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HYBRID ACO-MPSO ALGORITHM FOR UNIT COMMITMENT PROBLEMS WITH POWER FLOW AND ENVIRONMENTAL CONSTRAINTS

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Abstract. *In this paper, ant colony optimization (ACO) and modified particle swarm optimization (MPSO) are proposed to solve power flow and environmental constrained unit commitment problem. Both economic load dispatch (ELD) and economic emission dispatch (EED) have been applied to obtaining optimal fuel cost and optimal emission of generating units for the entire time horizon. The unit commitment (UC) solution for the environmental constrained problem has been formulated as a multi-objective problem by considering both ELD and EED simultaneously. The common economic emission dispatch (CEED) bi-objective problem is converted to single objective function by adding a price penalty factor. This proposed algorithm introduces an efficient unit commitment approach considering environmental constraints along with power flow constraints that obtains the minimum operating cost satisfying both unit and network constraints. The UC problem is decomposed in two sub-problems. The UC sub-problem is solved by the ant colony optimization method and the economic dispatch sub-problem is solved by the particle swarm optimization method.*
Keywords: Ant colony optimization, Particle swarm optimization, Unit commitment, Economic emission dispatch, Dynamic economic dispatch, Power flow

1. **Introduction.** Electricity really is different from other commodities in its need for short-term coordination. (Short-term coordination here means day-head, on-the-day, and real-time coordination.) The system operator has to be able to control the plants. Whatever changes are made, the system operator still has to be in charge of the system and has to tell plants when to run, when to increase or reduce output, and when to stop. He or she has to make sure the load is met at all times, relieve congestion on the transmission system, and call for reserves and use them when necessary [1].

Recently, distributed generations (DGs) have received great attentions and may bring distribution systems into a new era for the multi-direction power flow [2-4]. The power flow is a very important tool for the fault analysis and is used in the operational as well as planning purposes in DGs application [5-7]. In the application of this method to unit commitment (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. An ant repeatedly hops from node to node using the pheromone trails to compute the probability of choosing next node until it eventually reaches the destination node. Due to differences among the ants' paths, the time step at which ants reach the destination node may differ from ant to ant. Ants traveling on shorter paths will reach their minimal costs.

Some of the previous formulations of a UC problem that account for emission constraints have been solved using Lagrange relaxation methods [8]. Lagrange relaxation in a combination with Dantzig-Wolfe decomposition has been applied to investigating long-term security constrained UC [9]. Formulations of emission functions for different types of pollutants are deliberated for various generating units. 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.

2. **Problem Formulation.**

Unit commitment is an optimization problem of determining the schedule of generating units within a power system with a number of constraints. For a given power system network, the design-optimization cost of generation problem thus takes the following form.

2.1. **The objective function.**

$$TC = Min \sum_{i=1}^{N_G} \sum_{t=1}^{T} f_i(FC, EC) + ST_{it} + SD_{it} \tag{1}$$

where TC is the total production cost for the UC schedules, N_G is the total number of generator units in the network, T is the total number of hours, and FC and EC are total fuel cost and total emission of generators respectively.

2.2. **Minimization of fuel cost.**

Total fuel cost of generation FC in terms of control variables generator powers can be expressed as

$$FC_{it}(P_{Gi}) = \sum_{i=1}^{N_G} a_i P_{Gi}^2 + b_i P_{Gi} + c_i \qquad (\$/\text{hr}) \tag{2}$$

where a_i, b_i, c_i are the cost coefficients of generator, and P_{Gi} is real power generated by the ith generator.

2.3. **Minimization of emission.**

Total emission of generation EC can be expressed as

$$EC_{it}(P_{Gi}) = \sum_{i=1}^{N_G} \gamma_i P_{Gi}^2 + \beta_i P_{Gi} + \alpha_i \qquad (\text{lb/hr}) \tag{3}$$

where γ_i, β_i, α_i are the emission coefficients.

