DETERMINISTIC AND STOCHASTIC SCHEDULING FOR PREVENTIVE MAINTENANCE IN ELECTRIC POWER SYSTEMS

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Introduction

The essential requirement from an electric power system is to provide a reliable and continuous source of electricity whenever required. A reliable generation system has enough reserve capacity to overcome service interruptions to customers caused by random equipment failures. In the long-term planning the reliability level can be increased by building new capacities. In short and medium term electric system planning the task is to find an acceptable value of generating system reliability under given constraints. These constraints are the installed capacity of the power system, the load pattern of the electricity consumption, and the random outages of the generating units.

In the short and medium term decisions the installed capacity of the system cannot be increased, the variations in the demand are determined by the consumption of electricity, and the forced outages can be influenced only by careful preventive maintenance. These planned outages have a considerable impact on power system reliability and production costs therefore the maintenance scheduling is a very important task in power system planning. The main aim of this scheduling is to satisfy all the constraints imposed on the system and to keep the electricity supply as reliable as possible.

Several methods are usually applied for maintenance scheduling [1]. The *reserve-levelling* approach is the most well-known and commonly used method because it demands relatively little computation and it provides rather good reliability level for the power system. However these methods do not take the uncertainty inherent into consideration in the power system. These techniques aim at keeping the amount of reserve almost level through the year by withdrawing units from the low load periods. The other group of the automated maintenance scheduling techniques consider the uncertainties in the demand and in the availability of generating units and based on *risk-levelling* methods which seek to spread the risk evenly as measured by some kind of reliability index.

The Basic Model of the Maintenance Scheduling

First of all we should fix the time horizon for scheduling (e.g. one year) which can be divided into equal time periods (e.g. weeks). Let us denote by $c_1, c_2, \ldots, c_n$ the capacity of the generating units where n is the number of generating units. The *installed capacity* of the power system is $c = \sum_{i=1}^{n} c_i$.

If the forced outage rate of unit i-th is f_i we can define X_i as the unavailability capacity for unit i. Let us suppose that the X_i-s $(i = 1,2,\dots,n)$ form a sequence of independent random variables where $X_i = c_i$ with probability f_i and $X_i = 0$ with probability $1 - f_i$.

Levelized Reserve Method

Let p_j be the *peak load* in the *j*-th time period. The gross reserve or *maintenance space* in this particular period is $s_j = c - p_j$, $j = 1,2,\dots,m$, where m is the number of periods in a year. Let n_j units be scheduled for maintenance in period j, consequently, $n - n_j$ are available. The *system reserve* r_j in this period is equal to

$$r_j = s_j - \sum_{k=1}^{n_j} c_{j_k} \qquad\qquad j = 1,2,\dots,m$$

where j_k is the index of the unit in the *k*-th position in sequence scheduled in the *j*-th period.

Roughly speaking the reliability level of the power system is proportional to the system reserve, so that we have to maximize the minimum system reserve over the time periods of the scheduling horizon:

$$r_{opt} = \max\left(\min_{1 \le j \le m} r_j\right)$$

The exact solution of this task can be obtained using linear integer programming algorithm [2]. Since it is well known there is no polynomial time algorithm for the task heuristic methods are commonly used in the practical applications (e.g. [1],[3]).

Levelized Risk Method

The other group of maintenance scheduling techniques consider the uncertainty inherent in power systems based on calculation of probabilistic reliability indices.

Let us denote by P_j the system load in the *j*-th time period. In power generation planning the forecast loads will be uncertain and regarded as random variable. Let n_j units be scheduled for maintenance in the period j, consequently, $n - n_j$ units are available. Then the LOLP(Loss of Load Probability) index for this particular period is :

$$LOLP_j = Pr\left\{ \sum_{k=1}^{n-n_j} X_{j_k} > \sum_{k=1}^{n-n} c_{j_k} - P_j \right\} \qquad\qquad j = 1,2,\dots,m$$

where j_k is the index of the unit in the *k*-th position in sequence scheduled in the *j*-th period.

The LOLP index measures the probability that the available capacity of the power system is insufficient to meet the system peak load in the given period.

The main objective of the maintenance scheduling is to keep the electricity supply as reliable as possible. An appropriate scheduling ensures a sufficient reliability level over the whole year. Consequently, we have to minimize the largest LOLP index over the time periods of the scheduling horizon:

$$LOLP_{opt} = \min\left(\max_{1 \le j \le m} LOLP_j\right)$$

The maintenance scheduling in case of risk-levelling method is much more complex from computational and theoretical point of view since in each step of the scheduling algorithm we should calculate the reliability index too and the objective function of the task will not be linear. Exact optimization methods (e.g. dynamical programming) need huge amount of storage capacity and calculation time requirement. To avoid these computational difficulties we are forced to use heuristic algorithms ([1],[4]).

The exact programming techniques mentioned above cannot be easily incorporated in planning programs which have to solve the maintenance scheduling problem repeatedly in an interactive way. It is a better approach to find heuristic algorithms which are able to generate reasonably good feasible schedule within a reasonable running time. In this presentation based on the observation that the maintenance scheduling task under some simplification can be formulated as a parallel machine scheduling problem, some heuristic algorithms are presented for deterministic and stochastic scheduling. Demonstrative examples are shown in which the optimal and the sub-optimal as well as the levelized-reserve and levelized-risk solutions will be compared.

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