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A Hybrid Dynamic Programming-Priority List Approach for Generation Scheduling Solution

***Abstract**. The objective of generation scheduling is to minimize the total cost and satisfy the predicted energy demand and other system restrictions, known as the unit commitment (UC) problem. This problem involves determining which units should be online in each period and how much energy each of these online units should produce. This paper presents a new fast, efficient, robust, and relaxed method to solve the unit commitment problem using a hybrid dynamic programming (DP) algorithm with a priority list method as a screening tool. The dynamic programming algorithm is used for each list to solve the economic dispatch problem of switched units for each list as a sub-problem. This method, an advanced optimization technique with many application areas, divides the problem into several smaller problems, solves them, and develops an optimal solution to the initial problem step by step. A ten-unit system is used to prove the effectiveness and efficiency of the proposed method. The optimization of these decisions allows for the generation of power at minimum cost while meeting demand and other operational constraints.*

***Streszczenie.** Celem planowania generacji jest minimalizacja całkowitego kosztu i zaspokojenie przewidywanego zapotrzebowania na energię oraz innych ograniczeń systemowych, co znane jest jako problem zaangażowania jednostek (UC). Problem ten polega na określeniu, które jednostki powinny być włączone do sieci w każdym okresie oraz ile energii każda z tych jednostek powinna wyprodukować. W artykule przedstawiono nową szybką, wydajną, wytrzymałą i zrelaksowaną metodę rozwiązywania problemu zaangażowania jednostek przy użyciu hybrydowego algorytmu programowania dynamicznego (DP) z metodą listy priorytetów jako narzędzia przesiewowego. Algorytm programowania dynamicznego jest używany dla każdej listy do rozwiązania problemu ekonomicznego rozdysponowania przełączonych jednostek dla każdej listy jako podproblemu. Metoda ta, będąca zaawansowaną techniką optymalizacji o wielu obszarach zastosowań, dzieli problem na szereg mniejszych problemów, rozwiązuje je i krok po kroku opracowuje optymalne rozwiązanie problemu początkowego. Do udowodnienia skuteczności i efektywności proponowanej metody wykorzystano dziesięcioelementowy system. Optymalizacja tych decyzji pozwala na wytwarzanie energii przy minimalnych kosztach, przy jednoczesnym spełnieniu zapotrzebowania i innych ograniczeń operacyjnych. (**Hybrydowe podejście do programowania dynamicznego z listą priorytetów dla rozwiązania do planowania generacji**)*

Keywords: Generation Scheduling problem, Dynamic Programming (DP), priority list screening, Quadratic programming approach.
Słowa kluczowe: Problem szeregowania generacji, programowanie dynamiczne (DP), przesiewanie listy priorytetów, podejście programowania kwadratowego.

Introduction

Electric power challenges are various issues confronting the power sector in responding to the growing demand for electricity on a sustained and reliable basis, such as security of energy, the aging electricity infrastructure, decarbonization, availability of energy, cost, load management and network integration. The ongoing process of the electricity industry deregulation and reorganization to implement competition, enhance efficiency, and decrease costs is driving the need for optimizing within the power sector. The highest typical costs are related to thermal power production. Unit commitment (UC) is scheduling power production units to meet the demand for electricity at different times while keeping the unit operating effectively and economically. This consists of deciding which power production units to use, when to turn them on when to turn them off, and how much power each unit should generate at particular times. [1-2] UC task is a highly critical optimization problem in the area of power system operation and design. The objective of the unit commitment problem is to minimize the total cost of energy generation while meeting the demand for power and meeting the operational requirements of the power system, such as the minimum and maximum power generation output of each unit, the ramp rate limitations, and the start-up and shutdown charges. [3-4] The resolution of the unit scheduling problem produces a schedule of which power production units to use and how much power each unit should generate at different times. This scheduling can be utilized to ensure that the power system is operated in a safe, effective, and economical way. [5] There are several distinct strategies for resolving the unit scheduling problem, such as deterministic and stochastic approaches. Deterministic approaches utilize both historical data and some other information to make precise forecasts of future demand and generating capability. In contrast, stochastic methods consider the uncertainty and variability of these variables. UC can also be resolved using exact mathematical optimization techniques, such as mixed integer linear programming (MILP) or mixed integer quadratic programming (MIQP). These tools can be used to solve the unit commitment problem for various time frames, from hours to days, based on the scheduling time frame of the power system manager [6]. As a simple method that does not require complicated optimization procedures and can be applied efficiently using a computer program such as a spreadsheet, the priority list approach is commonly used as a heuristic approach in the field of power system operations and design to solve the unit commitment problem. The priority list method consists of prioritizing power production units according to their operating specifications and then choosing the units in order of their priorities to meet the power supply demand. The priority of each unit is established by a series of rules that take into account factors such as the unit's minimum and maximum output, the start-up and shutdown time of the facility, and the cost of generating the unit's power. The priority list method works as described below:

