18th
International
Power System
Conference

برق
بین المللی
کنفرانس
۱۸

81-E-SEA-791

Evaluation of Reliability-Environment-Economy Impacts of Reliability Centered Maintenance for Deregulated Power Systems

Bahman Kermanshahi
Department of Electrical and Electronics Engineering
Tokyo University of Agriculture & Technology
(JAPAN)

Keywords: Long-term Generating Maintenance Scheduling, Benders Decomposition, Integer Programming, Linear Programming, Independent System Operator (ISO), Optimization

Abstract

This paper presents a practical and efficient method for long-term generating maintenance scheduling with various constraints for the deregulated power system. Using the Benders Decomposition, an approach has been developed for the long-term maintenance scheduling of generating units. This approach is efficient because a solution is obtained usually within a few iterations. The resulting long-term generation maintenance scheduling provides the time intervals, for a one year planning horizon, when generating units in a GENCO is taken off-line for planned preventive maintenance. The algorithm minimizes the total operating cost for a GENCO. Since in a competitive deregulated environment, both GENCO and ISO (Independent System Operator) are operated independently of each other, we apply Benders Decomposition to include the ISO's constraints in the long-term generating maintenance-scheduling problem to meet the energy demands, reliability and other system requirements.

1. Introduction

As a result of the deregulation in the electric power industry, power generation planning has become more complex in recent years due to the constant push for energy from the limited available energy resources and various environment constraints. On the one hand, the move towards a deregulated market and flexible decentralized control scheme demand more generation to be available for sale and for profit. On the other hand, the inability to add more system generation in the past decade due to environmental concerns results in much older generating units still being used today and the need for more generating unit maintenance to ensure the adequacy of supplies until new generation can be built. These two forces tend to oppose each other, and therefore a long-term generation maintenance-scheduling program, which balances both aspects, is needed more than ever before. Long-term generation maintenance scheduling is not as easy as it seems, because any acceptable generation maintenance schedule must satisfy the followings:

- Reduction of the operation cost of the GENCO (GENeration COmpany)
- Maintenance of the reliability of the system
- Extension of the life span of the generating unit
- Investment cost saving for the installation of new generating units

Classical optimization methods such as, linear programming, integer programming, dynamic programming, and multi-object programming have been used to solve the Maintenance scheduling problem since the early days. However, these were usually done for small-scale power systems.

For this study, the Benders Decomposition is applied to provide a long-term generating maintenance scheduling solution. The Benders Decomposition is designed using two methods, namely, integer programming and linear programming, which proved to be suitable for this type of problem. The results of this study are examined for their effectiveness and validity. The Benders Decomposition is applied to solve the generating unit maintenance formulation. The proposed technique decomposes the original problem into a master problem, which is a relaxation of the original problem, and several independent sub problems. The result for a simple system is analyzed and the proposed method is also applied to the 24-bus IEEE-RTS (Reliability Test System), which consists of 32-generation units, and 38 transmissions. The results will be presented in this paper.

2. Problem Formulation

This section describes the nature of the long-term generation maintenance scheduling problem formulation and its constraints. The simulation has been carried out by satisfying the following formulation of long-term generation maintenance scheduling. The most commonly used objective function is the cost objective function. The cost is the sum of the production cost, the replacement and the maintenance cost. Another objective function that has been considered by a number of researchers is the reliability objective function, which evaluates the risk of the generation system and attempts to achieve the minimum loss of load probability (LOLP) for the year.

