A risk-based model for performance-based regulation of electric distribution companies

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A R T I C L E   I N F O

A B S T R A C T

In this study, a model is presented to obtain the parameters of penalty and reward scheme (PRS) in performance-based regulation (PBR) for each electricity distribution company (EDC) using analytical hierarchy process (AHP) and fuzzy c-means clustering (FCM). In the FCM algorithm, similar companies were categorized into clusters. By using AHP, score of effective factor in reliability index was obtained. In this model, external factors affecting EDCs performance were considered to reduce the risk of PBR implementation for companies and customers. The proposed model was applied on the EDCs in Iran. The results, including AHP score, parameters of PRS and PRS cost were calculated.

1. Introduction

Electricity distribution companies (EDCs) are regulated by cost-based rate-of-return (ROR) and cost-of-services (COS) methods (Abedi and Haghifam, 2013a; Moradkhani et al., 2015). The problem of the cost-based regulation is that it might encourage EDCs to invest into excessive capacity, causing efficiency losses (Abedi and Haghifam, 2013a). In order to increase efficiency and reduce costs, incentive regulation or performance-based regulation (PBR) methods such as price caps and revenue caps have been introduced (Jamasb and Pollitt, 2000; Cossent and Gómez, 2013). However, PBR with cost savings may reduce the quality of service (Simab and Haghifam, 2012). Research (Ajodhia et al., 2006; Ter-Martirosyan, 2003) has shown that PBR allowed the EDCs to increase their profits by reducing the quality of service. Because of the strong efficiency incentive of PBR, regulators can utilize service quality regulation to ensure an adequate level of quality (Simab and Haghifam, 2012). Four regulatory instruments used to ensure an adequate level of reliability are data publication, minimum quality standards, reward-and-penalty schemes, and premium quality contracts (Simab and Haghifam, 2012; Ajodhia and Hakvoort, 2005).

With regard to the recently adopted regulatory instruments, the incentive based penalty and reward scheme (PRS) for quality performance proves to be an advanced regulatory instrument to motivate the regulated company to deliver a desired service quality level to customers. This incentive scheme impacts on revenues of companies according to their performance against a predefined service quality indicator, e.g. the system average interruption duration index (SAIDI) or the system average interruption frequency index (SAIFI) (Growitsch et al., 2010). In this case, the EDCs which provide poor reliability are penalized and those with good reliability are rewarded (Fumagalli et al., 2007).

Billinton and Pan evaluate financial risk of Canadian distribution companies associated with PRS on the basis of historic reliability data taken from Canadian electricity association service continuity reports (Billinton and Pan, 2004). In Fotuhi et al. (2006), different penalty and reward schemes were applied on reliability data and a new method was presented to obtain the scheme for each distribution company. In Tanure et al. (2006), a methodology was proposed for performance target setting related to continuity metrics in electricity distribution networks. In Mohammadnezhad-Shourkaei and Fotuhi-Firuzabad (2010), a method was presented not only to provide incentives for electricity distribution companies to improve their service quality, but also, the total rewards paid and total penalties received by regulators were equal, that is, the implementation cost of PBR was zero. The companies that provided

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Nomenclature

A_{ij}	AHP score related to external factors j for company i
A_{ik}	AHP score of factors k affecting reward slope for company i
A_{im}	AHP score of factors m affecting penalty slope for company i
CDB	Center of Dead Band
C_{ij}	Outage duration/frequency reduction cost of factor j for reliability index i
DBW_i	Dead Band Width of company i
$EPRSC_i$	Total expected PRS cost for company i
PF_{ij}	Productivity of factor j for reliability index i
PF_{ik}	Productivity of factor k related to reward slope for company i
PF_{im}	Productivity of factor m related to penalty slope for company i
PC_i	Penalty cap of company i
PCP_i	Penalty cap point of company i
PP_i	Penalty point of company i
PS_i	Penalty slope of company i
RC_i	Reward cap of company i
RCP_i	Reward cap point of company i
RP_i	Reward point of company i
RS_i	Reward slope of company i
SD_i	Average standard deviation of historical reliability index for company i
W_{ik}	Weighting value of reliability index k for company i
ΔC_{ik}	Cost of reduction of reliability index i related to factor k
ΔC_{im}	Cost of reduction of reliability index i related to factor m
$\Delta INDEX_{ij}$	Outage duration/frequency reduction of reliability index i related to factor j
$\Delta SAIDI_{ik}$	Improvement of index SAIDI of company i due to expenditures on factor k
$\Delta SAIDI_{im}$	Improvement of index SAIDI of company i due to expenditures on factor m
ζ_i	Interest rate of company i
γ_i	Opportunity cost rate of company i