1. Order the power production plants in descending sequence of their cost of operation per unit of energy generated.
2. Beginning with the unit with the smallest operating cost, verify that the unit can be successfully started and ramped up to supply the power demand. If so, then start the

unit and allocate the required power output. If not, proceed to the following unit.

3. Continue with step 2 for the other units, in sequence, until the power demand is satisfied.

4. After all units that can be turned on have been started, verify if additional power is required to meet the power demand. If so, turn on the next unit on the priority list that can be started and ramp up to meet the remaining power demand.

5. Continue with step 4 until the power demand is completely met or all the units available have been started.

The priority list approach is simple and efficient in solving the unit scheduling problem. However, it does not ensure an optimal solution and may only consider some operational restrictions of the power system. Therefore, it is often used as a screening tool to obtain an initial resolution that can be refined with more sophisticated optimization techniques. The same can be said for complete enumeration using dynamic programming techniques to solve the unit commitment. A complete enumeration involves a large computational requirement, so the technique cannot be used for a more extensive system. For this purpose, we proceed as a contribution to combine the DP procedure with the priority list approach, resulting in an efficient, direct, and reliable technique. For each list, we involve a dynamic programming (DP) approach to resolve the economic dispatch (ED) problem for the dispatched generation units as a sub-problem [7-8]. By optimizing this problem, power can be generated at the least possible cost while meeting the load and other operational restrictions.

Formulation of the problem

A. Unit commitment

The goal of the unit commitment problem, in general, is to realize the minimization of the cost of production, which comprises the start-up and fuel costs as well as the shutdown cost. The main challenge in solving the UC is the large size of the space of feasible combinations. The problem of unit commitment can be challenging. As a conceptual approach, consider the following scenario. (1) we have to set up a loading scheme for m time periods. (2) we have n-generation units to be engaged and dispatched. (3) the m loading levels and limits of the n units to operate are so that any unit can supply the single charges, and any combination of generation units can supply the charges as well. All (2n-1) m candidate combinations for the n units are supplied for the entire m periods, which turns out to be a scary number to be dealing with. Such huge numbers constitute the maximal number of required computations. However, the constraints on the generation units and the capacity limits of load relationships of the standard power systems make it possible to reduce this number. Although the main challenge to the unit commitment optimal problem is the large size of the possible problem space, the following are the most broadly reported existing techniques for addressing the unit-commitment solution: priority list schemes, dynamic programming (DP), and the Lagrange relation, genetic algorithms, simulated annealing, etc. The goal of this optimization function is to minimize the total operating cost on the scheduling period. Consequently, the objective function is stated to be the sum of the production units' fuel and startup-related expenses [9-10]:

(1) $$Total\ cost\ C_{i,t} = F_i(P_{i,t}) + S_i^t$$

where:

(2) $$F_i(P_{i,t}) = a_i + b_i(P_{i,t}) + c_i(P_{i,t})^2$$

B. The constraints include the following:

• The start-up cost is modeled by the following function of the form:

(3) $$S_i^t \begin{cases} HS^i, & if\ X^t{}_{off} \le T_i^{down} + CH_i \\ CS^i, & if\ X^t{}_{off} > T_i^{down} + CH_i \end{cases}$$

