'96 대한전기학회 하계학술대회 논문집 (1996. 7. 22~24)

Window환경에 기초한 발전기 예방정비계획 프로그램 개발

박영문, 박종배, O원종률, 정만호, 김진호, 추진부(**), 전동훈(**)
서울대학교 전기공학부(*), 한국전력공사 전력연구원(**)

A Development of Maintenance Scheduling Program Based on Windows

Young Moon Park, Jong Bae Park, OJong Ryul Won, Man Ho Jhong, Jin Ho Kim, Jin Boo Choo, Dong Hoon Jeon
College of Elec. Eng., Seoul National University Korea Electric Power Research Institute

1. Abstract

This paper proposes a preventive maintenance scheduling system which is a user-friendly decision-making support system. The objective of the development of the package is to supply KEPCO's working experts with a useful tool for gaining a practical maintenance schedule. This program based on the MS Windows is made up of two main modules. The first is an interactive decision-making support module(IDSM). The main objective of this module is to provide various useful text and graphic information to users, and enable practicing engineers with sensitivity analysis of a targeting maintenance schedule. The second is a mathematical optimization module(MOM). In this module, the objective function of levelizing net reserve ratio with daily time-increment is optimized using the relaxation method.

2. Introduction

Preventive maintenance scheduling is to decide the maintenance period of each generating unit which maximizes(or minimizes) the objective function with various technical/physical constraints throughout the scheduling horizon (typically a year) of study.[1], [2], [3]

During the past decades, numerous theories and methodologies have been suggested and applied to the maintenance scheduling optimization problem. These include the branch-and-bound[4], dynamic programming [5], integer programming [6], nonlinear programming[7], multi-objective approach[8],[9], and artificial intelligence approach [10]. Since most of the researches adopt typically 10 days or a week as a time increment because of memory limits and computation time, these have a potential limit for direct application to a practical large-scale power system. [2],[11]

Korea has experienced the drastic increase of peak demand since 1990, which has resulted in low net reserve margin. For example, the net reserve rate dropped into the 2.8 percent in 1994, which resulted in an emergency operating situation. In these reasons, the needs for development of useful maintenance scheduling package which can directly applicable to the very large-scale KEPCO's generation system have increased. To meet these needs, we developed a MS Windows based user-friendly decision support software for the maintenance scheduling with time increment of a day.

In this program, we applied object-oriented programming(OOP) techniques using MS Visual C++ 1.51 in a MS Windows 3.1 environment. The hardware requirements for running this program are a compatible IBM 386 or above machine with a mouse and a MS Windows version of 3.1 or Windows 95. With a good man-machine interface(MMI) in windows, graphic and text outputs are directly provided to users for any maintenance scheduling alternative. Furthermore, users are able to directly edit and modify various input data in a window environment.

The developed program is classified into two parts. One is input/output(I/O) database part, the other is preventive maintenance scheduling accomplishment part. Also, the latter is composed of two main modules. The first is an interactive decision-making support module(IDSM). The main objective of this module is to provide various useful text and graphic information to users, and enable practicing engineers with sensitivity analysis of a targeting maintenance schedule. The provided information of a candidate alternative covers daily net reserve capacity, daily net reserve ratio, a set of generators under maintenance of a day etc. After that, experts judge whether the alternative satisfies several technical/physical constraints or not, and adjust input data and each unit's maintenance period on the basis of their accumulated experience to get the physical optimal solution. The second is a mathematical optimization module(MOM). In this module, the objective function of levelizing net reserve ratio with a day time-increment is optimized using the relaxation method.

The developed package allows automatic data transfer between IDSM and MOM. Therefore, we can effectively combine the mathematical optimization and experts' heuristic rules for yearly maintenance scheduling.

3. Fundamental Structure

3.1 Basic Structure

This package is mainly composed of three parts; input database, output database, maintenance scheduling accomplishment part, respectively.

3.2 Input Database

There are four types of input data files. These include chronological hourly load data of a year, hydro plants related data, thermal plants related data, and additional data provided by experts or users. Files edited under a Windows or a DOS environment can be loaded on the package.

Data of Thermal Plants

In this file, information on an equivalent hydro plant transferred from the hydro plants file, pumping storage and thermal plants is described. Just like as the hydro plants data, these data should include such information as each generator's name, capacity, required maintenance days, permissible maintenance period.

These three input files should be loaded before we execute the preventive maintenance scheduling program.

Data of Hydro Plants

These data include such information as each generator's name, capacity in MW, required maintenance duration, and permissible maintenance period in days. The maintenance period of each hydro plant is treated as fixed one in this package, since the hydro power-plants' capacity are relatively small to the total generation capacity of Korea. However, it is possible to perform a sensitivity analysis by changing the maintenance period of one or more hydro plants. All the hydro plants are represented as an equivalent generator with net reserve capacity, and this information is transmitted to thermal plants data.

