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A model for the preventive maintenance scheduling of power plants including wind farms

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ABSTRACT

This paper considers the problem of Power Plant Preventive Maintenance Scheduling (PPPMS). The goal is to evaluate which generators must stop production to be checked periodically for safety reasons. Preventive maintenance is crucial because a failure in a power plant may cause a general breakdown in an electric grid. This situation might result in a disruption of electric service to customers. The objective is to perform the problem of PPPMS from a reliability perspective, so the reliability of the system is maximized. The model presented considers the integration of wind power plants or wind farms into a traditional electric generating system comprising thermal, hydroelectric, and nuclear power units. The resulting model is categorized as an optimization problem. A case study based on a real power system is presented. Its main objective is to validate the efficiency of the proposed analysis.

1. Introduction

The aim of a power plant in a power system is to supply the electric demand in an economical, reliable, and environmentally acceptable way. Various power plants can meet these requirements in different ways. This paper addresses the problem of power plant preventive maintenance scheduling (PPPMS). The main task is to determine the period for which generators of an electric system should be stopped for planned preventive maintenance over a certain time horizon. This problem is classified in the long-term exploitation of electric energy production systems [1].

Several types of power plants are considered here: wind, thermal, hydroelectric, and nuclear power plants. Incorporating wind power into an electric system makes the problem of PPPMS more realistic, given current energy production circumstances.

In general for complex systems, e.g., electric systems, maintenance does not necessarily mean replacing the whole system. It often includes the repair or replacement of a part of the system. There are many preventive maintenance policies [2–4]. For power plants, preventive maintenance consists of periodic inspection to detect potential failures. This planned maintenance is designed to extend the useful life by minimizing breakdowns and depreciation during normal operation. The amount of preventive maintenance needed at a power plant depends on many factors, such as technical, human, and operations.

Considering that power plants are integrated into a global electric system, an unforeseen failure could affect the whole system, and cause an undesirable break in the electric supply. Immediate customer complaints would be unavoidable.

Different authors have addressed the issue of planning of power plant preventive maintenance. They have introduced models of the problem and methodologies such as heuristic techniques [5], mixed integer programming [6], stochastic programming [7], decomposition methods [8], fuzzy methods [9], tabu search [10], multiobjective optimization [11], or hybrid approaches [12].

To date, most related industries have been unable to achieve highly efficient maintenance decisions because decision-making employs historical data rather than optimization processes. In addition, wind power plants have not been sufficiently considered in the problem of PPPMS.

An approach based on reliability centered maintenance is proposed in order to select a suitable maintenance strategy. To maintain efficiency, power plants must be disconnected periodically to review how well they function. The consequence is an increase in reliability. The resulting optimization problem of this study is framed as 0/1 mixed integer linear programming.

The topic touches on both traditional power plant management as well as concurrent wind generating systems. In addition, a case study based on a real power system is depicted in order to validate the efficiency of the proposed analysis. These points summarize the most interesting contributions of this paper.

The remainder of the paper is organized as follows. Section 2 presents a conceptual framework of wind power and its integration in

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electric systems. Section 3 explains the features of the model. Section 4 describes the mathematical formulation of the problem. Section 5 gives the methodology for the problem resolution. A case study based on a real power system is shown in Section 6. Finally, conclusions and future work are drawn in Section 7.

2. The wind power and its integration in electric systems

Wind is one of the most important alternative sources of electric energy, as evidenced by the exponential growth of wind turbines installation around the world in recent years [13]. Wind power has interesting features such as high reliability, low cost, economy of scale, a high performance versus price ratio, and low environmental impact. It is estimated that wind power could constitute 20% of capacity by 2030 in industrialized countries. Achieving this capacity requires an exhaustive analysis of how the integration of this new technology affects power systems [14].

The increase of wind power makes a power system more efficient from an economic and environmental perspective [13]. The associated value is the decrease of total costs because other energies are too expensive. Each kilowatt-hour (kWh) that is produced by wind farms will replace on kilowatt-hour that otherwise would have been produced from another non-renewable power plant. In short, when wind availability is low, cost of production is higher. If wind availability is high, the adoption of wind energy in power systems makes sense due to its efficiency.

According to the World Wind Energy Association [15], in 2011 wind energy production was over 3% of total worldwide electricity usage, and increasing rapidly at a 25% per year. Energy from wind is a complement to other types of energy, such as nuclear, thermal, or hydroelectric. It represents more than 10% of the electricity consumed in some regions of Denmark, Spain, Germany, or Sweden. In Spain, a leading country in this sector, the percentage over the global production was 14.5% in 2011 [16]. The total wind power capacity in the world in 2011 [15] is shown in Table 1.

The growing importance and popularity of wind power in the world and its implications in power systems are the reasons to take into account this type of power plant when examining the problem of PPPMS.

3. Features of the problem and model description

Two aspects of the problem can be distinguished: minimization of the *reliability impact* [5,12] and minimization of the *global cost* [17,18]. Electric energy demand must be supplied with an adequate reliability level. Moreover, the associated cost of shutdown of an electric generating system must be as low as possible to maximize the benefits.

Table 1
Wind power capacity in the world.

Position	Country	Total installed capacity (MW)
1	China	62,364
2	USA	46,919
3	Germany	29,075
4	Spain	21,673
5	India	15,880
6	Italy	6737
7	France	6640
8	United Kingdom	6018
9	Canada	5265
10	Portugal	4083
	Rest of the world	32,362
	Total	237,016

In general, the problem analyzed is combinatorial and non-linear, although the model presented is linear. The complexity of planning power plant preventive maintenance is due to the enormous size of the system to be modeled. There are a large number of variables and constraints. Balancing complexity, problem size, model calculating time, and reality approximation level is essential.

3.1. Time horizon and periods

The time horizon selected is 1 year, which can be expressed as either 13 periods or 52 weeks. A period is a block of 4 weeks. In this work, 13 periods was chosen because the average maintenance duration for power units is equal to 4 weeks.

3.2. Preventive maintenance duration

The duration of preventive maintenance depends on the type of power plant. The same maintenance duration is assumed to be one period on average for all power plants. This is a typical duration in real cases.

3.3. Electric demand

Each period of time is divided into two parts according to electric demand: business days and weekend days. Demand is greater during the period of business days. Each part is then divided into three subparts depending on electric demand or load. The subparts, from higher to lower demand are: peak, middle, and low demand. This distinction is made under a typical distribution profile of electric demand. Thus, there are six subperiods with different duration in a period of time.

The above detailed distribution is repeated three times because three possible electric demand scenarios are considered: high (s_h), medium (s_m), and low (s_l). This distribution describes how uncertainty in power demand is modeled. Each scenario has a probability associated with it according to the chance of occurrence. So, the elements are

s = power demand scenario (s_h, s_m, s_l);
k = period (from 1 to 13); and
n = subperiod (from 1 to 6).

The model presented is flexible, which means that it is possible to consider as many power demand scenarios, periods of time and subperiods, as necessary.

4. Mathematical model

PPPMS is an optimization problem. Objectives such as reliability maximization or cost minimization can be proposed, and the problem can be solved to satisfy a set of constraints.

4.1. Key variables

The most relevant variables in this problem are the maintenance variables, represented as $x_{i,k}$. They are binary variables (0/1) and indicate:

$x_{i,k}$ is equal to 0 if generator i is not in maintenance during period k, 1 otherwise.

Related binary variables denote the maintenance start-up, represented as $c_{i,k}$: