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THE DEVELOPMENT OF THE TABU SEARCH TECHNIQUE FOR EXPANSION POLICY OF POWER PLANT CENTERS OVER SPECIFIC DEFINED RELIABILITY IN LONG RANGE PLANNING*

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Abstract – In this paper, a new approach for optimizing the expansion policy (EP) of power plant networks has been developed based on the recursive Tabu search technique. The objectives of the EP model are minimizing the fixed investment and the operational cost over certain network reliability in the long term. The EP problem is the NP-complete mixed integer-programming model. The model deals with optimizing the region allocation to power plant centers and the power plant center capacity over a specified planning horizon (years) by considering the 3E's (Energy, Environment, Economic) and the network reliability constraints. Examples are given to illustrate that the approach is able to resolve the EP model in short CPU time in comparison with an analytic approach.

Keywords – Power plant expansion, Tabu search, network reliability, optimization technique

1. INTRODUCTION

In any region of the world, economic development is deeply related to the availability of energy. In developing countries there are great energy concerns, especially industrial areas. In some of these countries, the regions are sometimes rapidly and indiscriminately connected to electricity power plant networks without considering the long term effects of the expansion policy of power plant centers. Obviously, high investment is a crucial element in EP. The EP has been discussed in numerous publications and the majority of existing literature considers the policy for one time period (year) and one load center. However, the people responsible for planning the expansion policy increase generation capacity in a specific time frame under certain objectives. The objectives typically include lower investment and operational costs.

In recent years, many notable studies mathematical methods such as linear [1-3] and dynamic programming [4-9] to study the EP. The EP generally exhibits a structure that divides decomposition into stages. This allows the appropriate use of dynamic programming or mixed integer programming (DP/MIP) when used in conjunction with other optimization techniques such as design analysis [8, 9], production [8], probabilistic simulation [5, 6] and expert systems [4, 10]. In most cases, the DP/MIP is applied to the last stage of planning after the trail solutions to the expansion policy problem have been generated. One pre-condition of using the DP/MIP is that the power plant sizes have to be known beforehand, a requirement that makes the DP/MIP unsuitable. In this paper, a new approach is used to solve the multi-location (centers) expansion center problem. A model and an algorithm are developed to find the best combination of center location, center size over a number of years, and power distribution. The problem is formulated as a mixed integer program. Due to the special structure of the problem and model, a well-developed recursive Tabu search approach is quite successful in obtaining an extremely satisfactory solution.

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2. PROBLEM DESCRIPTION

This section includes the concept of expansion policy, the assumptions of either the simplicity or clarity of the EP, and the mathematical model of EP.

a) Concept and assumption

A two-period illustration of a power plant/distribution network system is shown in Fig. 1. It consists of a few power plant centers located in '**C**', where different centers and many regions are fed. Each region is connected to the best power plant center in a certain period of time with minimum cost. If the produced power energy of the region i in period t is greater than the demand of the power energy of the region i in period t, then the excess energy may be injected into the other centers. Therefore, drawing power from the other centers with surplus production rectifies any shortfall in the energy supply of one center.