Chronological Load Data

Hourly chronological load data during a year should be retrieved in advance. The daily peak demands of a year are selected, and transmitted to IDSM and MOM of the maintenance scheduling program.

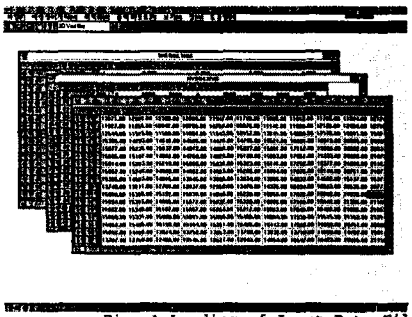

Fig. 1 Loading of Input Data Files

Experts' Input Data

This file includes information such as drop of reservoir's water level, derated operation of thermal plants, performance drop of deteriorated thermal plants, change of output due to heat-supply of cogeneration plants, low output performance of gas-turbine in summer peak-season, power purchase from IPPs, etc. Unlike the aforementioned three data files, these data are optional and should be provided by practicing experts by their nature. In this paper, the net reserve capacity(ratio) is considered as a reliability index, and defined as follows;

Net Reserve Capacity (MW) = Total Capacity - { (Maintenance) + (Drop of Reservoir's Water Level) + (Derated Operation of Thermal Plants) + (Performance Drop of Deteriorated Thermal Plants) + (Change of Output due to Heat-supply of Cogeneration Plants) + (Low Output Performance of Gas-turbine in Summer Peak-season) - (Power Purchase from IPPs) } (1)

3.3 Program Modules

The maintenance scheduling program consists of two modules; the interactive decision-making support module(IDSM) and the mathematical optimization module(MOM). The following figure shows the screen where the preventive maintenance scheduling program is executed. The screen is divided into two parts. The upper part contains each generator's name, capacity, required maintenance days, permissible maintenance period in days, resultant maintenance period(i.e., solution) of each plant. The lower part provides various useful information such as the daily peak load, total capacity, net reserve capacity, net reserve ratio, and experts' input data.

Interactive Decision-Support Module(IDSM)

Figure 2 shows the basic structure of ISDM of the maintenance scheduling program. The main objective of this module is to provide experts with a simple and useful tool to refine an obtained maintenance schedule. Also, it is possible for experts to establish a maintenance schedule by themselves through various text and graphic outputs. Therefore, experts judge whether the underlying maintenance schedule(i.e., initial or mathematical optimal solution) is acceptable or not on the basis of their experience. The main functions(menus) of IDSM are recapitulated as follows;

- Sort generators by the order of capacity magnitude, maintenance starting dates, by fuel types.
- Create reports by graphics and texts.

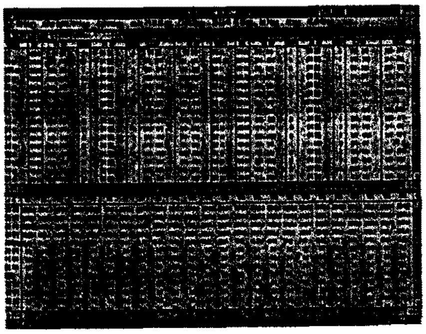

Fig. 2 Screen of Preventive Maintenance Scheduling Program(IDSM & MOM)

- Provide yearly, monthly, and weekly net reserve ratio graphics of a targeting alternative.
- Provide experts' data to calculate accurate net reserve capacity and ratio.
- Provide mathematical optimization function.
- And other functions provided in commercial windows-based packages.

Mathematical Optimization Module(MOM)

This module is also operated in the screen of figure 2. To execute MOM, one should click the Module 2 of Optimization Menu(O). The results(i.e., optimal maintenance schedule) are automatically transferred to IDSM. The mathematical formulation of this module is given in the following equations.

$$Min \sum_{j=1}^{J} \left\{ \left[\frac{1}{J} \sum_{i=1}^{J} \left(\frac{C_i - L_i}{L_i} \right) \right] - \left(\frac{C_j - L_j}{L_j} \right) \right\}^2 \quad (2)$$

$$C_j = \sum_{i=1}^{I} G_i (1 - x_{ij})$$

where, J : index which denotes the number of time-increments(365days)

I : index which denotes the number of total generators

L_j : peak demand of jth period(jth day)

G_i : rated capacity of ith generator

x_{ij} : state of ith generator in jth period

($x_{ij} = 1$ when maintenance, otherwise 0)

The considered constraints for the objective function are the required maintenance days and permissible maintenance period. All other technical/physical constraints, which are difficult to express in a mathematical form, are considered in IDSM by working experts. The objective function implies that the most net-reserve-ratio levelized alternative becomes the optimal solution. Since the problem has non-monotonous characteristic, and is combinatorial optimization problem in its nature, we can not apply such optimization technique as the branch-and-bound, dynamic programming approach, etc. Therefore, we adopted the relaxation method as the optimization technique for real-time application of a large-scale power system.