2.4. **Equality constraints.**

Power balance of generation EC can be expressed as

$$\sum_{i=1}^{N_G} P_{Gi} = P_{Dt} + P_{Rt} + P_{Lt} \tag{4}$$

2.5. **Inequality constraints.**
1) Minimum up-time

$$0 \le T_{it} \le \text{No. of hours units } G_i \text{ has been on} \tag{5}$$

2) Minimum down-time

$$0 \le T_{id} \le \text{No. of hours units } G_i \text{ has been off} \tag{6}$$

3) Maximum and minimum output limits on generators

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \tag{7}$$

4) Ramp rate limits for unit generation changes

$$P_{Gi(t)} - P_{Gi(t-1)} \le UR_i \quad \text{as generation increases} \tag{8}$$

$$P_{Gi(t-1)} - P_{Gi(t)} \le DR_i \quad \text{as generation decreases} \tag{9}$$

where P_{Dt}: Demand at the tth hour, P_{Rt}: Spinning reserve, P_{Lt}: Total system losses, T_{it}: Minimum up-time, T_{id}: Minimum down-time, UR_i: Ramp-up rate limit of unit i (MW/h), DR_i: Ramp-down rate limit of unit i (MW/h), and $P_{Gi}^{\min}$, $P_{Gi}^{\max}$: Minimum and maximum value of real power allowed at generator i.
5) Emission limit

$$EC_{it} \le \frac{EC^{\max}(P_{Dt} + P_{Rt})}{\sum_{i=1}^{N_G} (P_{Dt} + P_{Rt})} \tag{10}$$

where $EC^{\max}$ is maximum value of emission one day.

2.6. **Power flow constraints.**

$$P_{Gi} - P_{Li} - \sum_{j=1}^{N_b} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{11}$$

$$Q_{Gi} - Q_{Li} - \sum_{j=1}^{N_b} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{12}$$

where N_b: Number of total buses, $|V_i|$: Voltage magnitude at bus I, δ_i: Voltage angle at bus I, and Y_{ij}: The ij-th elements of Y-bus matrix.

2.7. **Price penalty factor.** The bi-objective combined economic emission dispatch problem is converted into single optimization problem by introduction of the penalty factor "h" as follows

$$TC = Min \sum_{i=1}^{N_G} \sum_{t=1}^{T} FC_{it}(P_{Gi}) + h * EC_{it}(P_{Gi}) + ST_{it} + SD_{it} \quad (\$/\text{hr}) \tag{13}$$

The price penalty factor h blends the emission with fuel cost and TC the total production cost in \$/hr. The price penalty factor h_i is the ratio between maximum fuel cost and maximum emission of corresponding generator. This method gives the appropriate value of price penalty factor for the corresponding load demand.

3. **Computation Procedures.** To solve power flow and environmental constrained unit commitment problem, the search space of generation scheduling problem is established using multi-process decision making concept. The main computation procedures are proposed in as the following.
Step 1: Ant Colony Optimization (ACO) Initiation

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. Figure 1 plots a multi-stage search space. Based on the concept of this multi-stage process, the search