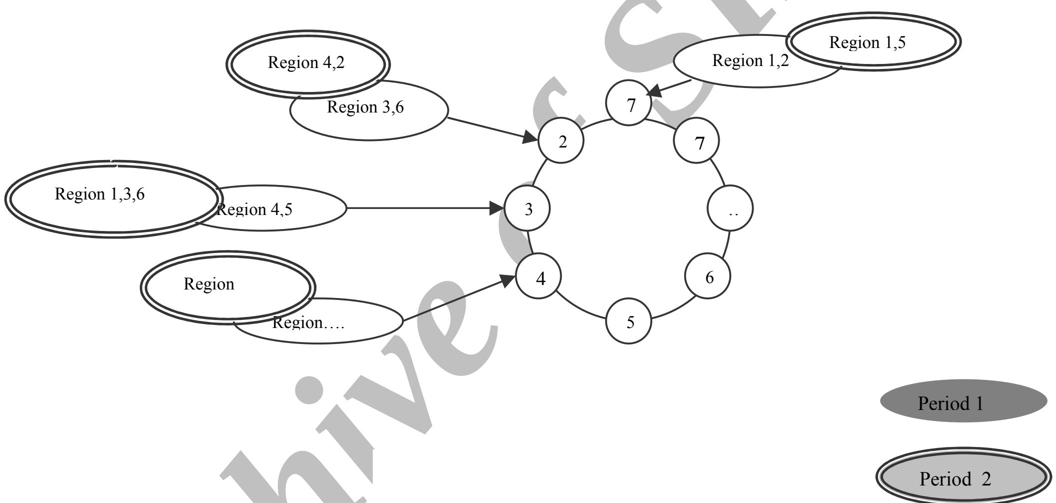

Fig. 1. Distribution of power over two periods

The expansion policy problem is discussed in this paper based on the following assumptions:

- The storage of electricity power increases costs and it is unacceptable.
- The power demand of each region is given as input of the model.
- Any shortage of the power supply causes lost power supply penalty (LPSP), which is related to network reliability constraint.
- Number of the power center in network is a decision variable that should be defined along with the size of each center.
- Inflation and other uncontrollable variables are kept out from the model.
- Drawing power from the other centers with surplus production to rectify any shortfall in energy supply of one center is allowed.

b) Problem formulation

Objective function: The total cost (TC) comprises the annual investment cost (Ic), the annual operation and maintenance cost (Mc), and the utilization cost (Uc).

$$TC = MIN \sum_{t=1}^{T} Ict + Mct + Uct \qquad (1)$$

The investment cost comprises a fixed cost and variable cost. The fixed cost is associated with the decision to locate a plant in particular region. The variable cost is the cost of generating power in region j in period t.

$$Ict = \sum_{J=1}^{J}[(T - t+1)W_{j,t} * P_{j,t} + \lambda_{j,t} * F_{j,t}] \quad \text{for } t = 1,2,\ldots,T \qquad (2)$$

The cost of maintenance and operation of the system tends to be minimized. This is a function of the unit cost and total capacity of a plant in a particular region. Suppose this depends on factors such as parts, wages, etc., it is generally assumed to be a fraction of the cost of the system.

$$Mct = \sum_{J=1}^{J} m_j * W_{j,t}\left(\sum_{r=1}^{t} P_{j,r}\right) \qquad \text{for} \qquad t = 1,2,\ldots,T \tag{3}$$

The utility cost is the net cost of the power exchange between the grid and centers in the network. Sometimes the grids are not very reliable, thus we should associate a penalty with the inability of a grid to meet the demand. The measure of the ability to meet electric power demand by any system is known as the Loss of Power Supply Probability (LPSP).

$$Uct = \sum_{j=1}^{J} ps_{j,t} * rs_{j,t} - \sum_{j=1}^{J} pb_{j,t} * cs_{j,t} \{(1-\Psi) + \Psi * \gamma\} \quad \text{for} \quad t = 1,2,\ldots,T \tag{4}$$

Constraint: *1-Reliability*: The amount of power produced by the center plus the amount of power supplied from the grid, less the amount of power supplied to grid should be equal to the load demand. We call this constraint reliability since it has played with LPSP.

$$\sum_{r=1}^{t}\sum_{j=1}^{J} p_{j,r} + \sum_{j=1}^{J} pb_{j,t} - \sum_{j=1}^{J} ps_{j,t} = \sum_{j=1}^{J} L_{j,t} \qquad \text{for} \quad t = 1,2\ldots,T \tag{5}$$

The power supplied from the grid to meet demand in region j in the period t should not exceed the total demand in that region.

$$pb_{j,t} \ \ldots \ L_{j,t} \quad \text{for} \quad t = 1,2,\ldots,T \tag{6}$$

2- Allocation: The Load of center j in period t is equal to the sum of the demand of all regions covered by center j in period t based on peak of demand load of regions in period t.

$$L_{j,t} = \sum^{I} \pi i, jt * d_{i,t} \quad \text{for} \quad t = 1,2,\ldots,T \ \ \& \ j = 1,2,\ldots,J, \quad i = 1 \tag{7}$$