4. Application

The developed package is applied to the large-scale Korea's generation system. Total installed capacity of Korea's system was 28,750 MW, while the peak demand recorded 26,696 MW in 1994. Also, the total number of generating units reached 278 including 9 nuclear plants, 21 coal-fired plants, 54 combined-cycle plants, and the others.

In figure 3, two results are compared. The first one is based on the historical maintenance record of each generator. After that, it is refined and adjusted by experts in IDSM. The second one is the result of MOM, which is also based on the historical maintenance record.

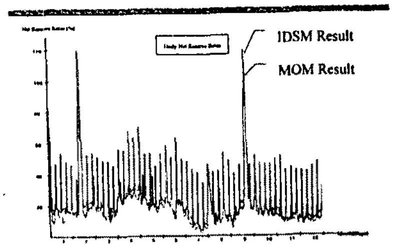

Fig. 3 Daily Net Reserve Ratio of Korea's System
(Results of IDSM & MOM)

The elapsed computation time for the mathematical optimization was about 7 minutes in 586 PC. In this case study, the iteration number was set as 3, the number of generators in a group as 1. Also, the number of generators for optimization was 113. Although the computation time increases exponentially in increasing the number of generators in a group for optimization, the developed package was successfully applied to the practical Korea's generation system.

5. Conclusion

This paper described a user-friendly decision-making support system for a preventive maintenance scheduling. The package is practically effective in providing the practicing experts with various text and graphic information to support a decision. The users are dynamically interact with input data as well as a maintenance schedule. Therefore, it is very easy to conduct a sensitivity analysis. The developed package is directly applicable to a practical large-scale power system since it reflects both the daily net reserve ratio optimization and technical/physical constraints by experts which are difficult to express in a mathematical form.

Acknowledgments

The authors would like to gratefully acknowledge the financial support of ddKEPCO grant KRC942143 and PROCOM contract PR9505.

References

[1] X. Wang and J. R. McDonald, *Modern Power System Planning*, McGraw-Hill Book Company, 1994.
[2] Zia A. Yamayee, Maintenance Scheduling : Description, Literature Survey, and Interface with Overall Operations Scheduling, *IEEE Trans. on PAS*, Aug., 1982, pp. 2770-2779.
[3] Rana Mukerji, et. al., Power Plant Maintenance Scheduling: Optimizing Economics and Reliability, IEEE Trans. on Power Systems, May, 1991, pp. 476-484.
[4] J. W. Jung, Generator Maintenance Scheduling via Branch-and-Bound Method, *Trans. KIEE*, Vol. 44, No.7, July, 1995, pp. 829-835.
[5] H. H. Zun and V. H. Quintana, Generator Maintenance Scheduling via Successive Approximation Dynamic Programming, *IEEE Trans. on PAS*, Vol.PAS-94, No.2, March, 1975, pp. 665-671.
[6] J. F. Dopazo and H. M. Merrill, Optimal Generator Maintenance Scheduling using Integer Programming, *IEEE Trans. on PAS*, Vol. PAS-94, No.5, Sep., 1975, pp. 1537-1545.
[7] J. Yellen, T. M. Al-Khamis et. al., A Decomposition Approach to Unit Maintenance Scheduling, *IEEE Trans. on Power Systems*, 1992.
[8] H. H. Zurn and V. H. Quintana, Several Objective Criteria for Optimal Generator Preventive Maintenance Scheduling, *IEEE Trans. on PAS*, Vol. PAS-96, No. 3, May, 1977, pp. 984-992.
[9] B. Kralj and N. Rajakovic, Multiobjective programming in power system optimization: new approach to generator maintenance scheduling, *Electrical Power & Energy Systems*, Vol. 16, No. 4, 1994, pp. 211-220.
[10] T. Satoh and K. Nara, Maintenance Scheduling by Using Simulated Annealing Method, *IEEE Trans. on Power Systems*, 1991, pp. 850-857.
[11] G. C. Contaxis, S. D. Kavatza, and C. D. Vournas, An Interactive Package for Risk Evaluation and Maintenance Scheduling, *IEEE Trans. on Power Systems*, Vol. 4, No. 2, May, 1989, pp. 389-395.