poor reliability faced substantial financial risks and this was not considered in Mohammadnezhad-Shourkaei and Fotuhi-Firuzabad (2010). In Simab et al. (2012), an algorithm was presented using data envelopment analysis (DEA) and fuzzy c-means clustering (FCM) to obtain the parameters of PRS for each electric distribution company. The result of the algorithm included DEA efficiency score, parameters of reward-and-penalty scheme and financial risk assessment. In Simab et al. (2012), external factors such as social behavior, traffic, and urban structure were not considered, even though these factors increased the financial risk of distribution companies. Also, unlike the DEA, AHP provides convenience, flexibility, and the ability to check inconsistencies (Stiakakis and Sifaleras, 2013). In Jooshaki et al. (2014), a new method for designing procedure of PRS in distribution system is proposed.

Quality in the electricity distribution sector comprises three main areas: commercial quality, voltage quality, and reliability (continuity of supply). Our analysis focuses on reliability. From a regulatory point of view, reliability has two quality dimensions. The first dimension is the availability of energy to customers. Accordingly, this dimension focuses on indicators of frequency and duration of interruption and the energy not supplied (ENS). The second dimension is the customers' preference for continuity of supply (Growitsch et al., 2010; Fumagalli et al., 2007). In Mirzaei et al. (2015), a new method is presented to estimate the failure rate of lamps based on the normal distribution function. In López et al. (2016), a model to solve the reconfiguration problem of electrical distribution systems, considering the minimization of total active power losses and improvement of customer-oriented reliability indices, was presented. In Fenrick and Getachew (2012), research reveals the reliability and operation and maintenance benefits of electric underground lines relative to overhead lines. In Abedi and Haghifam (2014), the concept of a reliability insurance contract was introduced and in the presence of these contracts, the revenue opportunities for distributed generation were evaluated. In Abedi and Haghifam (2013b), customer damage function based insurance contracts were designed and, with respect to these contracts, investment incentives provided by reliability insurance scheme were calculated. In Božič and Pantoš (2013), a new method was presented for reliability investment decisions when a reward-and-penalty scheme is applied to the regulation of distribution system

operators. In Alvehag and Awodele (2014), a method was developed for use by the regulator prior to enforcement in order to understand the impact of different PRS design solutions on the EDC's financial risk.

The main objective of our analysis is to propose a new model for determining the parameters of reward-and-penalty schemes using analytical hierarchy process (AHP), fuzzy c-means clustering, and productivity factor (PF). There are numerous internal and external factors of companies that affect the reliability indices and should be taken into account when determining the parameters of PRS. In our analysis, we use AHP to consider external factors, including traffic, urban structure, social behavior, and weather conditions to minimize the risk of PBR implementation for distribution companies. By means of FCM algorithm, the distribution companies with similar parameters were categorized into one cluster and a competition was created between companies. AHP and FCM have not been previously used to determine the parameters of PRS.

The article proceeds with the following sections. Section 2 presents the proposed model and Section 3, discusses the numerical results. Our conclusion is presented in section 4.

2. Proposed model

In our analysis, FCM algorithm was used to find the similar electricity distribution companies. Clustering was based on factors outside the distribution company's control. Parameters of PRS were calculated based on mean and standard deviation of historical reliability indices, analysis hierarchy process, and productivity factor. The proposed model can be used to create financial incentives for electricity distribution companies to improve their service quality levels so as not to be exposed to high penalties. The flowchart of the proposed model is shown in Fig. 1 and has the following steps:

Electricity distribution companies clustering: This involves selection of a number of attributes in order to group similar companies and cluster companies into different categories by using FCM. Its use is based on the selected network and weather conditions, respectively.