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LONG TERM POWER PLANT CENTERS EXPANSION POLICY IN IRAN. A TABU SEARCH TECHNIQUE APPROACH

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Abstract. In this paper, the problem of optimal distributions of regional power demand to electrical power plant centers is analyzed and solved. The criterion for the optimal power demand distribution will be the minimization of the fixed investment costs and of the operational costs. The Tabu search technique will be used to achieve a satisfactory network reliability in the light of the above criterion .Generally, electrical power plant centers capacity and the number of the centers are determined after specific plant locations have been selected. In this paper an expansion policy of power plant centers is considered in the context of which the selection of regions that must be allocated to power plant centers and the power plant centers capacity are simultaneously determined over a specified planning horizon (years). The problem is illustrated as a NP-complete mixed integer programming model and it is solved by applying the developed recursive Tabu search technique to find the optimal number of centers and the optimal distribution of power with respect to 3 E's (Energy, Environment , Economy) objective function subject to long term reliability constraints.

Keywords: Power Plants, Expansion Policy, Tabu Search, Iran

1. INTRODUCTION

In any region of the world, economic development is strongly related to the availability of energy. This happens especially in the industrial areas of developing countries. In some of these countries, the regions are sometimes rapidly and indiscriminately connected to electric power plant networks without considering the expansion policy of power plant centers (EP) in the long term. Obviously, the relevant high investment cost becomes a crucial element in EP. The EP has been discussed in numerous publications and the majority of the 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 specific time frame under certain objectives. The objectives typically include low investment and operational costs.

Many researchers use mathematical models, such as linear programming [19, 20, 25] and dynamic programming [9,12, 13, 15, 22, 23] to study the EP. The EP, in general, exhibits a structure that makes necessary the decomposition in to stages. This makes dynamic programming or mixed integer programming (DP/MIP) to be very appropriate when they are used in conjunction with other optimization techniques such as design analysis [15, 23], production [22], probabilistic simulation [12,13] and expert systems [9, 24]. 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 in prior, a requirement that makes the DP/MIP unsuitable . In this paper, a neural network 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 programming problem. Due to the special structure of the problem and model, a well-developed Tabu search approach is applied which is proved to be quite successful in obtaining a highly satisfactory solution.

2. PROBLEM DESCRIPTION

In this section the concept of expansion policy and the assumption of either the simplicity or clarity of the EP are analyzed as well as the mathematical model expressing the EP .

2.1 Concept and Assumption

An illustration of power plant/distribution network system is shown in Figure 1. It consists of a few plant centers located in C different centers from which a number of regions are fed. Each region is connected in a best way to a power plant center in a specific period of time at a minimum cost. The produced power energy and the demand for power energy of region i in period t are expressed by Oi and Li respectively. If Oi is more than Li , then the excess energy may be injected into the other centers if applicable .Therefore, drawing power from the other centers with surplus production rectifies any shortfall in energy supply of one center .

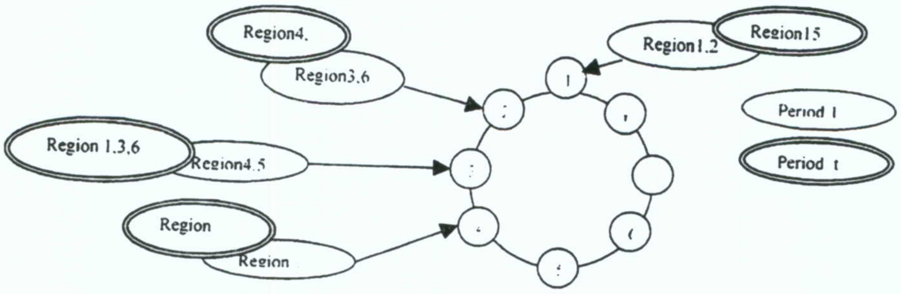

FIGURE 1. Total view of power network

The discussion of the expansion policy problem is based on the following assumptions:

- Storage of electricity power causes cost and it is unacceptable
- Power demand of each region is given as an input of model
- Any shortage of power supply causes lose power supply penalty (LPSP) that is related to network reliability constraint
- The number of power centers in the 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 the other centers with surplus production, to rectify any shortfall in energy supply of a center, is allowed .

2.2 Notation

T= Number of periods (year)
I = Number of regions
J = Number of centers
Tc = Total cost
Ic_t = Total Investment cost in period t
Mc_t = Total Maintenance & Operational cost in period t
Uc_t = Total Utility cost in period t
$Ic_{i,t}$ = Investment cost on center j in period t
$Mc_{i.t}$ = Investment cost on center j in period t
$Uc_{i.t}$ = Utility cost on center j in period t
$W_{j.t}$ = production cost of center j in period t unit power (kw/h)
$P_{j.t}$ = expansion capacity of center j in period t
$\lambda_{j.t}$ = 1 if capacity of center j is increased in period t otherwise 0
$F_{j.t}$ = fixed investment of center j in period t per unit power
$m_{j.t}$ = coefficient of maintenance & operational cost 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
$pb_{j,t}$ = supplied power to center j in period t
$cs_{j.t}$ = cost of purchase of unit power from network for center j in period t
Ψ = Lose power supply probability (network reliability)
γ = Lose power supply penalty
$L_{j.t}$ = Load of center j in period t
$d_{i.t}$ = peak of demand load of region i in period t
$\tau_{I,j.t}$ = 1 if demand of region i is covered by center j in period t
INV_t = allocated budget to center j in period t
H = upper limit of capacity in each center
$\xi_{j.t}$ = zero-one variable to control upper limit of capacity of center j period t
$\beta_{j.t}$ = 1 if center j dedicate power to network . otherwise 0
CO_2 = rate of CO_2 for an unit of power
SO_2 = rate of SO_2 for an unit of power
NO_x = rate of NO_x for an unit of power
$STDCO_2$ = standard level of CO_2 per period
$STDSO_2$ = standard level of SO_2 per period
$STDNO_x$ = standard level of NO_x per period

2.3 Problem formulation

Objective Function

$$TC = MIN \sum_{t=1}^{T} Ic_t + Mc_t + Uc_t \qquad (1)$$

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

$$Mc_t = \sum_{j=1}^{J} m_j * W_{j,t} (\sum_{\ell=1}^{t} P_{j,\ell}) \quad \text{for } t = 1,2,\ldots,T \quad (3)$$

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

Constraints

1-Reliability

$$\sum_{\ell=1}^{t} \sum_{j=1}^{J} P_{j,\ell} + \sum_{j=1}^{J} pb_{j,t} - \sum_{j=1}^{J} ps_{j,t} = \sum_{j=1}^{J} L_{j,t} \quad \text{for } t = 1,2,\ldots,T \quad (5)$$

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

2- Allocation

$$L_{j,t} = \sum_{i=1}^{I} \tau_{i,j,t} * d_{i,t} \quad \text{for } t = 1,2,\ldots,T \ \& \ j = 1,2,\ldots,J \quad (7)$$

3- Budget

$$\sum_{j=1}^{J} (1 + m_j) * W_{j,t} (\sum_{\ell=1}^{t} P_{j,\ell}) + \sum_{j=1}^{J} \lambda_{j,t} * F_{j,t} \leq INV_t \quad \text{for } t = 1,2,\ldots,T \quad (8)$$

3- Expansion Size

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

4- Capacity

$$ps_{j,t} \leq \beta_{j,t} * \sum_{i=1}^{I} d_{i,t} \quad \text{for } t=1,2,\ldots,T \quad j=1,2,\ldots,J \quad i \neq j \quad (10)$$

$$\sum_{\ell=1}^{t} \sum_{j=1}^{J} P_{j,\ell} \geq \sum_{j=1}^{J} ps_{j,t} \quad \text{for } t=1,2,\ldots,T \quad (11)$$

$$\sum_{\ell=1}^{t} \sum_{j=1}^{J} P_{j,\ell} \leq H * \sum_{j=1}^{J} (\beta_{j,t} + \xi_{j,t} * d_{i,t}) \quad \text{for } t=1,2,\ldots,T \quad (12)$$

$$\xi_{j,t} \leq \lambda_{j,1} \quad \text{for } j=1,2,\ldots,J \quad (13)$$

$$\xi_{j,t-1} \leq \xi_{j,t} \quad \text{for } j=1,2,\ldots,J \quad t=1,2,\ldots,T \quad (14)$$

$$\xi_{j,t} \leq \lambda_{j,t} \quad \text{for } j=1,2,\ldots,J \quad t=1,2,\ldots,T \quad (15)$$

$$\xi_{j,t} \geq \beta_{j,t} \quad \text{for } j=1,2,\ldots,J \quad t=1,2,\ldots,T \quad (16)$$

5- Environment

$$\sum_{\ell=1}^{t} P_{j,\ell} * CO_2 \leq STDCO_2 \quad \text{for } j=1,2,\ldots,J \quad t=1,2,\ldots,T \quad (17)$$

$$\sum_{\ell=1}^{t} P_{j,\ell} * SO_2 \leq STDSO_2 \quad \text{for } j=1,2,\ldots,J \quad t=1,2,\ldots,T \quad (18)$$

$$\sum_{\ell=1}^{t} P_{j,\ell} * NO_x \leq STDNO_x \quad \text{for } j=1,2,\ldots,J \quad t=1,2,\ldots,T \quad (19)$$

Since solving this model while the scale of model being large is NP –complete, in this paper an appropriate EP Tabu search model is proposed that can be used to find the best solution for the EP model.

3. TABU SEARCH TECHNIQUE

Glover (1977) developed Tabu as a deterministic search technique that is able to escape from local optima by using a list of forbidden neighboring solutions which is known as 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, evaluates all solutions in the neighborhood of it except those in the current Tabu list. Then the search moves to the best neighboring solution outside the current Tabu list 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, the Tabu list can also be used to avoid the re-visiting of recent neighbors recorded in the list and thus save computational time

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 recent solution if it could lead to a new path towards a 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 solution space is less than or equal to the size of the Tabu list. In this case, the search may be freezed unless the last 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 a 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 restarting the search from a different initial solution. Without diversification, the search may be limited to a subset of the 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 and 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 trapped to a very small area. As a matter of the fact, the diversification allows for Tabu search to restart from a new subset simply by relocating the next search point to that subset. The optimal solution cannot be reached unless the search starts from one of its immediate neighbors and 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. THE PROPOSED EP TABU SEARCH ALGORITHM

To find an optimal expansion policy of power plant centers on a long term basis a Tabu search algorithm, incorporating both aspiration and diversification strategies, has been developed and it is presented in this section. An array that generates the neighborhood solution space is used in the algorithm. It has I+J cells and each cell could have only one status of a center or of a region. Each center covers the total power demand of all region cells before itself till 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. Consequently, by changing the sequence of the cells, we will be able to generate a neighboring solution. Note that, only one generated sequence, that causes all centers get together in the left side of all regions, is the forbidden solution and therefore it should be discarded.

Step1. Initial solution

1. Read value of I and J
2. Read input data, and specify the maximum allowed search time Tmax and Tabu list size Tsize
3. Set $Cb \leftarrow Mb$ (a big number), $Mc=0$, $T\_list=\{\emptyset\}$, and $Sb=\{\emptyset\}$
4. Create an array with I+J cells and create a sequence of regions and centers in array as S^{**}
5. Calculate the objective function $G(S^{**})${i.e. TC), set $G(S^{**})=Mb$

Step 2. Searching

1. 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 $S^{**} \leftarrow S$ if $G(S)<G(S^{**})$, otherwise discard S. Repeat this for all feasible neighbors of S^{**}
2. Set $G(S^{**}) \leftarrow G(S^{*})$, $S^{**} \leftarrow S^{*}$ and update Tabu list T-list
3. In case of improvement i.e $G(S^{**})<Cb$, update the best solution: $Cb \leftarrow G(S^{**})$, $Sb \leftarrow S^{**}$
4. If time is over i.e time>Tmax Stop. Otherwise update the number of moves made so far in the current phase and go to Step 3 , Otherwise Go to step 2

Step 3. Diversification

Clear Tabu list and diversify the search path by choosing last center sequence and Go to step 2

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

This algorithm is coded in C++ and applications of it are presented in the next section.

5. NUMERICAL RESULTS

The problem presented above is a mixed integer programming one. Since integer variables are complex variables and the scale of the model is large, the computational time required to solve the problem is considerable. In this paper, the proposed Tabu search algorithm and the existing analytical methods, such as Benders, have been used to solve several examples and the results are shown in Table 1. Despite certain weaknesses of the proposed Tabu search algorithm, mainly associated with the initial solution, it is often faster and more efficient for NP- complete problems. By comparing several example results, we found that the analytical approaches, such as Benders decomposition, face a large-scale difficulty. In Table 1 and Figure 2, the maximum level of model complexity we could solve on Sun Ultra was 712 constraints, 162 integer variables and 162 constant variables with corresponding average CPU time equal to 3:48:00. Moreover, this kind of model is a NP complete problem and for any models larger than trail 6, we should look at a numerical method to solve it. In this paper, the proposed Tabu search algorithm helps to solve this kind of model for EP with minimum variation. In Table 2, "the other approach and deviation" column shows the reference solution deviation from the proposed Tabu search algorithm corresponding results. The large-scale difficulty makes it necessary for all models after model V to be resolved by other approaches.

6. CONCLUSION

This paper illustrates an approach to find the optimal number and capacity of power centers and the optimal distribution of power with respect to a long term basis expansion policy of power plant centers (EP) minimizing fixed investment and operational costs and maximizing network reliability. This approach, the Tabu search, is able to escape from local optima by using a list of forbidden neighboring solutions. Since the EP model is NP-complete, the proposed Tabu search algorithm may resolve the model faster and more efficiently with respect to several tries over a bunch of examples. Table 1 and 2 show that, although the proposed algorithm is able to find a solution very close to the optimal one, however, improving the initial solution is vital for the improvement of the proposed algorithm CPU time requirements.

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 1. CPU Time

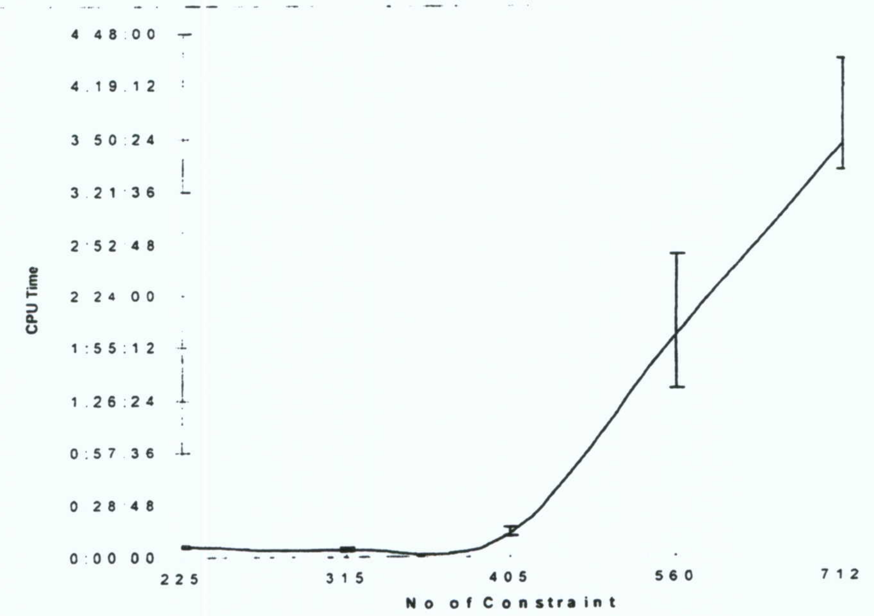

FIGURE 2. CPU Time Curve and standard deviation

MODEL	No.OF YEAR	No.OF REGION	No.OF CENTER	Tabu Search CPU time(H:M:S)	Other Analytical Approach/Deviation from Neural solution
I	1	5	5	0:00:20	%0
II	5	5	5	0:01:05	%0
III	1	43	5	0:12:43	%0
IV	16	43	5	0:18:02	%1
V	16	43	10	0:15:23	%2
VI	16	43	16	0:25:00	%7
VII	16	43	20	0:39:20	%5
VIII	16	43	30	0:23:51	%6
IX	16	43	43	0:45:18	%3

TABLE 2. Table of EP and analytical method results

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