The maintenance scheduling problem constraints can be categorized into two main groups, the maintenance constraints and the power system constraints. Maintenance scheduling constraints can be summarized as follows:

A. Objective function:

$$Minimize \sum_{i} \sum_{t} \left\{ C_{it}\left(1 - x_{it}\right) + c_{it} g_{it} \right\} \quad (1)$$

Where,

C_{it}: Generation maintenance cost for unit i for week t

x_{it}: unit maintenance state

c_{it}: generation cost of unit i at week t

g_{it}: generation capacity

B. Maintenance constraints:

$$\left.\begin{array}{l} x_{it} = 1 \\ x_{it} = 0 \quad (2) \\ x_{it} = 0, 1 \end{array}\right\}$$

C. System constraints:

$$Sf + g + r = d \qquad (3)$$

$$g \leq \bar{g}\,\square @ \qquad (4)$$

$$r \leq d \qquad (5)$$

$$|f| = \bar{f} \qquad (6)$$

$$\sum_{i} r_{it} = \varepsilon \qquad (7)$$

Where

f : load flow

d : weekly peak load at bus

r $_{it}$:real power interruption at bus i in week t

The generation maintenance problem is decomposed into two problems. The first problem, which in this model is an integer-programming problem, is solved to generate a trial solution for maintenance schedule decision variables. Equation (2) corresponds to a mixed-integer programming problem. The variable, x it, is an integer variable and the variable, g i,t is continuous. The objective function (1) is to minimize the total maintenance and production costs. The set of system constraints (3) ~ (7), which represent the peak load balance; transmission flow limits and allowable unserved energy will be checked by the ISO.

D. Economy Index

The fuel cost of a thermal unit can be regarded as an essential criterion for economic feasibility._ The fuel cost curve is assumed to be approximated by a quadratic function of generators' active power output and is shown below:

$$F_{COSt} = \sum_{i=1}^{n} \left(\alpha_i \mathrm{P}_i^2 + \beta_i \mathrm{P}_i + \gamma_i\right) \qquad (8)$$

Where, α_i, β_i and γ_i are the cost coefficients.

E. Environment Impact Index

The amount of Nitorogen-Oxid (NOx) emission is taken as environmental constraint. The amount of NOx emission is given as a function of generator outputs, that is, the sum of quadratic and exponential functions [7] of generator active power outputs as,

$$F_{NOX} = \sum_{i=1}^{n} \left\{a_i + b_i p_i + c_i p_i^2 + d_i \exp(e_i p_i)\right\} \qquad (9)$$

Where, a_i, b_i, c_i, d_i and e_i are the NOx coefficients

3. A Solution Algorithm for Long-term Generation Maintenance Scheduling Problem - Application of the Benders Decomposition

The Benders decomposition algorithm is developed for exploiting mixed-integer program. It has many applications in a restructured power system, which is represented by a series of independent entities.

The generating unit maintenance problem is decomposed into a master problem (GENCO) and a set of independent operation sub-problems (ISO). The master problem, which in this model is an integer-programming problem, is solved to generate a trial solution for maintenance schedule decision variables. This master problem is a relaxation of the original problem as it contains only a subset of constraints. Once xit variables are fixed, it will be used to solve the set of ISO independent sub-problems, one for each time period t, assuming that there are no constraints across time period. At each iteration, the solutions of the sub-problems generate dual multipliers. These dual multipliers are used to form one or more constraints, which are added to the master problem for the next iteration. This process is shown in Figure 1.

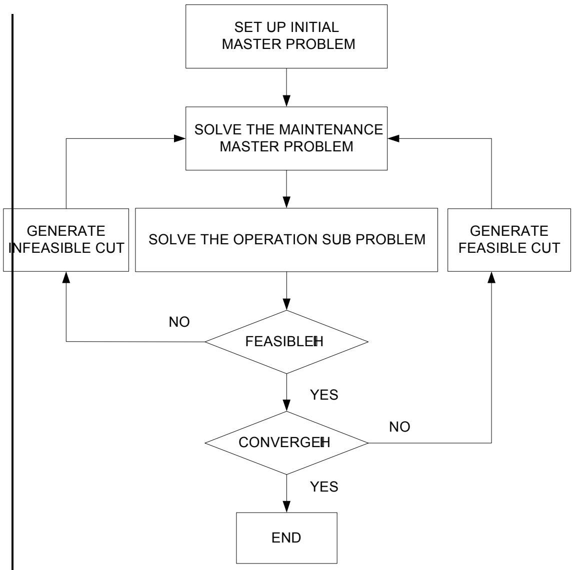

Fig.1 Flow chart of solution algorithm

4. Application to the IEEE Reliability Test System

The approach described previously is applied to the IEEE Reliability Test System (IEEE-RTS). The input data and assumptions, cost and reliability results will be examined and discussed in the following sections.

