INTELLIGENT START-UP SCHEDULE OPTIMIZATION SYSTEM FOR A THERMAL POWER PLANT

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Abstract: This paper proposes an intelligent start-up schedule optimization system for a thermal power plant. This system consists of a dynamic simulation, a neural network, and an interactive multi-objective programming technique. The features of this system are as follows. (1) The start-up schedule can be optimized based on multi-objective evaluation and (2) the optimal start-up schedule can be determined with a reasonable computing time and calculation accuracy through interaction between human beings and computers.

Keywords: Power generation, steam turbines, optimization, multiobjective optimisations, neural networks, genetic algorithms, simulation, dynamic models.

1. INTRODUCTION

Typically, the start-up scheduling problem of a thermal power plant has several conflicting objective functions, such as those for start-up time, fuel consumption rate, lifetime consumption rate of machines, and pollutant emissions rate. These parameters are affected by the varying market price of electricity as well as fuel, maintenance, and environmental costs. Therefore, it is important to achieve a flexible start-up schedule based on multi-criteria decision making in the overall plant management strategy.

The start-up characteristics are evaluated by using a dynamic simulation; however, determining the optimal start-up schedule is complicated because it is necessary to iterate the dynamic simulation on the basis of trial and error using the engineer's intuition and experience. Several methods for optimizing the start-up schedule have been proposed. For instance, a fuzzy expert system (Matsumoto, *et al.*, 1996), a genetic algorithm with enforcement operation (Kamiya, *et al.*, 1999), and a nonlinear programming technique (Shirakawa, *et al.*, 2005). However, all these authors aimed to optimize a single-objective function (e.g., only the start-up time is minimized under the operational constraints). In cases with multi-objective functions, it is very difficult to adjust the weights of each objective function. Moreover, the computing time increases drastically, making applications to practical problems impossible.

This paper proposes an intelligent start-up schedule optimization system for a thermal power plant. This system consists of a dynamic simulation, a neural network, and an interactive multi-objective programming technique. This system can determine the optimal start-up schedule among multi-objectives with a reasonable computing time and calculation accuracy through interaction between human beings and computers.

2. COMBINED CYCLE POWER PLANT

2.1 *Plant configuration*

This study considers a multi-shaft type combined cycle power plant, as shown in Fig. 1. It consists of three gas turbine units, three heat recovery steam generator (HRSG) units, and one steam turbine unit. The gas turbines and the steam turbine drive the generators. Also, the HRSGs generate steam for the steam turbine using waste heat from the gas turbines. This plant generates a total output of 670 MW.

2.2 *Start-up scheduling problem*

The start-up schedule of this plant is shown in Fig. 2. In this study, the following schedule variables, objective functions, and operational constraints are considered to optimize the start-up schedule.

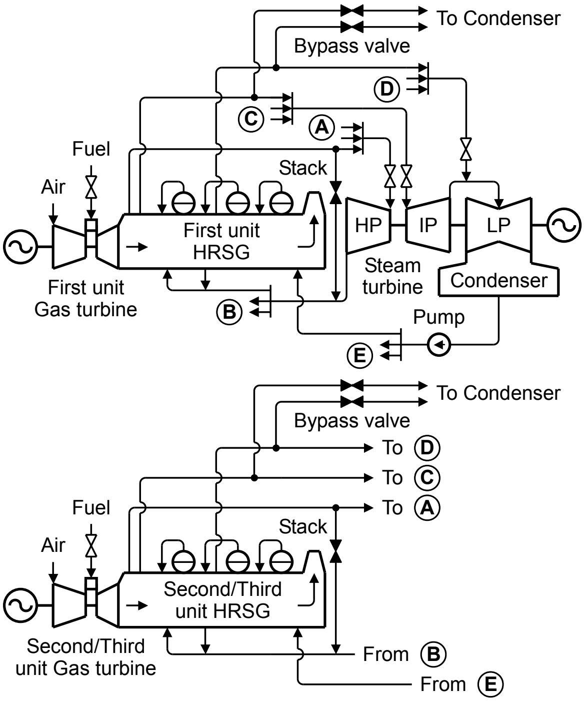

Fig. 1. Plant configuration.

