CHAPTER 2
PROBLEM FORMULATION

2.1 INTRODUCTION

The goal of maintenance modelling and scheduling in a system is to allocate an effective maintenance timetable for the system equipment while optimizing system reliability, reducing total operating cost and extending equipment lifetime. Currently, the electric power industry throughout the world is shifting toward maintenance scheduling. The aim of this chapter is to investigate and model all cost factors that affect the maintenance activates of the power systems. In this framework, a full model was proposed which considers not only direct maintenance cost, but also all indirect maintenance costs, opportunity costs and cost of failure.

There are two types of facility maintenance in a power system: generating unit’s maintenance and transmission lines maintenance. They may be evaluated independently. Maintenance scheduling creates a preventive outage schedule within a planning horizon for a given facility. The solution process will drive the time horizon to short periods and then determine the starting time for each facility outage in order to optimize the given objective (Marwali and Shahidehpour 2000a). It is very important for the effective operation of a power system to determine when its generators should be taken off-line for preventative maintenance or when is the best time for the transmission line maintenance or when both need to happen. This is primarily because other planning activities are directly affected by such decisions.
2.2 MAINTENANCE SCHEDULING MODELS

The maintenance scheduling has been modelled in literature with several representations for power systems. In the integrated power systems structure the operator has full control of the power system as well as complete technical and costing information of each operation and maintenance activity, and solves the maintenance scheduling problem centrally. A maintenance schedule is produced coordinating with other planning activities using the complete costing and technical information. Researchers have classified the power system unit maintenance scheduling problem as a large scale problem. It includes long-term and short-term scheduling and co-ordination of maintenance activities of generators and transmission systems (El-Sarkh and El-Keib 2003) and (Marwali and Shahidehpour 2000b). In most scenarios the generators maintenance scheduling and transmission maintenance scheduling are treated as separate problems, for simplicity.

2.2.1 Objectives in Solving Maintenance Scheduling Problem

Power systems maintenance scheduling can be modelled as a multi-criterion constrained combinatorial optimization problem, with non-linear objectives and constraint functions (Baskar et al 2003). One of the most common reliability objectives in a centralized structure is the levelling of the reserve generation over the entire operational planning horizon. In the case of a large variation of reserve, minimizing the sum of squares of the reserves can be an effective approach (Dahal et al 2000b). Alternatively, the quality of reserve is considered, whereby the risk of exceeding the available capacity is levelled over the entire period by using the equivalent load carrying capacity for each unit and an equivalent load for each interval. Minimizing the sum of the individual loss of load probabilities for each interval can also be a reliability objective under the conditions of load uncertainty and random forced outages of units (Endrenyi et al 2001). Minimizing production (i.e. fuel
cost) and operation costs (i.e. maintenance cost) is considered to be the most common economic objectives.

2.3 OBJECTIVE FUNCTION

The objective function of the proposed model is to minimize the total maintenance and production costs over the operational planning period.

\[
\text{Min } F_T = \sum_{t=1}^{T} \sum_{i=1}^{N} \left\{ \left( F_{it} (P_{it}) n_t \right) U_{it} + \left\{ (P_{it} + R_{it}) OMFC \ n_t \right\} U_{it} \right\} + \sum_{t=1}^{T} \sum_{i=1}^{N} \left\{ P_{i\text{MAX}} OMFC \ n_t \right\} / 8760
\]

(2.1)

\[
\text{Profit} = \sum MCP \times P_{it} - F_T
\]

(2.2)

\[
F_{it} (P_{it}) = A_i + B_i P_{it} + C_i P_{it}^2 \text{ Rs/hr}
\]

(2.3)

2.4 CONSTRAINTS OF MAINTENANCE SCHEDULING PROBLEM

There are typical constraints for maintenance scheduling problems. Any maintenance timetable must satisfy a given set of constraints. The following are some of the constraints presented in the literature (Dahal and McDonald 1997).

In order to make the maintenance schedule feasible, certain constraints should be fulfilled. Some of basic constrains which should be set up are continuousness maintenance of some unit, maintenance manpower, maintenance window, maintenance duration and so on.

2.4.1 Load Balance

\[
\sum_{i=1}^{N} U_{it} P_{it} = D_t
\]

(2.4)
2.4.2 Generator Output Limit

Each unit is designed to work between minimum and maximum power capacity. The following constraint ensures that unit is within its respective rated minimum and maximum capacities.

\[ U_i P_{i \text{min}} \leq P_{it} \leq U_i P_{i \text{max}} \]  \hspace{1cm} (2.5)

2.4.3 Spinning Reserve

Spinning reserve is a safety margin that usually is given as a demand proportion. This indicates that the total capacity of the units running at each interval should not be less than the specified spinning reserve for that interval.

\[ \sum_{i=1}^{N} U_{it} P_{i \text{max}} \geq D_t (1 + r_t \%) \]  \hspace{1cm} (2.6)

2.4.4 Maintenance Resources

\[ \sum_{i=1}^{N} R_i (k) (1 - U_{it}) \leq \alpha_t (k) \]  \hspace{1cm} (2.7)

2.4.5 Maintenance Area

A maximum number of maintenance is imposed in the period t.

\[ \sum_{i=1}^{U_t} (1 - U_{it}) \leq \beta \]  \hspace{1cm} (2.8)

2.4.6 Crew Constraints

There is limited available manpower in each maintenance area.

\[ \sum_{i=0}^{P} (1 - U_{it}) < M_{it} \]  \hspace{1cm} (2.9)
2.4.7 Fuel Constraints

In some cases thermal units may face fuel shortages. Then required energy should be purchased from outside.

\[ \sum_{x=1}^{M} f_{it} = Y_i \]  
\[ (2.10) \]

2.4.8 Maintenance Window

The maintenance timetable stated in terms of maintenance variables \( S_i \). The unit maintenance may not be scheduled before their earliest period or after latest period allowed for maintenance.

\[ U_{it} = \begin{cases} 
1 & t \leq e_i \text{ or } t \geq l_i + d_i \\
0 & s_i \leq t \leq s_i + d_i \\
0,1 & e_i \leq t \leq l_i
\end{cases} \]  
\[ (2.11) \]

2.4.9 One-Time Maintenance

Each unit has an outage for maintenance just once along the time horizon considered.

\[ \sum_{t=1}^{T} s_{vit} = 1 \]  
\[ (2.12) \]

2.4.10 Reliability Indices

For simplicity most of the time, no uncertainty is considered which means that appropriate unit are provided. Nevertheless, unit forced outage rates can be approximately taken into account derating their corresponding capacities.

\[ P_{\text{max}}^{+} = (1 - for_{i}) * U_{it} * P_{\text{max}} \]  
\[ (2.13) \]

\[ \sum_{t=1}^{N} P_{\text{max}}^{+} * (1 - for_{i}) - \sum_{t=1}^{N} P_{f}(t) \geq \% \ r_{f} * d_{t} \]  
\[ (2.14) \]
\[ I(t) = \frac{\sum_{i=1}^{N} \sum_{j=1}^{T} P_{ij}(1-U_{ij})(1-f_{ij}) - D_t}{\sum_{i=1}^{N} \sum_{j=1}^{T} P_{ij}(1-f_{ij}) - D_t} \] (2.15)

In this chapter, we can see that researchers have focused much attention on maintenance scheduling problems for power systems in order to improve the economic posture of the generation companies. Reducing the total generation cost, including the fuel cost, operation and maintenance cost is one of the main objectives in power system maintenance scheduling.