4.1 System input data and assumptions

The proposed methods were applied to the standard IEEE-RTS (Reliability Test System), which is shown in Figure 2. The system annual peak load is 2850[MW]. In this model, there are 32 generators, which is composed of 8 different sizes of generators, 24 buses, and 38 transmission lines.

Fig2. IEEE-Reliability Test System (RTS)

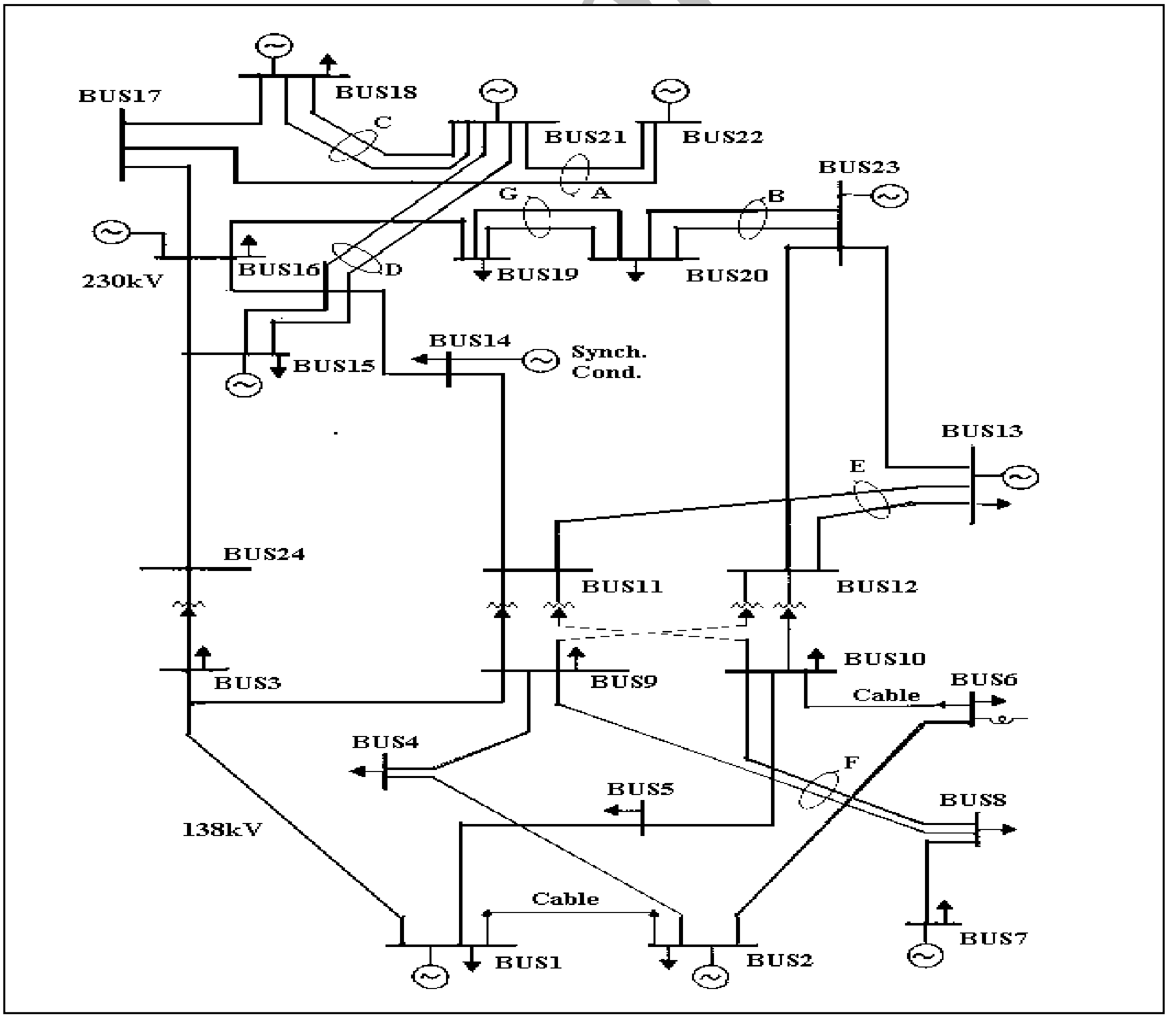

Table 1 shows a summary of the generator characteristics according to their sizes, number of units, forced outage rates and scheduled maintenance.

Table 1 Characteristic of Generators

Unit Size (MW)	Number of Units	Forced Outage Rate	Schedule Maintenance (Weeks/Year)
12	5	0.02	2
20	4	0.01	2
76	4	0.02	3
100	6	0.04	3
155	4	0.04	4
197	6	0.05	4
350	1	0.08	5
400	2	0.12	6

Table 2 Characteristic of Generator

Pi		Cost Coefficients			NOx Coefficients				
min	max	αi (*e-2)	βi	γi	Ai (*e-2)	Bi (*e-5)	Ci (*e-7)	Di (*e-5)	Ei (*e-2)
2.4	12	2.533	25.547	24.389	4.900	-7.800	2.00	0.01	0.6
4.0	20	1.561	37.963	118.908	2.210	-3.610	0.94	1.80	0.5
15.2	76	0.962	13.504	81.826	4.500	-7.801	2.00	0.01	0.6
25.0	100	0.623	18.000	217.896	5.302	-5.400	0.80	2.00	0.3
54.2	155	0.481	10.737	142.735	2.121	-7.025	1.10	0.50	2.0
68.9	197	0.259	23.000	259.131	6.131	8.291	1.15	0.01	1.0
140.0	350	0.150	10.842	176.057	5.326	-5.299	0.75	2.00	0.3
100.0	400	0.194	7.491	310.002	0	0	0	0	0

Table 3 Weekly NOx Emissions

Week	NOx (ton/h)	Week	NOx (ton/h)	Week	NOx (ton/h)	Week	NOx (ton/h)