• Power balance:

(4) $$\sum_i^N u_i^t P_i^t = D^t$$

• Spinning reserve requirements:

(5) $$\sum_i^N u_i^t P_i^{max} \ge D^t + R^t$$

• Production limits:

(6) $$u_i^t P_i^{min} \le P_i^t \le u_i^t P_i^{max}$$

• Constraint of minimum operating uptime:

(7) $$\left(X_{on,i}{}^{t-1} - T_i^{up}\right)\left(u_i^{t-1} - u_i^t\right) \ge 0$$

(8) $$X_{on,i}{}^t = \left(X_{on,i}{}^{t-1} + 1\right) u_i^t$$

• Constraint of minimum operating down time:

(9) $$\left(X_{off,i}{}^{t-1} - T_i^{down}\right)\left(u_i^t - u_i^{t-1}\right) \ge 0$$

(10) $$X_{off,i}{}^t = \left(X_{off,i}{}^{t-1} + 1\right)\left(1 - u_i^t\right)$$

• The cost function of fuel Fi (Pit) is frequently expressed as a function of a polynomial

(11) $$F_i\left(P_i^t\right) = a_i + b_i P_i^t + c_i^t (P_i^t)^2$$

Where:

F_i (P_i^t) is the cost of fuel of plant *i* at interval *t* ($); P_i^t is the power generation of unit *i* at interval *t* in MW; S_i^t is the start-up cost of plant *i* at interval *t* ($); *N* is number of overall production units; *T* is number of horizon interval; u_i^t is the state of plant *i* at period *t*,(u_i^t =1: plant is switched on and u_i^t = 0 plant *i* is switched -line); a_i, b_i, c_i are uadratic cost parameters of the production unit *i*; $X^t_{off,\,i}$ and $X^t_{on\,i}$ are hours where the plant was switched off / switched on in (*h*); X^0_i is the original status of plant *i* at *t* = 0, X^0_i > 0 (switched on the plant), X^0_i < 0: (switched off the plant) in [*h*]; T_i^{up} is minimum operating up_time [h]; T_i^{down} is minimum operating down_time [h]; HS^i, CS^i hot or cold start cost of the plant *i* [$]; CH^i is is the cold start time [h]; D^{is} demand from customers in the time period *t*, and R^t is the requirements of spinning reserve;

Priority list screening method

The objective function of the unit commitment problem involves the generation cost and the power start-up cost function of the power plant. The latter includes the cost of power to start up the plant. The start-up cost is bringing the unit online from offline status (Si) [11], [12]. It may be described by a simple linear expression:

(12) $$S_i(t) = F_0 \times t + C_f$$

Here, F_0 is the cost of keeping the plant at the operational temperature, and C_f is the fixed plant operating cost, taking into account the expenses of personnel and maintaining the plant.

The easiest way to commit units is to create a list of all the possible combinations of enabled and disabled units, along with the associated total cost to generate a priority schedule, and then decide based on that schedule. The process is referred to as the priority list screening. The ordering is performed using the minimum average production cost of the selected plant. The average unit operating cost μ_i is determined as given in.

(13) $$\mu_{\rm i} = F_i(P_i)/P_i$$

In common, the output power is very close to the nominal power rating at the minimum average generation cost of the plant. The sequence of stages in the priority ranking approach is resumed as described below [13-14]:

1. Step (1): Compute the lowest average generation cost of every plant, and arrange the plants based on the lowest $\mu_{i,\,min}$ value. Create the priority list.
2. Step (2): If the loading grows for that hour, find out which plant can be restarted according to the minimal downtime of the plants. Then choose the units to be restarted from the priority list based on the load growth.
3. Step (3): If the loading declines in this hour, decide how many units may be stopped according to the units' minimum operation time. Next, choose the remaining units to be shut off using the priority list according to the load decrease.
4. Step (4): Continue the above-mentioned steps during the following hour.

Reduced dynamic programming by pl screening

Using an advanced dynamic programming technique to solve the unit commitment, the complete possible enumeration will be reduced to only (2n-1) combinations.