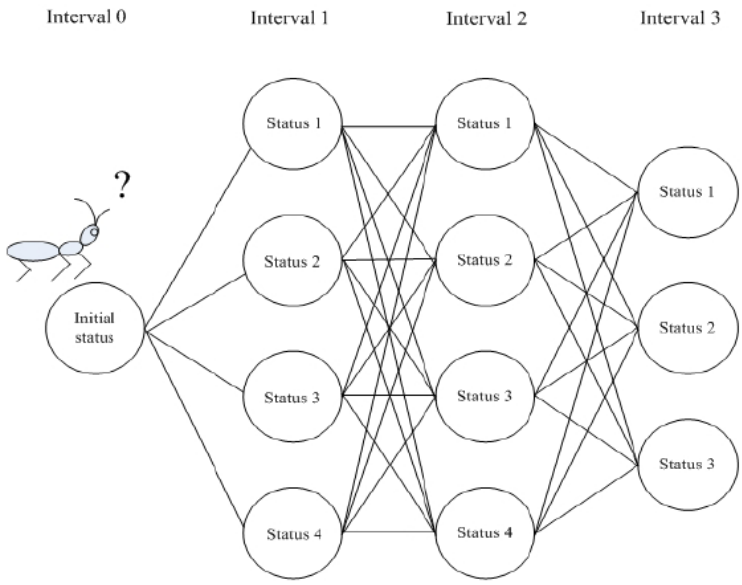

FIGURE 1. The multi-stage search space

space of thermal generation scheduling problem can be established. All the possible permutations constitute this search space. The ants are dispatched based on the level of pheromone:

$$P_{ts}^{k} = \left\{ \begin{array}{ll} \dfrac{[\tau_{ts}]^{\alpha}[\eta_{ts}]^{\beta}}{\sum\limits_{l \in N_t^k} [\tau_{ts}]^{\alpha}[\eta_{ts}]^{\beta}}, & \text{if } s \in N_t^k; \\ 0, & \text{if } s \notin N_t^k, \end{array} \right\} \tag{14}$$

where N_t^k is the neighborhood of ant k, when in status s. η_{ts} is the start-up and shut-down costs of the units changing to the next status.

Step 2: Fitness Evaluation by MPSO and Penalty Methods

In this step, the fitness of all ants is assessed based on the corresponding objective function. The idea of converting the constrained problem into a sequence of appropriately formed unconstrained problem is very appealing, since unconstrained problems can be solved both efficiently and reliably. The original constrained function, Equation (1), is transformed into a sequence of unconstrained problems via the penalty function.

$$PTC = Min \left\{ \sum_{t=1}^{T} \sum_{i=1}^{N_G} [f_i(FC, EC) + ST_{it} + SD_{it}] + \Omega(P_{Gi}) \right\} \tag{15}$$

where $\Omega = R \times \left\{ \left[\min \left(\left(\sum_{i=1}^{N_G} P_{Gi} - P_{Dt} - P_{Rt} \right), 0 \right) \right]^2 + [\max((EC_{it} - EC_{it}^{\max}), 0)]^2 \right\}$ is the parabolic penalty used for constraints. It is required to approximate the constrained solution with accuracy.

Step 3: Update of Pheromone Trails

Global updating is performed after all ants have completed their tours. The pheromone level is updated by applying the updating rule $\tau_{ts}^{m+1} = (1 - \rho)\tau_{ts}^{m} + \Delta\tau_{ts}^{m}$, where $\Delta\tau_{ts}^{m} = 1/PTC_{ts}$, PTC_{ts}: the cost of the sth status at the tth hour, m: the iteration numbers of ants, t: the tth hour, and s: the sth status.

Step 4: Adjustment of Power Flow Constraint

Applied penalty function method found the optimal solution nearby the closely feasible region, and it was to be the feasible solution by adjusting a small amount with *Newton-Raphson power flow solution* for slack bus [10,11]. Because it makes up the difference between the scheduled loads, this *generator bus* generated power that is caused by the losses in the network.

4. **Simulation Results.** The proposed method is tested on IEEE 30 bus system. The network topology and the test data for the IEEE 30 bus system are given in http://www.ee.washington.edu/research/pstca. As shown in Table 1, the total production cost of ACO/MPSO is shown to be less expensive than those of GA and SA on IEEE 30 bus system over 10 runs. The result of the generation scheduling is presented in Table 2 [12-14].

