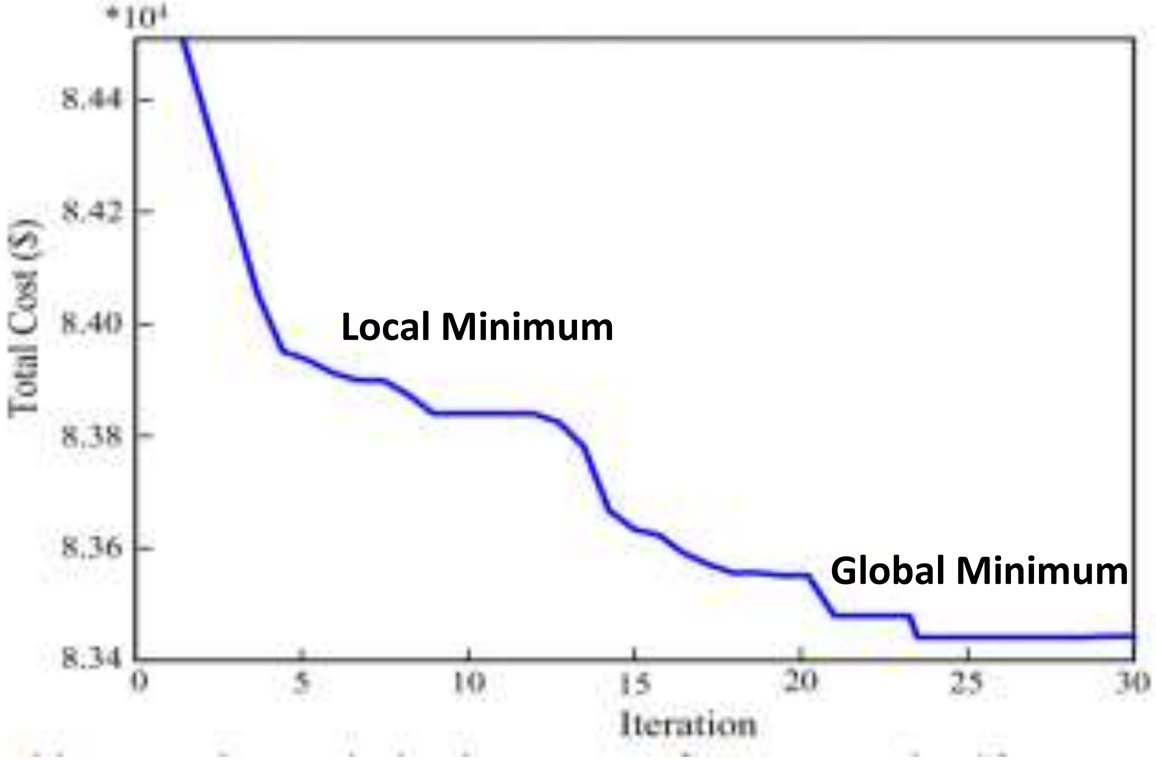


Load Demand Curve

unit	Pmax	Pmin	α (\$/h)	β (\$/MWh)	γ (\$/MW²h)	MU (h)	MD (h)	HSC (\$)	CSC (\$)	Cs_hrs (h)	initial state (h)
1	200	80	82	1.2136	0.00148	3	2	70	176	3	4
2	320	120	49	1.2643	0.00289	4	2	74	178	4	5
3	150	50	100	1.3285	0.00135	3	2	50	113	3	5
4	520	250	105	1.3954	0.00127	5	3	110	267	5	7
5	280	80	72	1.3500	0.00261	4	2	72	180	3	5
6	150	50	29	1.5400	0.00212	3	2	40	113	2	-3
7	120	30	32	1.4000	0.00382	3	2	35	94	2	-3
8	110	30	40	1.3500	0.00393	3	2	45	114	1	-3
9	80	20	25	1.5000	0.00396	0	0	40	101	0	-1
10	60	20	15	1.4000	0.0051	0	0	30	85	0	-1

Characteristics of 10 Generators

Results



Speed of Convergence to Optimal Solution

Hour	Load (MW)	Unit number										cost ($)
		1	2	3	4	5	6	7	8	9	10	
1	1170	1	1	1	1	1	1	0	0	1	1	2433.121
2	1250	1	1	1	1	1	1	1	1	0	1	1605.756
3	1380	1	1	1	1	1	1	1	1	1	0	2890.637
4	1570	1	1	1	1	1	1	1	1	1	1	3295.703
5	1690	1	1	1	1	1	1	1	1	1	1	3578.545
6	1820	1	1	1	1	1	1	1	1	1	1	3906.292
7	1910	1	1	1	1	1	1	1	1	1	1	4146.285
8	1940	1	1	1	1	1	1	1	1	1	1	4229.597
9	1990	1	1	1	1	1	1	1	1	1	1	4378.066
10	1990	1	1	1	1	1	1	1	1	1	1	4378.066
11	1970	1	1	1	1	1	1	1	1	1	1	4316.945
12	1940	1	1	1	1	1	1	1	1	1	1	4229.597
13	1910	1	1	1	1	1	1	1	1	1	1	4146.285
14	1830	1	1	1	1	1	1	1	1	1	1	3932.427
15	1870	1	1	1	1	1	1	1	1	1	1	4038.283
16	1830	1	1	1	1	1	1	1	1	1	1	3932.427
17	1690	1	1	1	1	1	1	1	1	1	1	3578.545
18	1510	1	1	1	1	1	1	1	1	1	1	3160.748
19	1420	1	1	1	1	1	1	1	1	0	1	2968.299
20	1310	1	1	0	1	1	1	1	1	1	1	2721.549
21	1260	1	1	0	1	1	1	1	1	1	1	2614.143
22	1210	1	1	0	1	1	1	1	1	1	1	2508.618
23	1250	1	1	0	1	1	1	1	1	1	1	2603.263
24	1140	1	0	0	1	1	1	1	1	1	1	2371.304
Total												833645.1374

Optimal Operation Scheme

Future Research

- Incorporate Energy Losses/ Transmission Losses of each Generation Unit in Cost Function.
- Perform Sensitivity/ Perturbation Analysis by relaxing or tightening some constraints.
- Use better penalty functions for violation of constraints, to increase rate of convergence to optimal solution.

References

- https://airccse.com/aeij/papers/3316aeij02.pdf