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A MULTI-AREA FUEL BASED GENERATION –TRANSMISSION PLANNING PROCEDURE

M.S. Sepasian
Power and Water Industry University
Tehran/Iran

H. Seifi
Tarbiat-modares University
Tehran/Iran

A. Akbari
Semnan University
Tehran/Iran

S. Rae
Tavanir Company
Tehran/Iran

ABSTRACT
In this paper, a Linear Programming (LP) optimization procedure is proposed in which the generations are so allocated that the cost of providing fuel supply as well as transmission reinforcements are minimized. DC load flow is employed to model the network. Various fuel supply scenarios are observed. The approach is successfully tested on Iranian Power Grid as a multi-area large scale system.

KEY WORDS
Generation Expansion, Transmission Expansion, Power System Planning, Planning, Transmission Planning

1. Introduction

Power system planning is an issue of interest to power system engineers [1]. It is a complex problem so that it is of normal practice to decompose it to Generation Expansion Planning (GEP) [ex.2], Network Expansion Planning (NEP) [ex.3] and Distribution Expansion Planning [ex.4]. NEP itself may be classified as Substation Expansion Planning (SEP) [ex.5] and Transmission Expansion Planning (TEP) [ex.6].

If GEP is performed independently of NEP, it may dictate a high cost of transmission reinforcements. A typical case is for the Iranian Power Grid in which the cost of fuel supply in the southern area is lower, while the consumption is mostly towards the northern areas. Ignoring transmission requirements may allocate generations at the south, while may necesitates transmission reinforcements towards the northern areas.

In this paper, an LP based optimization procedure is proposed in which both the fuel supply cost and the transmission reinforcement requirements are minimized.

Basic strategy is discussed in section 2. Detailed algorithm is covered in section 3. Numerical result are provided in section 4. Some concluding remarks are given in section 5.

2. Basic Strategy

The basic algorithm in which transmission enhancement strategies are determined, is shown in Figure 1.

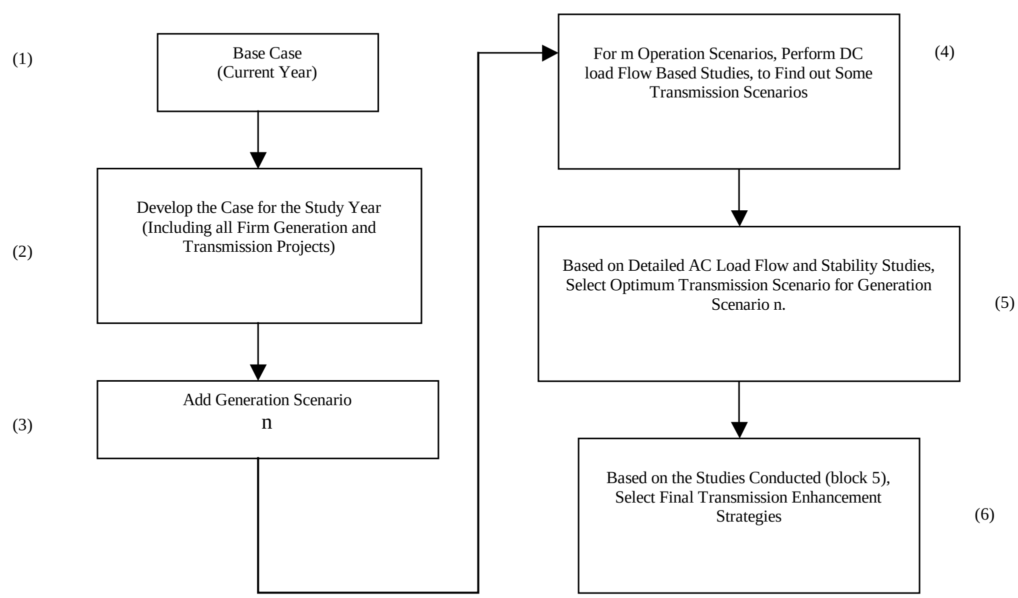

Fig. 1. Basic Strategy

As shown, if, for instance, the study is to be performed for year 2015, after developing the base case network (2007) in block (1), the case for 2015 is developed in block (2) with all new firm generation and transmission elements to appear from 2007 to 2015. However, the generation deficiency (for the known demand in 2015) may be considered as various generation scenarios in block (3), since the exact locations of new generation additions are not known in advance. For each generation scenario, preliminary studies in block (4) and advanced studies in block (5) are performed to determine the optimum transmission scenario. Based on the results of block (5), it is then investigated (block (6)) that what transmission enhancement strategies have to be chosen in order to have a strong grid, capable of performing its function satisfactorily for the generation scenarios, based on the probability of occurrence.