3- Budget: The amount of money available for investment is restricted. The generation capacity of the centers installed each period is thus restricted by the amount of money available for investment of each period.

$$\sum_{j=1}^{J}(1 + m_j) * W_{j,t}\left(\sum_{r=1}^{t} P_{j,r}\right) + \sum_{j=1}^{J} \lambda_{j,t} * F_{j,t} \ \ldots \ INVt \quad \text{for} \quad t = 1,2,\ldots,T \tag{8}$$

4- Expansion Size: It is desirable to limit the size of the various centers based on factors such as economic growth of the region.

$$P_{j,t} \ldots H \ \text{for} \quad t = 1,2,\ldots,T \tag{9}$$

5- Capacity: The amount of power fed into the grid should not exceed the total load demand in the other locations.

$$ps_{j,t} \ \ldots \ \beta_{j,t} * \sum_{i=1}^{I} d_{i,t} \qquad \text{for} \quad t = 1,2,\ldots,T \quad j = 1,2,\ldots,J \quad i \mid j \tag{10}$$

The amount of power that is sent from regions to the grid in period t would not exceed the generation capacity in that region.

$$\sum^{t}\sum^{J} P_{j,r} \geq \sum^{J} Ps_{j,t} \qquad \text{for} \quad t = 1,2,\ldots,T \tag{11}$$

The maximum possible power output from region i in period t should not exceed the peak of the demand from region i in period t if no power is sent to the grid.

$$\sum^{T}\sum^{J} P_{j,r} \ldots H * \sum^{J}(\beta_{j,t} + \xi_{j,t} * d_{i,t}) \qquad \text{for} \qquad t=1,2,\ldots,T \tag{12}$$

$$\xi j,t \ \ldots \ \lambda j,1 \qquad \text{for } j=1,2,\ldots,J, \qquad \xi j,t-1 \ \ldots \ \xi j,t \qquad \text{for } j=1,2,\ldots,J \ \ t=1,2,\ldots,T$$

$$\xi j,t \ \ldots \ \lambda j,t \qquad \text{for } j=1,2,\ldots,J \ \ t=1,2,\ldots,T, \qquad \xi j,t \ \geq \beta j,t \qquad \text{for } j=1,2,\ldots,J \ \ t=1,2,\ldots,T$$

6- Environment: To control the pollution in each region, the capacity of each power center should meet the following constraints:

$$\sum_{r=1}^{t} P_{j,r} * \mathrm{CO2} \ \ldots \ \mathrm{STDCO2} \qquad \text{for } j=1,2,\ldots,J \ \ t=1,2,\ldots,T \tag{13}$$

$$\sum_{r=1}^{t} P_{j,r} * \mathrm{SO2} \ \ldots \ \mathrm{STDSO2} \qquad \text{for } j=1,2,\ldots,J \ \ t=1,2,\ldots,T \tag{14}$$

$$\sum_{r=1}^{t} P_{j,r} * \mathrm{NOx} \ \ldots \ \mathrm{STDNOx} \qquad \text{for } j=1,2,\ldots,J \ \ t=1,2,\ldots,T \tag{15}$$

Since solving this model while the scale of the model being large is NP-complete, we offer a developed EP Tabu search model that can be used to find the best solution for the EP model.

3. TABU SEARCH TECHNIQUE

Glover [11-13] developed the Tabu search in 1977 as a deterministic search technique that is able to escape from local optima by using a list of forbidden neighboring solutions which are known as a Tabu list. This technique has been successfully applied to many combinatorial optimization problems. The Tabu search process starts with a feasible solution, and during each iteration it evaluates all solutions in the neighborhood except those in the current Tabu list. Then the search moves to the best non-Tabu solution in the neighborhood and the best solution found so far will get updated. When the Tabu list is full and a new entry arrives, the oldest entry in the list will be kept out from the list. In addition to escaping local optima, using the Tabu list can also be used to avoid the re-visiting of recent neighbors recorded in the list and thus save computational time.