Despite that, the computational requirement is significant, and the technique cannot be used for a larger system. For this purpose, we combine the DP procedure with the priority list approach based on the no-load cost and incremental heat rate data to eliminate some infeasible and higher-priced states. In addition, we include the constraints of the unit up and down time, which can also reduce the selection states [15]. For instance, before committing units using the forward DP algorithm, we initially ordered the units based on the priority list and the minimum unit up/downtime. The first portion of the unit order are the units to go up, the last portion is the units to go down, and the mid portion is the ranking of the units based on the minimum average production cost of the remaining units. By doing this, the amount of PD calculation will be significantly decreased [16]. The sequence procedure in the proposed method is resumed as described below:

1. For each power level (at time t):

-select the feasible states (I), using the priority list order (The former is described in §.III)

2. According to the recursive algorithm of dynamic programming, we can compute the minimum total cost:

(14) $$F_{tc}(t,I) = \min_{\{L\}} \begin{bmatrix} F(t,I) + S_c(t-1, L \Rightarrow t, I) + \\ F_{tc}(t-1, I) \end{bmatrix}$$

Where:

$F_{tc}(t,I)$: The total cost from the initial state to hour t state I

$S_c(t-1, L \Rightarrow t, I)$: The transition cost from the state (t − 1, L)
to state (t, I)

{ L }: The set of feasible states at hour t − 1

$F(t,I)$: The production cost for state (t, I).

1. Repeat the process for the next hour (t+1).
2. Solve the master problem of UC and calculate the total production cost

Remark: in the extensive network, we reinforce min uptime/min downtime rules to reduce the feasible states in each power level

Results and discussion

Our suggested approach utilizes MATLAB language to determine the optimal path. We employ hybrid dynamic programming with a priority list as a screening tool to resolve the engagement of the units for a 10-unit power system. The power system data and loading scheme are given in Table 1. The solution approach for the unit engagement problem is realized in MatlabR2018b. A power system with ten generating units is employed to show the suggested approach.

In our implementation, energy and reserve are considered simultaneously in the formulation of 24 hours scheduling period. The fuel cost function of each generating unit is estimated in quadratic form. To solve this problem, we have to check all the 10-unit combinations. Certain combinations will not be feasible if either the sum of all the

We notice that of the 1023 possible combinations (210– 1), there are only eight combinations representing the 24 states of the day.

Every 24 hours, and according to the time demand, Units 1 and 5 no longer work, and Units 2 and 6 operate all-day The third one works from 8 a.m. to 7 p.m. The fourth unit operates from 6 a.m. to 9 p.m. The seventh one works from 10 a.m. to 8 p.m. The eighth unit only stops at the last hour (at 24 hours). The ninth unit started from 7 a.m. until the end of the day. The tenth unit only stops at the last three hours (from 22 hours).

The operating cost equals 535273 £

Table 1. Unit data of the 10-unit test system

Unit	Pmin [MW]	Pmax [MW]	Start_cost_cold [£]	Min_up_time [h]	Min_down_time [h]	In.status [h]	Coef_a [£]	Coef_b [£/MWh]	Coef_c [£/MWh^2]	Shut_down_cost [£]
1	30	100	2050	5	4	-10	820	9.023	0.00113	0
2	130	400	1460	3	2	10	400	7.654	0.00160	0
3	165	600	2100	2	4	-10	600	8.752	0.00147	0
4	130	420	1480	1	3	-10	420	8.431	0.00150	0
5	225	700	2100	4	5	-10	540	9.223	0.00234	0
6	50	200	1360	2	2	10	175	7.054	0.00515	0
7	250	750	2300	3	4	-10	600	9.121	0.00131	0
8	110	375	1370	1	3	10	400	7.762	0.00171	0
9	275	850	2200	4	3	-10	725	8.162	0.00128	0
10	75	250	1180	2	1	10	200	8.149	0.00452	0