As evident, the choice of a generation scenario is crucial in the studies. The investors normally seek investing for power plants in low fuel cost regions. However, the choice may pose high cost for transmission expansion requirements.

As shown in section 3, an optimum strategy is proposed in which both indices are considered in an optimal manner. Based on that, various generation strategies are developed (block (3), Fig. 1). Then preliminary studies are performed (block (4)). The studies of blocks (5) and (6) are the subject of a paper, to be published later.

3. Proposed Algorithm

3.1 Basic Principles

Basic principle is illustrated using a three-area test system as depicted in Figure 2. The areas are connected by tie lines, denoted by C1-C3. From DC load flow, the flow of each connecting line, I, denoted by S_i is:

$$S_i = \sum_{i=1}^{n} a_{ij} P_j \tag{1}$$

where:

- n : Number of areas
- P_j : Generation in the jth area
- a_{ij} : The sensitivity, of flow in line i, with respect to the generation in area j

The flow in the line should be, also, limited to its maximum (S_{imax}) and minimum (S_{imin}) values as:

$$S_{i\min} \leq S_i \leq S_{i\max} \tag{2}$$

For three-area test case, if area 3 generation is considered as the slack, the governing equations can be depicted as in Figure 3. It is seen that, if point A illustrates the current operating point (corresponding to generations P_{1A} and P_{2A}), the dashed region shows how P_{1A} and P_{2A} may be changed to P_{1B} and P_{2B} (corresponding to point B), without violating any transmission limit. Section 3.2 proposes an algorithm, showing an optimization problem by which the optimum generation allocation for each area is determined.