Table 1. Comparison of total production costs over 10 runs

Methods	Best ($/day)	Mean ($/day)	Worst ($/day)
GA	28100	28711	30314
SA	27941	29406.89	32372
ACO/MPSO	27928	28290.4	28898

Table 2. The generation scheduling of the best solution obtained by ACO/MPSO method

Hr	Load (MW)	Loss (MW)	Unit 1 (MW)	Unit 2 (MW)	Unit 3 (MW)	Unit 4 (MW)	Unit 5 (MW)	Unit 6 (MW)	Max emission (lb/hr)	Emission output (lb/hr)	Penalty factor	Fuel cost ($/hr)	Minimum operating cost ($/hr)
1	169	4.4524	101.69	37.501	0	12.258	10	12	271.74	197.36	1.7331	271.74	961.77
2	199	4.0208	96.251	39.085	15	13.809	16.876	22	319.97	238.04	1.8223	319.97	1015.6
3	229	7.5792	148.36	59.085	17.793	0	11.342	0	368.21	318.28	1.6944	368.21	1269.9
4	267	9.1131	148.24	79.085	0	0	19.342	29.441	429.31	393.06	1.7446	429.31	1555.9
5	283.4	9.2601	159.62	65.955	32.527	0	0	34.564	455.68	417.29	1.773	455.68	1677.1
6	272	6.8607	107.68	80	0	32.18	19.004	40	437.35	375.89	1.8252	437.35	1901.2
7	246	5.7193	116.28	60	23.028	0	22.409	30	395.55	308.3	1.8192	395.55	1392.6
8	213	6.2044	125.9	48.05	25.252	0	0	20	342.49	254.58	1.7547	342.49	1067.1
9	193	6.0424	126.5	50.762	0	0	21.784	0	310.33	220.9	1.6856	310.33	1025.9
10	164	4.721	126.08	0	15	0	27.639	0	263.7	187.98	1.7464	263.7	881.14
11	150	2.7698	81.514	0	28	11.617	19.639	12	241.19	173.45	1.8795	241.19	1118
12	163	5.1876	124.55	20	0	0	11.639	12	262.09	195.38	1.6972	262.09	946.76
13	173	5.3427	118.7	40	0	0	19.639	0	278.17	182.81	1.6823	278.17	792.34
14	188	6.3629	123.74	58.988	0	0	11.639	0	302.29	222.12	1.66	302.29	873.08
15	208	7.0642	141.97	53.458	0	0	19.639	0	334.45	262.09	1.6733	334.45	1007.5
16	226	4.6794	110.71	44.653	22.063	25.61	27.639	0	363.39	267.54	1.7983	363.39	1482.5
17	246	7.944	163.03	41.674	0	16.61	19.639	12.989	395.55	365.49	1.7233	395.55	1467.8
18	241	6.97	135.67	61.674	0	0	27.639	22.989	387.51	314.25	1.7559	387.51	1332.7
19	236	8.8038	158.22	66.948	0	0	19.639	0	379.47	340.06	1.6693	379.47	1268.8
20	225	7.4194	144.65	60.135	0	0	27.639	0	361.78	294.79	1.692	361.78	1134.1
21	204	5.9849	147.94	0	32.043	0	30	0	328.01	269.2	1.7741	328.01	1237.3
22	182	4.9984	131.26	0	0	0	30	25.735	292.64	215.73	1.7905	292.64	1062.7
23	164	3.5797	83.391	31.09	15.363	0	22	15.735	263.7	179.38	1.8207	263.7	874.85
24	134	3.084	81.43	26.654	15	0	14	0	215.46	131.86	1.7441	215.46	581.4
Commitment Schedule by ACO/MPSO									Total Cost 27928 ($/day)				

5. **Conclusions.** This paper proposed a novel integrating algorithm (ACO/MPSO) for solving unit commitment problem with power flow and environmental constraints in two phases. The first phase employs ACO to obtain a feasible path, while the second part employs MPSO to determine the optimal economic dispatch. Thus, ACO/MPSO is observed to be efficient in terms of minimizing the cost and thermal emission solution. In the future, we would like to include this kind of uncertainly using fuzzy theory into a profit-based UC problem with carbon trading.

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