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Invited Review

Maintenance scheduling in the electricity industry: A literature review

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ABSTRACT

The reliability of the power plants and transmission lines in the electricity industry is crucial for meeting demand. Consequently, timely maintenance plays a major role reducing breakdowns and avoiding expensive production shutdowns. By now, the literature contains a sound body of work focused on improving decision making in generating units and transmission lines maintenance scheduling. The purpose of this paper is to review that literature. We update previous surveys and provide a more global view of the problem: we study both regulated and deregulated power systems and explore some important features such as network considerations, fuel management, and data uncertainty.

Introduction

The production of movement, heat, or light needs a common input: energy. Energy can be produced from fuel (e.g., oil, gasoline, uranium, gas, coal, wood) or natural forces (e.g., wind, water). The consumption of energy is growing with the development of countries and the increasing world population, and the production must meet this demand. Therefore, the reliability of power plants, and wind and solar farms is extremely important. In this context, equipment maintenance management is a major economic issue. Just to cite few examples, equipment maintenance management in electric power systems is concerned with decisions such as: when to stop a generating unit for maintenance, when to re-start it again, and how much resources (e.g., technicians) are to be assigned to the maintenance of a given unit during a given period. These decisions are taken under complex environments and constraints such as resource availability, demand satisfaction, and reliability thresholds.

One of the most successful contributions of operations research to improve decision making in equipment maintenance management is the application of optimization techniques to solve maintenance planning and scheduling problems. In the particular case of electric power systems, these problems range from simple technician-equipment assignments to complex problems considering interactions between different stakeholders and uncertainty in the problem parameters. In this paper, we build on the work of Yamayee (1982), Kralj and Petrović (1988), Dahal (2004), Khalid and Ioannis (2012) to update the state-of-the-art and provide a global overview of the current stream of research in the field. To make the document easier to read, the various acronyms used in this paper are summarized in Table 1.

The paper is organized as follows. Section 1 presents a brief description of the energy industry, Section 2 reviews maintenance scheduling problems rising in *regulated* and *deregulated* environments, Section 3 discusses existing solution methods for these problems, and Section 4 concludes the paper and outlines research perspectives.

1. The energy industry

The energy industry carries out three activities: production, transmission, and distribution. Traditionally the industry is organized in a centralized, vertically integrated way (see Fig. 1): a single company has a monopoly of the entire system in its area of operation. However, the government regulates the situation directly or indirectly: the entity must not take advantage of the end consumer. Therefore, the term *regulated monopoly utilities* is also used. With the deregulation of the electricity industry from the end of the 1990s, competition has been replacing monopolies in most places.

1.1. Deregulation of the power industry

The deregulation (or liberalization) of the power industry has opened up the electricity market to competition. Several companies

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Table 1
List of key terms and their acronyms.

Acronym	Term
GENCO	Generation company
TRANSCO	Transportation company
DISCO	Distribution company
RETAILCO	Retail company
ISO	Independent system operator
GMS	Generator maintenance scheduling
TMS	Transportation maintenance scheduling

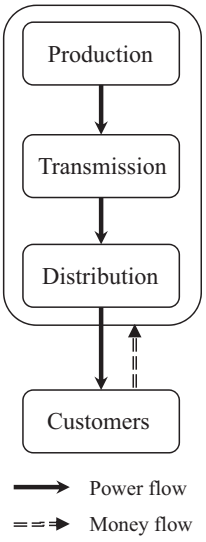

Fig. 1. Interactions in a vertically regulated utility.