The Tabu search has two other features that make it more sophisticated, *aspiration* and *diversification*. Aspiration is a criterion that allows the search to override the Tabu status of a solution. This feature provides backtracking to a recent solution if they can lead to a new path of better solution. Furthermore, aspiration prevents the search from being trapped into a solution surrounded by Tabu neighbors. This is more likely to occur when the size of neighborhood is less than or equal to the size of the Tabu list. In this case, the search may be frozen unless the least neighbor's Tabu status can be ignored by an aspiration criterion. For instance, the aspiration criterion can be satisfied if all the solutions in the current neighborhood are Tabu, i.e., all of them are in the Tabu list. Therefore, the Tabu status of the best neighboring solution can be ignored and the move will be made to this solution.

Diversification is often used to explore some sub-domains that may not be reached otherwise. Diversification is done by redirecting the search path or re-starting the search from a different initial solution. Without diversification, the search may be limited to a subset of solution space. To simplify the search approach, a new concept called "partition set" is introduced. A partition set is defined as a set of connected neighbors separating the entire solution space into two sections whereby the objective values are higher than those of the adjacent neighbors in the two separated sections. A partition set could be either closed or open. Without diversification the search will not be able to pass the partition barriers, and the search may be limited to a very small area. In fact, the diversification helps the search to restart the search from a new subset simply by relocating the next search point to that subset. The optimum solution cannot be reached unless the search starts from one of its immediate neighbors. This is most likely to happen only when diversification methods such as restarting from the best solution obtained so far and restarting from a randomly selected point do not work.

4. DEVELOPED EP TABU SEARCH ALGORITHM

To solve the expansion policy of power plant centers in the long term, a Tabu search algorithm incorporating both aspiration and diversification strategies has been developed and is presented. An array that generates the neighbor solution is used in the algorithm. It has I+J cells and each cell could have only one status of center or region. Each center covers the summation of power demand of all region cells before itself until the previous center. If there are more than two centers being put together, we will assume that the capacity of the right center in the array is equal to zero. By pair wise exchanging the cells in the array, we will be able to generate a neighboring solution. Note that only one generated sequence that causes all centers to get together in the left side of all regions is the forbidden solution, and therefore should be discarded. With reference to the notations defined in section [7]:

Step 1. Initial solution: Read value of I and J

1. Read input data and specify the maximum allowed search time Tmax and Tabu list size Tsize
2. Set Cb← Mb (a big number), Mc=0, T_list={∅}, and Sb={∅}
3. Create an array with I+J cells and create a sequence of regions and centers in array as S^{**} based on Min.Max matrix, which is the allocation of the demand of the regions to the least cost centers, respectively, by turn.
4. Calculate the objective function $G(S^{**})$ {i.e. TC), set $G(S^{**})$=Mb

Step 2. Searching: Generate a feasible neighbor sequence s for S^{**}. If s is not in the current Tabu list, calculate G(S) and update the best sequence in the neighborhood S^{**}← S if $G(S)<G(S^{**})$, otherwise discard S. Repeat this for all feasible neighbors of S^{**}

1. Set $G(S^{**})$← $G(S^{*})$, S^{**}← S^{*} and update Tabu list T-list.
2. In case of improvement, i.e $G(S^{**})<Cb$, update the best solution: Cb ← $G(S^{**})$, Sb← S**.
3. If time is over, i.e time>Tmax , then Stop and Go To Step 4 *(Modification of search parameters).* Otherwise update the number of moves made so far in the current phase and if the number of moves passes the maximum allowed move then go to Step 3 *(Diversification)*, Otherwise Go to step 2 of (*Searching).*

Step 3. Diversification: Clear Tabu list and diversify the search path by choosing last center sequence and Go to step 2 *(Searching)*

Step 4. Modification of search parameters: Choose one or both options and Go to 2 of Step 1

1. Change Tabu list size.
2. Change the length of each search phase.

The diversification policies in the algorithm are used to further reduce the chance of cycling. As shown in the algorithm, the search process is divided into a number of search phases when the diversification policy is applied. Each of the search phases consists of the maximum number of moves. At the end of each search phase, the Tabu list is cleared and a diversification option, which would be the same or a different one used in the previous phase, is selected for the next phase. If diversification is not preferred, a sufficiently large number of moves should be used and the entire search process includes only a single phase.