Table 2. Uc results by dynamic programming

Hour	Demand	Tot. Gen	Min MW	Max MW	ST-UP Cost	Prod. Cost	F-Cost	State	Units ON/OFF 1 2 3 4 5 6 7 8 9 10
0	-	-	365	1225	0	0	0	100	0 1 0 0 0 1 0 1 0 1
1	1025	1025	365	1225	0	9670	9670	100	0 1 0 0 0 1 0 1 0 1
2	1000	1000	365	1225	0	9447	19117	100	0 1 0 0 0 1 0 1 0 1
3	900	900	365	1225	0	8561	27678	100	0 1 0 0 0 1 0 1 0 1
4	850	850	365	1225	0	8123	35801	100	0 1 0 0 0 1 0 1 0 1
5	1025	1025	365	1225	0	9670	45471	100	0 1 0 0 0 1 0 1 0 1
6	1400	1400	495	1645	1480	13434	60385	218	0 1 0 1 0 1 0 1 0 1
7	1970	1970	770	2495	2200	19218	81803	591	0 1 0 1 0 1 0 1 1 1
8	2400	2400	935	3095	2100	23815	107718	836	0 1 1 1 0 1 0 1 1 1
9	2850	2850	935	3095	0	28254	135972	836	0 1 1 1 0 1 0 1 1 1
10	3150	3150	1185	3845	2300	31702	169974	991	0 1 1 1 0 1 1 1 1 1
11	3300	3300	1185	3845	0	33220	203193	991	0 1 1 1 0 1 1 1 1 1
12	3400	3400	1185	3845	0	34242	237436	991	0 1 1 1 0 1 1 1 1 1
13	3275	3275	1185	3845	0	32966	270401	991	0 1 1 1 0 1 1 1 1 1
14	2950	2950	1185	3845	0	29706	300107	991	0 1 1 1 0 1 1 1 1 1
15	2700	2700	1185	3845	0	27260	327367	991	0 1 1 1 0 1 1 1 1 1
16	2550	2550	1185	3845	0	25820	353187	991	0 1 1 1 0 1 1 1 1 1
17	2725	2725	1185	3845	0	27502	380688	991	0 1 1 1 0 1 1 1 1 1
18	3200	3200	1185	3845	0	32206	412894	991	0 1 1 1 0 1 1 1 1 1
19	3300	3300	1185	3845	0	33220	446114	991	0 1 1 1 0 1 1 1 1 1
20	2900	2900	1020	3245	0	28899	475013	881	0 1 0 1 0 1 1 1 1 1
21	2125	2125	770	2495	0	20698	495711	591	0 1 0 1 0 1 0 1 1 1
22	1650	1650	565	1825	0	15878	511589	289	0 1 0 0 0 1 0 1 1 0
23	1300	1300	565	1825	0	12573	524162	289	0 1 0 0 0 1 0 1 1 0
24	1150	1150	455	1450	0	11111	535273	156	0 1 0 0 0 1 0 0 1 0

Conclusion

In this paper, we propose an advanced dynamic programming and efficient priority list screening approach for the UC problem. The priority list screening is based on the no-load cost and incremental heat rate data to eliminate some infeasible and higher-priced states. In addition, we include the constraints of the unit up and down time, which can also reduce the selection states. The priority list screening technique is implemented to obtain a superior starting solution quickly. The simulation results clearly show the efficiency of the priority list screening approach. The proposed solution in this paper can speed up the solution process, and, therefore, the number of economic dispatch calculations can be reduced. We imply a dynamic programming (DP) method for each list to solve the economic dispatch problem for commuted plants as a partial problem. A newly developed approach algorithm was employed to address the thermal unit commitment problem using the dynamic programming (DP) based approach. For discrete individuals,

the maximum MW of the involved units is lower than the loading or if the total of all the minimum MW of the engaged plants is greater than the loading. The plants must be dispatched for each feasible combination using the priority list method. The results are presented in Table 2 below.

subproblems, dynamic programming with no discretization of generation levels proved to be an effective method. This approach offers the benefits of non-discretization of the production levels and is found to be effective for those systems with a limited number of units subject to ramp rate restrictions. This method designed to produce feasible solutions is effective, and near-optimal solutions are obtained.

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