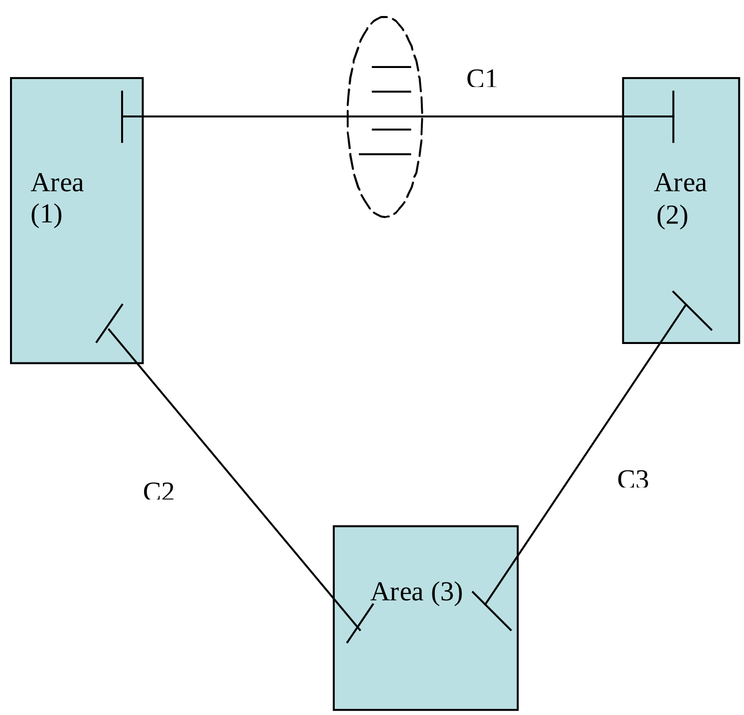

Fig. 2. A Three-area System

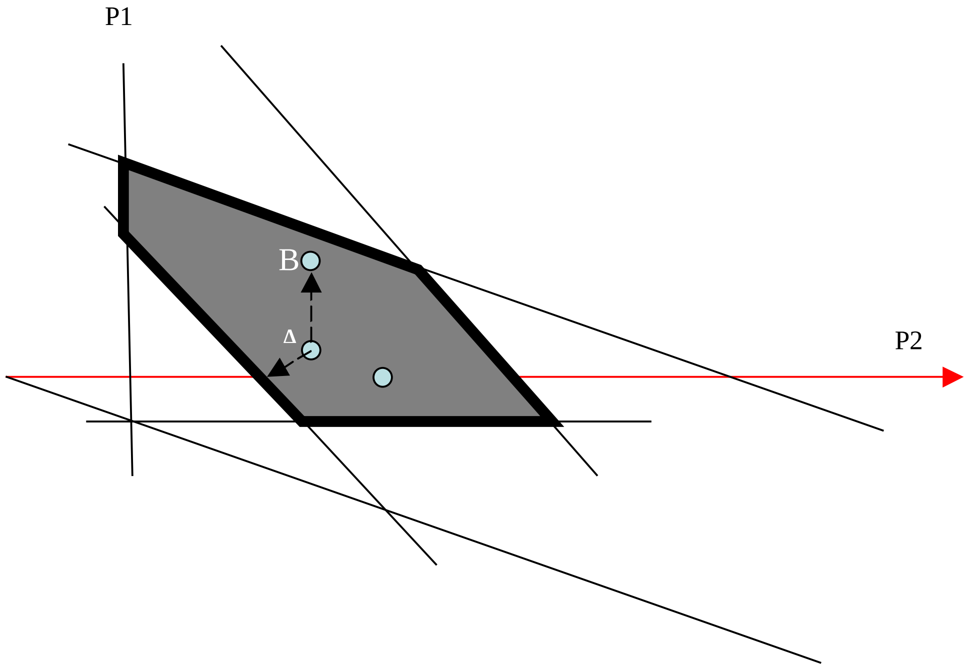

Fig. 3. Three-area System Behavior

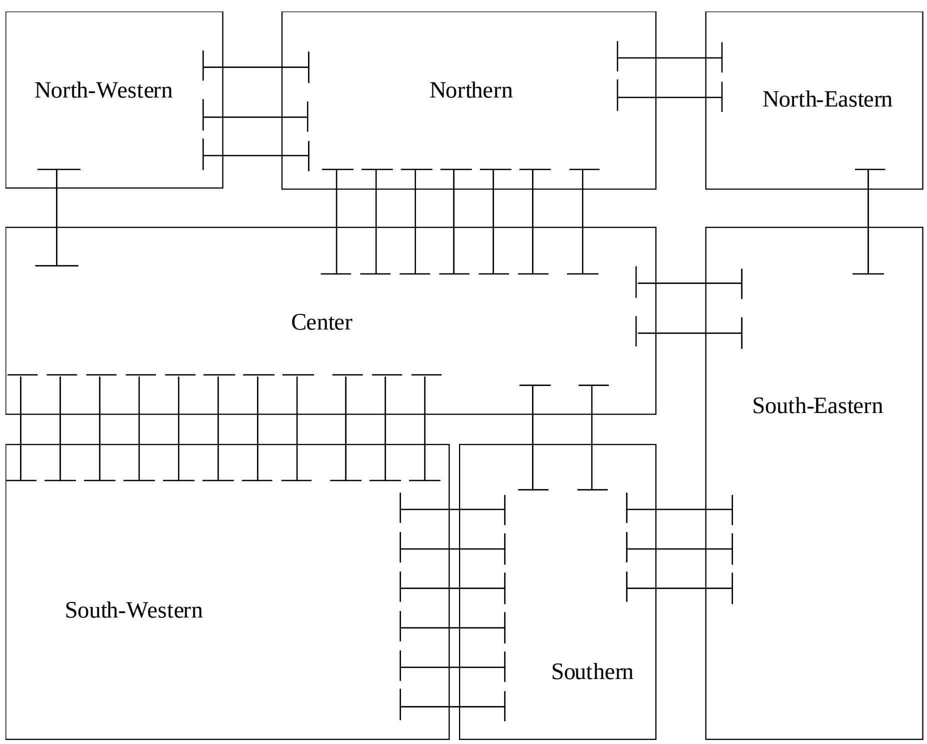

Fig. 4 . Multi-Area Network of IRAN

3.2 Generation Allocation

The aim is to allocate a generation level for each area, i, so that while, minimizing the transmission expansion requirements for the connecting lines, the fuel cost of each area is also observed. Therefore, the objective function is:

$$Min\left(\sum_{i=1}^{n}\alpha_i P_i + \sum_{j=1}^{m}\beta_j b_j\right) \quad (3)$$

where:

- α_i : Relative fuel cost of area i
- P_i : Generation level of area i
- n : Number of areas
- m : Number of connecting corridors
- β_j : The cost of corridor j enhancement
- b_j : The amount of corridor j enhancement

The constraints are as follows:

$$b_j S_{j\max} \le \sum_{k=1}^{n} a_{jk} P_k \le b_j S_{j\max} \qquad j = 1, 2, \ldots, m \quad (4)$$

$$1 \le b_j \le b_{j\max} \qquad j = 1, 2, \ldots, m \quad (5)$$

$$P_{k\min} \le P_k \le P_{k\max} \qquad k = 1, 2, \ldots, n \quad (6)$$

$$\sum_{k=1}^{n} P_k = P_D \quad (7)$$

(4) shows the limiting constraint on connecting line, j. b_j ((5)) shows the amount that transmission corridor j enhancement is possible (b = 1 corresponds to the case where no enhancement is possible). (6) denotes the constraint on an area generation, dictated by any reason. P_D ((7)) is the total generation requirement, known, from total demand.

The problem so defined is a linear optimization problem, to be solved by revised simplex method.

4. Numerical Studies

The algorithm proposed in section 3 is applied to the Iranian Power Grid for 2015. The details are as follows.

4.1 System under Study

The Iranian Power Grid consists of 16 regional utilities, interconnected tightly by 400 and 230 kV transmission elements. Based on National Dispatching Center principles, the network is divided into seven areas as shown with the connecting lines in Fig. 4. Some details are provided in Table I. Fuel resources are mostly centered at the southern area. While hydraulic resources are mainly located at the south-western area. Consumption is mainly located at the northern region (Tehran).

4.2 Generation Scenarios

For fuel supply of a power plant in the southern area, it is assumed that the cost of installation (piping, station, etc) is 2 MT/MW, where T corresponds to 10 Iranian Monetary unit. This figure is based on the Ministry of Oil principles. For the central, south-eastern and south-western areas, this figure is doubled, while for the northern, north-eastern and north-western areas, this figure is tripled. Also, it is assumed that the cost of the imported fuel (Gaz) from Turkmenistan in the northern region is 50% higher than the internal cost. As the operating cost of fuel is the same all over the country, for generation allocation in terms of fuel supply, it is only necessary to consider the cost of installations required. Also, based on detailed hydraulic studies, the hydraulic Power generation up to 7000 MW is foreseen for the south-western region. For comparison purposes, other scenarios are also assumed. Regarding fuel scenarios, they are summarized as in Table II. For instance, scenario 1 corresponds to the above mentioned situation. Scenario 2 corresponds to the case where the cost is the same all over the country. The third scenario is the same as the first, except for the import possibility from Turkmenistan . Case studies are summarized in Table III.

4.3 Results

Assuming the cost of a transmission link to be roughly 0.2 MT/MVA*km, the system as described above is fully modeled. However, only the costs of tie-lines reinforcements are considered. For each case study of Table III, the algorithm described in section 3 is tested as summarized in Table IV.

4.4 Discussion

For case 1, where the practical case is observed, it is shown that mostly, the generation required will be located at the southern part. However, transmission reinforcement between some areas would be necessary. Other cases can be discussed similarly.

4.5 Further Improvements

As discussed in section 3 and demonstrated in section 4-1 through 4-4, the algorithm proposed was based on a simplified model so that it could be readily applied to practical large-scale systems. That is why the Iranian power grid with all its interconnections was considered in section 4.1. The solution methodology was based on linear programming so that, although the model was simple, the global optimum results are guaranteed. More complex models may be proposed and employed. However, its optimum solution may not be readily achieved for large-scale systems. Moreover, in the proposed algorithm, it is assumed that transmission enhancement is of continuous nature, while in practice, the enhancement may be achieved through voltage upgrading, conductor change or new line installation. Also, a_{ij} defined in equation (1) should be updated, once the topology is changed. Based on the above mentioned points, the authors are developing hybrid algorithms involving heuristics and linear programming. Meanwhile, evolutionary based (such as Genetic Algorithm) techniques for a complex model of the problem is under investigation, so that while practical constrains are observed, the solution for a practical large scale system is possible. The results will be published soon.

