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Modelling generator maintenance scheduling costs in deregulated power markets

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ABSTRACT

Generating companies use the maintenance cost function as the sole or main objective for creating the maintenance schedule of power generators. Usually only maintenance activities related costs are considered to derive the cost function. However, in deregulated markets, maintenance related costs alone do not represent the full costs of generators. This paper models various cost components that affect the maintenance activities in deregulated power markets. The costs that we model include direct and indirect maintenance, failures, interruptions, contractual compensation, rescheduling, and market opportunity. The loss of firm's reputation and selection of loyalty model are also considered using the Analytic Hierarchy Process (AHP) within an opportunity cost model. A case study is used to illustrate the modelling activities. The enhanced model is utilised in generator maintenance scheduling cases. The experimental results demonstrate the importance and impact of market related costs in maintenance schedules.

1. Introduction

The electricity sector in many countries has moved from a centralised structure to deregulated markets separating the integrated power system into various competitive entities. This has created an open electricity market pool by allowing competition with respect to the supply of power and allowing consumers to choose their preferred supplier of electric energy (Cai, Deilami, & Train, 1998; Galloway, Dahal, Burt, & McDonald, 2004; Shahidehpour & Marwali, 2000). In power systems, generators must be maintained in order to supply electricity with high reliability. Power generating companies (GENCOs) apply different maintenance strategies, such as reliability centre maintenance (Bertling, Allan, & Eriksson, 2005; Park & Yoon, 2011), corrective maintenance (Bertling et al., 2005), preventive maintenance (Cai et al., 1998; Canto, 2008), and age-based maintenance (Huynh, Castro, Barros, & Bérenguer, 2012), to achieve their objectives in terms of quality and cost. Regardless of the type of maintenance carried out, the generator units must be taken out of service for a period of time ranging from several hours to several weeks (Dahal & Chakpitak, 2007; Shahidehpour & Marwali, 2000). In the deregulated environment, the decision when to take the generator out of service depends on various factors such as the effect of maintenance outages on the overall system, reliability, loss of services, loss of firm's reputation and loss of revenue (Chen, Huang, & Huang, 2008; Conejo, García-Bertrand, & Díaz-Salazar, 2005). The coordination of this is usually done by the Independent System Operator (ISO).

This paper concentrates on the maintenance cost modelling of power generators for GENCOs in a deregulated environment. There are different costs associated with generator maintenance activities in deregulated power markets that influence maintenance scheduling and other planning activities. Reducing the maintenance cost is one of the main objectives in scheduling power system maintenance but this can be problematic. As the major factor for scheduling maintenance, formulating the problem requires the maintenance cost to be carefully modelled to reflect the real-world scenarios. It must be accurately quantified to ensure the optimal solution found represents a realistic optimised schedule (Canto, 2008).

In Al-Arfaj, Dahal, and Azaiez (2007) preliminary modelling concepts and opportunity costs of planning generator maintenance have been introduced. We extend these ideas by developing two complete maintenance cost models under "no-failure" and "failure" cases. The developed models also include "reputational costs", "interruption" and "contractual compensation"[1] (hereafter

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[1] In case of failure to generate power, GENCOs are obliged to supply the contractual volume by buying in the spot market. Hence the compensation cost will be equal to the difference between spot price and contracted price (see expression 6 for further details).

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"compensation") costs. The reputational cost is quantified with the selection of the best loyalty model to minimise the loss using the Analytic Hierarchy Process (AHP). The paper also shows the data gathering process for the proposed cost models. The developed cost model has been utilised in two generator maintenance scheduling cases to demonstrate the impact of the "reputational costs" with the AHP loyalty models on the maintenance schedule.

2. Related work

Maintenance cost in power systems includes direct and indirect costs. Examples of direct maintenance costs include the costs of labour, spare parts, and cleaning materials. The indirect costs include costs for inventory, shipment, indirect labour (e.g. health insurance), test equipment, etc. Most formulations, however, concentrate only on total (fixed and variable) direct maintenance costs in the delivery of maintenance cost models (Chen et al., 2008; Kralj & Petrović, 1988; Shahidehpour & Marwali, 2000). A general model for scheduling maintenance is presented in Shahidehpour and Marwali (2000), which uses maintenance costs of power generating units and the energy production cost within the objective function. This model has been described with different objective functions (Marwali & Shahidehpour, 1998), such as minimising total operating cost or minimising the loss of revenue, but using the same maintenance cost function. The model presented by Leou (2001) focuses on improving reliability by maintaining the units as early as possible. The model is a cost minimisation model which includes the direct maintenance cost. The maximisation of the profit objective function was considered by Chen et al. (2008) to find the best maintenance schedule for generators in deregulated power systems.