This algorithm is coded in C and the application of the algorithm is applied for several models that are presented in Section [5].

5. RESULT

Indeed the problem presented as EP model is a mixed integer program. By increasing the number of centers, regions, and period of study, the dimension of the model will be increased and become known as large-scale model. Consequently, the model is NP-complete and quite difficult to be solved in a limited time. In this paper, the developed recursive Tabu search algorithm and analytical methods such as Benders have been used to solve several examples, and the results are shown in Table1. Although the developed Tabu search algorithm suffers from initial solution, wall problem, Tabu list size, and time consumption, it is often faster and more efficient for NP-complete problems such as the EP model. By comparing the several example results, we find that the analytical approaches such as Benders decomposition have difficulty in solving the large-scale models. For instance, the largest model that could be solved on Sun Ultra has 712 constraints, 162 integer variables, and 162 constants variables for 3:48:00 CPU time. Table 1 and Fig. 2 depict the average CUP time and the dimension of several models along with the maximum dimension of a model that could be solved by analytical approaches. From the run time stand point of view, the EP model is an NP-complete problem. Therefore, the models with dimension larger than trail 6 are supposed to be solved by the meta heuristic approach which would be applied to combinatorial optimization problems by escaping from local optima solution.

The developed recursive Tabu search algorithm helps to solve the NP-complete EP model with minimum variation from optimum solution in remarkable CPU time. Table 2 presents the result of application of the algorithm on a significant number of models, along with the result of the other approaches and the deviation columns. The deviation column shows the deviation of the Tabu search algorithm result with other technique results. Since the models I,II, III, IV and V could be solved by the analytic approach, the CPU time has come from the Bender decomposition technique. Because of the large-scale problem, the other models could not be solved by the analytic approach. Therefore, we have to use the other meta-heuristic methods to find the approximate solution. However, the other meta-heuristic methods have shortcomings in solving the NP-complete EP models with respect to the recursive Tabu search algorithm.

To check the performance of the Tabu search algorithm, we check the convergence, accuracy and effect of the Tabu list size. To examine the performance of the proposed Tabu search algorithm, the convergence curves based on the outputs corresponding to the best Tabu list size are checked. They show the improvement process has no reduction after approximately one third of CPU time presented in Table 2 for all models. The accuracy of the heuristic solution is examined by comparing the solution with the optimal solution obtained by the analytical approaches in Table 2.

Table 1. CPU Time with respect to the various criteria

Trail	No. of constraints	No. of Integer variable	No. of Constant variable	Average C.P.U time H:M:S
1	225	60	60	0:05:28
2	315	84	84	0:03:25
3	405	108	108	0:12:08
4	560	150	150	2:02:11
5	712	162	162	3:48:00
6	>712	>162	>162	Impossible

Table 2. Table of EP and analytical method results

Model	No. of year	No. of region	No. of center	Tabu search CPU time(H:M:S)	Effective Tabu search CPU time(H:M:S)	Analytical approach CPU Time(H:M:S)	Other Analytical approach/Deviation from Tabu solution
I	1	5	5	0:00:20	0.00:07.66	0:00:12.85	%0
II	5	5	5	0:01:05	0.00:56.81	0:05:28.50	%0
III	1	43	5	0:12:43	0.03:50.15	0:04:23.40	%0
IV	16	43	5	0:18:02	0.04:01.23	0:05:46.18	%1
V	16	43	10	0:15:23	0.03:08.05	0:07:45.60	%2
VI	16	43	16	0:25:00	0.04:30.42	0:06:48.33	%7
VII	16	43	20	0:39:20	0.08:30.01	0:12:08.25	%5
VIII	16	43	30	0:23:51	0.07:10.73	2:02:11.27	%6
IX	16	43	43	0:45:18	0.18:20.37	0:36:15.16	%3

6. CONCLUSION

This paper illustrates an approach to find the optimum number and the capacity of centers, the optimum distribution power with respect to a minimized fixed investment cost, operational cost, and maximum network.