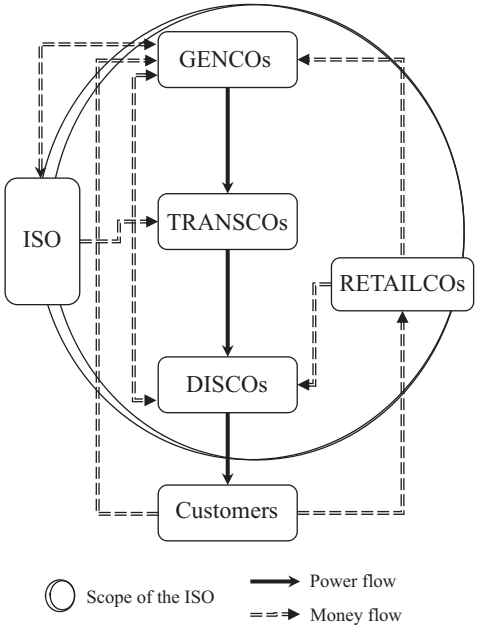

Fig. 2. Interactions between market players under deregulation.

can now produce or distribute energy; it is, however, more difficult to introduce competition for the transmission management. Energy prices are no longer regulated by the government (hence the terms deregulation and liberalization) but are subject to market interactions. Regulations remain (sometimes the term *restricted power system* is used) but monopolies are no longer acceptable. Given the success of this system in the aeronautics, gas, and telephone industries, this reform is promoted as a benefit for the sector. It is intended to favor innovation, to lower prices, and to lead to better service. This new system introduces challenges such as the organization of the electricity market, the price-setting mechanism, and the coordination of the various actors.

Indeed, the introduction of market players leads to the emergence of new actors or redefines the role or activities of existing actors. An independent system operator (ISO) is responsible for the reliability and security of the system. It dispatches all or part of the energy transactions and can decrease loads on the network to avoid congestion. The ISO is the leading entity in a power market, and it must be fair. It manages the interactions between three key entities: the generating companies (GENCOs), transmission companies (TRANSCOs), and distribution companies (DISCOs). When a single TRANSCO owns the entire transmission network, the ISO operates the transmission lines. The TRANSCO is then paid for the use of its lines and the maintenance of its network (Shahidehpour, Yamin, & Li, 2002). Retail energy service companies (RETAILCOs) act as intermediaries between GENCOs and consumers by buying energy from the former to sell to the latter. Other actors exist but their roles are relatively minor.

Energy transactions of different natures can take place in this new market structure. In a power exchange model, GENCOs and RETAILCOs negotiate bilateral contracts defining prices and quantities independently of the ISO. However, the availability of the transmission lines must be checked with the system operator to maintain security. This decentralized approach is opposed to the centralized approach (pool-based model) where market participants share extensive information (e.g., energy offer, start-up costs, generation costs, ramp-rate for each generator) with the ISO, which is responsible for ensuring the social and economic welfare of the market while keeping the system safe. Two kinds of bids are submitted to the ISO: producers' bids consist of energy blocks and their selling prices, and buyers' bids consist of energy blocks and their buying prices. The power price is determined by the balance between supply and demand using a market clearing process. Several markets such as day-ahead, intra-day, real-time or a combination can be encountered. Although they are different, both pool-based and power exchange models can coexist. Moreover, a transmission market deals with the purchase and sale of transmission rights. For a more detailed explanation of all these specificities, the reader is referred to Shahidehpour et al. (2002). Fig. 2 summarizes the various interactions between the actors. It is however difficult to define a typical organization because several structures are possible.

Liberalization modifies and sometimes complicates power industry issues. GENCOs, TRANSCOs, and DISCOS mainly serve their own interests, which may call into question the stability of energy production and/or energy distribution. Regulations are therefore required.

After this brief presentation of the electricity industry, we discuss, in the next section, optimization problems in maintenance scheduling of generating units and transmission lines rising in both regulated and deregulated power systems. We focus on network constraints, on data uncertainty, and on fuel consumption and supply management. To provide a global overview, Table A1 classifies the references according to the problem they solve, the power system they target and the features they deal with.

2. Maintenance in the electricity industry

Maintenance represents the actions required to ensure that a product provides reliable service. Maintenance can be split into two categories: corrective and preventive. Corrective maintenance is performed after a breakdown. Preventive maintenance is performed at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure. Maintenance in the electricity industry concerns generating units and transmission lines; the