5. Conclusion

An algorithm was proposed in which by considering the cost of supplying fuel and transmission reinforcements, generations may be so allocated that the total cost of supplying fuel as well as transmission reinforcements are minimized. The algorithm was successfully tested for the Iranian Power Grid.

Table 1
System Under Study (2007)

NO.	Area	Generation Capacity in 2007($10^3\times$MW)	Load in 2015 ($10^3\times$MW)
1	Northern (N)	10.9	15.28
2	North-Western (NW)	2.87	3.4
3	North-Eastern (NE)	4.08	3.78
4	Central (C)	6.22	11.36
5	Southern (S)	3.62	6.62
6	South-Western (SW)	6.6	9.44
7	South-Eastern (SE)	3.66	8.34

Table 2
Fuel Scenarios

Relative Fuel Supply Costs							
No	Northern (N)	North-Western (NW)	North-Eastern (NE)	Central (C)	Southern (S)	South-Western (SW)	South-Eastern (SE)
1	3A	3A	3A	2A	A*	2A	2A
2	A	A	A	A	A	A	A
3	3A	3A	1.5A	2A	A	2A	2A

*A is the cost of fuel supply installation in the southern area

Table 3
Case Studies

Case	DESCRIPTION
A	Fuel scenario No. 1 + Hydraulic Generation
B	Fuel scenario No. 1 without Hydraulic Generation
C	Fuel scenario No. 2 + Hydraulic Generation
D	Fuel scenario No. 2 without Hydraulic Generation
E	Fuel scenario No. 3 + Hydraulic Generation
F	Fuel scenario No. 3 without Hydraulic Generation

Table 4
Results

Case	Generation Requirements ($10^3\times$MW)							Transmission Reinforcement Requirements ($10^3\times$MVA$\times$ km)									
	N	NW	NE	C	S	SW	SE	N-NE	N-NW	N-C	NW-C	NE-SE	C-SE	S-SE	S-SW	C-SW	C-S
A	-	-	-	0.91	7.35	-	2.97	-	-	67.1	-	-	-	2.3	41.2	42.1	-
B	-	-	-	3.48	9.1	1.58	4.02	-	-	1.9	-	-	-	2.3	61.6	-	-
C	-	1.95	-	2.87	-	-	6.42	-	-	-	-	-	-	-	-	-	-
D	-	2.75	-	6.4	4.27	-	4.83	-	-	-	-	-	-	-	-	-	-
E	-	-	1.45	2.75	5.52	-	1.52	0.5	-	-	-	-	-	2.3	8.6	-	-
F	-	-	0.86	2.68	8.9	2.12	3.7	0.4	-	-	-	-	-	2.3	55	-	-

References

[1] X. Wang, and J. R. McDonald, *Modern Power System Planning*, McGraw-Hill Publication, 1994.

[2] IAEA, "Wien Automatic System Planning (WASP) Package, A Computer Code for Power Generation System Expansion Planning, Version WASP-IV, User's Manual", International Atomic Energy Agency, 2000.

[3] G. Latorre, R. D. Cruz, J. M. Areiza and A. Villegas "Classifications of Publications and Models on Transmission Expansion Planning", IEEE Trans. Power Systems, vol. 18, pp.938-946, May 2003.

[4] I.J. Ramírez-Rosado and J. Antonio Domínguez-Navarro, " Possibilistic Model Based on Fuzzy Sets for the Multi objective Optimal Planning of Electric Power Distribution Networks", IEEE Trans. on Power Systems, pp 1801-1810, November 2003.

[5] M. S. Sepasian, H. Seifi, A. Akbari Foroud, S. H. Hosseini and E. Mohseni Kabir, "A New Approach for Substation Expansion Planning", IEEE Trans. on Power Systems, Vol. 21, No.2 pp. 997-1004, May 2006.

[6] L. Bahiense, G. C. Oliveira, M. Pereira and S. Granville "A Mixed Integer Disjunctive Model for Transmission Network Expansion", IEEE Trans. Power Systems, vol. 16, pp 560-565, Aug 2001.