Reliability along with other economical and environmental objective functions in the long term as an expansion policy of power plant centers (EP), has been considered in this study. This approach is the Tabu search and is able to escape from local optima by using a list of forbidden neighboring solutions. Since the EP model is an NP complete, the developed Tabu search algorithm may resolve the model faster and more efficiently with respect to our experience with several attempts over a large number of examples as is shown in Fig. 2.

According to the information indicated in Table 1 and Table 2, although our algorithm is able to find a solution extremely close to the final solution, working on the initial solution stil remains vital to improve the CPU time of our algorithm.

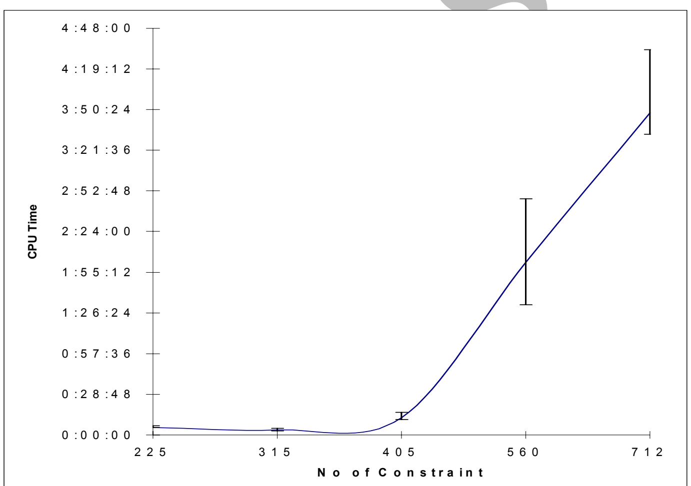

Fig. 2. CPU time curve and standard deviation

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NOMENCLATURE

Cb	lowest objective function value obtained so far
CO_2	rate of CO_2 for a unit of power
$cs_{j,t}$	cost of purchase of unit power from network for center j in period t
$d_{i,t}$	peak of demand load of region i in period t
$F_{j,t}$	fixed investment of center j in period t per unit power
G(S	total cost of Solution S
H	upper limit of capacity in each center
I	number of regions
$Ic_{i,t}$	investment cost on center j in period t
Ic_t	total investment cost in period t
INV_t	allocated budget to center j in period t
J	number of centers
$L_{j,t}$	load of center j in period t
Mb	big integer number
Mc	counter used to record the total number of moves made so far
$Mc_{i,t}$	investment cost on center j in period t
Mc_t	total Maintenance & Operational cost in period t
$m_{j,t}$	coefficient of maintenance & operational cost of center j in period t

NO_x	rate of NO_x for a unit of power
$pb_{j,t}$	supplied power to center j in period t
$P_{j,t}$	expansion capacity of center j in period t
$ps_{j,t}$	dedicated power to network by center j in period t
$rs_{j,t}$	revenue center j in period t
S**	best solution in the immediate previous neighborhood
S^*	best solution in the current neighborhood
Sb	best solution found so far
SO_2	rate of SO_2 for a unit of power
$STDCO_2$	standard level of CO_2 per period
$STDNO_x$	standard level of NO_x per period
$STDSO_2$	standard level of SO_2 per period
T	number of periods (year)
T_list	Tabu list
Tc	total cost
Tmax	maximum allowed search time
Tsize	Tabu-list size
$Uc_{i,t}$	utility cost on center j in period t
Uc_t	total Utility cost in period t
$W_{j,t}$	production cost of center j in period t unit power (kw/h)
γ	lost power supply penalty
Ψ	lost power supply probability (network reliability)
$\tau_{i,j,t}$	1 if demand of region i is covered by center j in period t
$\lambda_{j,t}$	1 if capacity of center j is increased in period t otherwise 0
$\beta_{j,t}$	1 if center j dedicate power to network , otherwise 0
$\xi_{j,t}$	zero-one variable to control upper limit of capacity of center j period t

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