Schedule variables. The steam turbine start-up schedule has a significant effect on the start-up characteristics of the entire plant. This is due to the thermal stress that develops in the steam turbine rotors, which is a factor that is particularly decisive for reducing the start-up time and fuel consumption rate. Therefore, four schedule variables are selected, i.e., the steam turbine acceleration rate x_1 , low-speed heat soak time x_2 , high-speed heat soak time x_3 , and initial-load heat soak time x_4 ; these are shown in Fig. 2. These schedule variables restrain the developed thermal stress by gently warming the steam turbine rotors.

Objective functions. The objective functions are to minimize the start-up time, fuel consumption rate, and thermal stress of the steam turbine rotors. A smaller thermal stress has the effect of further extending the service lifetime of the steam turbine. However, these objective functions have a trade-off depending on the above-mentioned schedule variables x_1 to x_4 . As the acceleration rate x_1 increases and the heat soak times x_2, x_3, x_4 decrease, both the start-up time and fuel consumption rate decrease; however, the thermal stress of the steam turbine rotors increases. This trend of the fuel consumption rate becomes more significant as the initial-load heat soak time x_4 is varied because the gas turbine load is higher with x_4 than with the other schedule variables x_1, x_2, x_3 .

Operational constraints. There exist many operational constraints in this plant. However, most of these operational constraints are safely controlled within the limits at any time (e.g., the drum water level and the steam temperature). As a result, the operational constraints consider only the thermal stress of the steam turbine rotors and the NOx

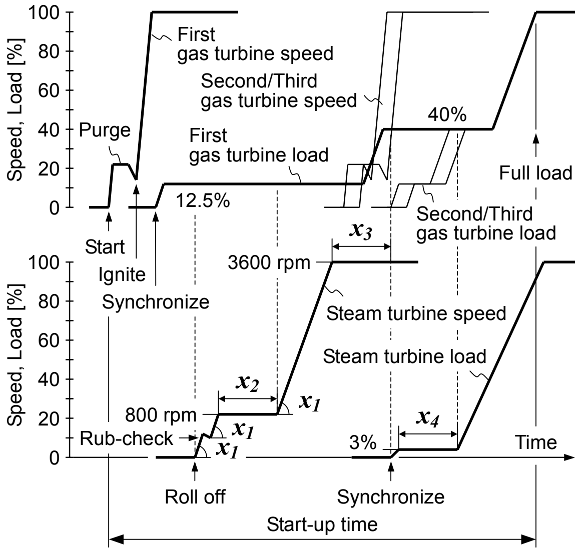

Fig. 2. Plant start-up schedule.

emission rate from the plant. The thermal stress of the steam turbine rotors in the above-mentioned objective functions has an upper limit to prevent metal creep and fatigue. The NOx emission rate from the plant increases significantly with the rapid start-up; however, it has an upper limit in accordance with the environmental regulations.

3. CONCEPT OF THE SYSTEM

A high accuracy plant simulator has been developed by one of the authors (Shirakawa, *et al.*, 2005). The dynamic models are derived from first principles (thermo-hydraulic conservation equations), and they are implemented in the software package MATLAB ™/Simulink™. When the values of the schedule variables are provided, the values of the evaluation functions (the evaluation functions represent both the objective functions and operational constraints) can be obtained by using the dynamic simulation. However, the high accuracy plant simulator is extremely time-consuming because detailed, large-scale, and nonlinear models are used. Moreover, there are many optimal solutions that are referred to as “Pareto solutions” in the multi-objective optimization; hence, a considerable amount of labor is required to find the final solution. Therefore, it is well known that the multi-objective optimization methods using the dynamic simulation require an unrealistic amount of time to obtain the optimal start-up schedule because they require a large number of dynamic simulation calls. In order to obtain quick solutions, the dynamic simulation, a neural network, and an interactive multi-objective programming technique are integrated by a cooperative human-machine system. Figure 3 shows the functional structure of an intelligent start-up schedule optimization system proposed in this paper. The major part of this system consists of a plant simulator, a human interface, and an optimization calculation.

3.1 Plant simulator part