1	1.15133	14	1.145245	27	1.14553	40	1.15057
2	1.14750	15	1.148217	28	1.13769	41	1.16500
3	1.15021	16	1.138885	29	1.13969	42	1.16094
4	1.15570	17	1.144681	30	1.13201	43	1.15374
5	1.14877	18	1.136943	31	1.15140	44	1.14781
6	1.13266	19	1.136007	32	1.14488	45	1.15359
7	1.16704	20	1.148666	33	1.16204	46	1.14419
8	1.15997	21	1.151614	34	1.16540	47	1.14063
9	1.16239	22	1.152191	35	1.16582	48	1.14656
10	1.16239	23	1.144654	36	1.15482	49	1.14035
11	1.15861	24	1.144217	37	1.15482	50	1.13677
12	1.15697	25	1.146379	38	1.16526	51	1.13288
13	1.16008	26	1.151146	39	1.16305	52	1.13881

Table 2 shows these characteristics according to their active power limitations, operating cost and NOx coefficients. The optimal maintenance schedule obtained and the maintenance crew assignment for the 52 weeks time-horizon are shown in table 2. _The maintenance costs used in the study are seasonal in nature. Winter maintenance cost is assumed to be most expensive, Spring and Fall costs are very close together, and Summer maintenance costs are the cheaper amongst the four. The unit's assignment mapping reflects the effect of seasonal difference in costs throughout the year.

4.2 Results

Table 3 shows the amount of weekly NOx emission._ The week with little quantity of NOx is a time of working atomic power. Conversely, while the thing with many amounts of discharge is working oil & coal power plant, it turns out that it increases.