The maintenance model for deregulated power systems should also include market related costs such as opportunity costs (revenue lost due to opportunity foregone), compensation costs and failure costs, in addition to the classical maintenance cost. The opportunity cost was introduced as an influencing factor in modelling cost and electricity pricing in restructured power systems (Baughman, Siddiqi, & Zarnikau, 1997; Chattopadhyay, 2004; Manbachi, Mahdloo, & Haghifam, 2010). Baughman et al. (1997) developed a mathematical model for real-time pricing of electricity, which includes selected ancillary services and incorporates constraints on power quality and environmental impact that often influence the operation of a power system. The model uses optimal nodal specific real-time prices both for real and reactive power that incorporate additional premiums, reflecting the effects of the various engineering and environmental operating constraints. The opportunity cost of market participation was included in the generator maintenance scheduling model in Manbachi et al. (2010).

Chattopadhyay (2004) developed a model that considered the trade-off between short- and long-term objectives to determine optimal generator maintenance profiles. All major costs associated with maintenance, namely direct maintenance expenses, opportunity costs, replacement costs and contractual compensation, are explicitly recognised in the model. Clearly, maintenance cost representations in this model differ from the traditional models.

In the deregulated environment a company can have only limited information on the activity of other companies, adding uncertainties to its own planning decisions (Conejo et al., 2005; Feng, Wang, & Wang, 2011; Kim, Park, Park, & Chun, 2005). In the competitive market, the interaction between GENCOs and the ISO can affect the profit of GENCOs, who are to maximise the profit against the time-varying market prices. Kim et al. (2005) presented a game-theoretical framework taking GENCOs as game players to maximise their profit in a competitive environment. Feng et al. (2011) investigated an iterative maintenance scheduling scheme in power markets, considering the influence of unexpected generating unit failures. Conejo et al. (2005) proposed a coordination method based on an incentive/disincentive programme between the ISO and GENCOs to overcome their conflicting maintenance scheduling objectives in a competitive environment. To attain the preferred level of reliability, the model proposes reallocating the maintenance outages to GENCOs that are making the least profit. This model aims to provide a compromise solution to both GENCOs and the ISO. This indicates that there is a cost pertaining to GENCOs' coordination, which is imposed by the ISO to ensure an appropriate distribution of maintenance outages over the period. Along with the competitive prices, GENCOs should also play an important role in delivering high reliability and customer care to enhance their corporate reputation and brand value by acting in a responsible manner which can make a significant impact on customer retention (Cai et al., 1998; Sullivan, Suddeth, Vardell, & Vojdani, 1996). Cai et al. (1998) analysed GENCOs' customers[2] who would switch to a competitor under various price discounts and service attributes (reliability, renewable power, energy conservation assistance, and customer service).

What follows from the above discussion is that different cost components have an effect on maintenance scheduling and that there is a need for a single model which incorporates all maintenance cost components in order to analyse their effect on GENCOs. Also, many of the cost components suggested in the literature are assigned to fixed values, restricting their use in optimisation models. In this paper, we model a wide range of cost components that affect the maintenance activities of deregulated GENCOs. We also model GENCOs' reputational cost due to the maintenance activities of generators. We propose loyalty models to minimise the loss of firm's reputation using the AHP.

The AHP has been applied to a number of applications in the literature (Nigim, Suryanarayanan, Gorur, & Farmer, 2003). The AHP approach is a subjective methodology where information and the priority weights of criteria may be obtained from a decision-maker using direct questioning or a questionnaire method (Eua-Arporn & Karunanoon, 2000). It is a decision approach designed to solve a complex multiple-criteria based problem in a number of application domains. Nigim et al. (2003) use the AHP to study the impact of Special Protection Schemes' (SPSs) mis-operations in a power system due to hidden failures in the SPS at the most critical bus locations. Hidden failures (i.e. failures that are not apparent during the normal operation of a system which become exposed during a fault) are major contributing factors for a serious system disturbance to happen. The AHP reduces time and effort in locating the most and least vulnerable SPS as it integrates an expert's service experience in the field and probability tools. Sato and Kataoka (1995) have introduced customer satisfaction surveys and analysed customers' perception of telecommunication services. All customers are surveyed regarding items such as service order reception, provisioning and repairs. The AHP was used to investigate each customer's perception of the importance of the Quality of Service, and to estimate the overall customer satisfaction weighted by importance. Medjoudj, Laifa, and Aissani (2012) developed an application of multi-criteria techniques for decision making in an electrical distribution system for customer satisfaction and financial success of the company. Cost-benefit analysis and the AHP were introduced to overcome the reputational issue of the company. A particular concentration is given to the AHP because it makes the selection process very clear with huge benefits for a company assuring public services. The AHP is applied to choose the best alternative to provide customer satisfaction and financial success. The result shows that both cost-benefit analysis and the AHP methods converge to an investment need.

[2] GENCOs customers include suppliers, retailers, traders, brokers and end users.