Table 4 shows a summary of the total cost._ The test system has 32 units and is assumed to have 4 maintenance crew groups. Generators are loaded into the system in decreasing order of operating costs. The maintenance schedule is modeled as 52 time blocks representing each of the weeks in the maintenance period.

Table 4 Total cost

Case	Cost ($\$10^6$)
52-weeks horizon	37.256

4.3. Reliability Evaluation of the IEEE-RTS

The reliability metrics measured for the system are the loss of load probability (LOLP), and the loss of energy probability (LOEP). To calculate these reliability indices, the rate of the accident of a dynamo, and the Load Duration Curve (LDC), shown in Figure 3, are needed. The following load duration curve is assumed in this study.

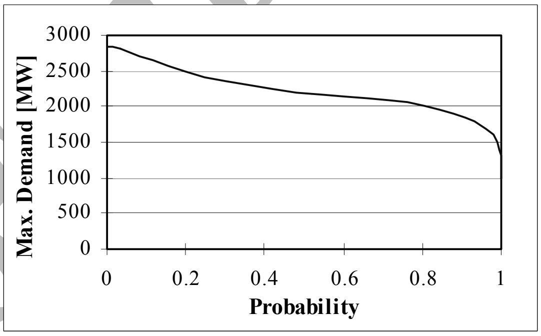

Fig3 Load Duration Curve

The reliability indices for the system for different number of generating units off-line is shown in Table 5. It can be observed that except for the first unit taken offline for maintenance, the LOLP and LOEP indices almost double for every unit taken offline. As a result, by the time two units are removed from the system for maintenance, the system LOLP will no longer satisfy the general LOLP criterion (equivalent to 0.1 day/yr). It is obvious that existing generation cannot sustain a reasonable maintenance scheduling program without the addition of new generating units.

Table 5 System Reliability evaluations

Number of Generating Units Off-Line	LOLP	LOEP [MWh]
0	0.000144	0.022871
1	0.000181	0.029112
2	0.000262	0.042807
3	0.000453	0.076482
4	0.000996	0.171399

5. Conclusion

This paper presents an approach to develop a generating unit maintenance-scheduling program to take into account the various environment and system constraints for a large power system. The original problem is divided into a master problem, which provides the maintenance decision variables and a set of sub problems which relates the system generation to the system conditions and environmental conditions. The results are usually obtained in a few iterations. System reliability is measured by the LOLP and LOEP. The results indicate that the existing generation is insufficient to sustain a reasonable generating unit maintenance schedule without the addition of new generating units. The adequacy of the existing system should be investigated more thoroughly.

6. References

[1] Roy Billinton, Ronald N. Allan "Reliability Assessment of Large Electric Power System", Kluwer Academic Publishers, 1988.

[2] J. Delson, M. Shahidehpour,"Linear Programming Applications to Power System Economics, Planning and Operations", IEEE Transactions on Power Systems, Vol. 7, No. 3, pp. 1155-1163, Aug. 1992.

[3] M. Shahidehpour, N. Marwali "Maintenance Scheduling In Restructure Power Systems", Kluwer Academic Publishers, 2000.

[4] J. F. Dopazo, H.M. Merrill "Optimal Generator Maintenance Scheduling Using Integer Programming", IEEE Transactions on Power Apparatus and Systems, Vol. 7, No. 3, pp. 1155-1163, Aug.1992.

[5] P.F. Albrecht, M.P. Bhavaraju, "IEEE Reliability Test System", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-98, No. 6, Nov/Dec. 1979.

[6] R.N. Allan R. Billinton, "THE IEEE Reliability Test System – Extensions To And Evaluation of the Generating System", IEEE Transactions on Power Systems, Vol. PWRS-1, No 4, Nov. 1986.

[7] B. Kermanshahi, et al, "Environmental Marginal Cost Evaluation by on-inferiority Surface", IEEE Transaction on Power Systems, Vol.5, No.4, pp.1151-1159 (1990).