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Multi-dimensional customer segmentation model for power system reliability-worth analysis

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ABSTRACT

Accurate assessment of customer interruption costs is essential for making informed decisions in power system planning and operation. This paper presents a multi-dimensional customer segmentation model for reliability-worth analysis of power systems. The proposed model uses a hierarchical clustering technique to cluster electricity customers into customer segments of similar cost characteristics. Three customer parameters – economic size, economic activity and energy consumption are used in the proposed model. The proposed model is examined on two case studies from South Africa and Sweden, and results are compared to the conventional customer segmentation models. The effectiveness of the proposed model is determined based on the coefficient of variation of the final CIC estimates for different duration and time of occurrence of power interruptions. The results show a reduction in the dispersion of the final CIC estimates and thus allow CICs to be estimated from smaller survey samples.

Introduction

Power system reliability is crucial in modern society. However, one difficult problem faced by power system operators and planners is to decide how much is justified to invest in reliability. A completely reliable system is impossible to obtain, instead, the task is to find an adequate balance between investment costs and reliability. Determination of what is an acceptable level of reliability should recognize the benefit or the perceived value of supply reliability seen by the customers [1–6]. Awareness of these benefits can provide valuable input to balancing the economic and reliability constraints associated with power system planning and operation [4,7–9]. Reliability must be quantified in monetary terms to relate investment costs to the level of supply reliability [2,3,9–11]. In reliability cost and worth analyses of power systems, the reliability-worth experienced by customers is compared to the cost incurred by the power utility. To measure the reliability worth experienced by customers, customer interruption costs are used [1,2].

Customer interruption costs (CICs) have been investigated by researchers in several countries including Greece, Norway, Sweden, Canada, and South Africa [1,10,12–16]. Many researchers have done much to get more accurate CIC estimates [17–20]. Being able to estimate CIC accurately is desirable from more than one aspect. From the regulatory point of view, accurate CIC estimates are essential in order to tune the incentives schemes. If the regulatory impact of the interruption is based on the socio-economic costs of the interruptions the DSOs are given incentives to make investments that are socio-economically correct. Consequently, correct incentive schemes and socio-economically correct valuation are only possible with accurate CIC estimates [21]. For a power utility, CIC estimates are inputs to cost-benefit analysis of power system reliability investment projects. If the CIC estimates are under-estimated there is risk of power system reliability deterioration due to postponed investments and tighter maintenance schemes, increasing the probability of power interruptions. On the other hand, over-estimated CIC values will result in premature investment and unnecessary cost to the electricity customers. In both scenarios the electricity customer is affected, therefore, determining accurate CIC values is the basis of good and acceptable customer service by the regulator and power utility.

Many different survey methods have been proposed [19,20,22,23]. Recently, CEER 2010 has published guidelines for surveys of different customer sectors [13]. Using the collected CIC data, customer segments are identified and for each customer segment, customer damage functions (CDFs) are formed [20]. Before the CIC estimates are used to derive CDFs, they must be normalized, for example with respect to annual energy consumption,

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peak demand or monthly energy cost [1,20,24]. The CDF describes the normalized CIC for each customer segment as a function of duration. Generally, there is a great diversity among CIC profiles of customers belonging to the same activity or associated with the same economic code or customer segment [1,17,18,23]. Grouping of electricity customers into customer segments of similar cost characteristics has therefore become one of the keys to obtain accurate CICs. The process of grouping customers into different customer segments of similar characteristics is referred to as customer segmentation.

In CIC analysis, customer segmentation requires a set of parameters derived from the utility database or any available standard data source. Generally, one- or two-dimensional customer segmentation methods are used [10,12–15,22,27,28]. Two problems of high internal variation (-dispersion) of final CIC estimates and large number of customer segments to be surveyed have been acknowledged by many researchers when using such customer segmentation methods [1,14,17,18,23]. In most cases the two problems have been tackled independently. However, from a power system management point of view, the two problems should be solved simultaneously. Given a set of parameters, it is possible to simultaneously produce accurate CIC estimates with a smaller number of customer segments. Multi-dimensional customer segmentation models have been applied in customer relation management for many fields of engineering and marketing [25,26]. Different clustering tools have been used to cluster different customers into customer segments of similar characteristics [25,26]. It is to the knowledge of the authors that multi-dimensional customer segmentation models using clustering tools have not been applied to CIC analysis for power system reliability worth analysis.

This paper proposes a multi-dimensional customer segmentation model based on a clustering technique to reduce the dispersion of the final CIC estimates and at the same time reduce the number of customer segments to be surveyed. The proposed multi-dimensional customer segmentation model is applied to two case studies using customer survey data from Sweden and South Africa. In the case studies the dispersion of the final CIC estimates in each customer segment is investigated. The results of the proposed multi-dimensional customer segmentation model are compared with existing one- and two-dimensional customer segmentation models.

This paper is organized as follows – Section 'Customer segmentation' briefly explains the basic concepts often used in customer segmentation. Section 'Proposed multi-dimensional customer segmentation model' presents the proposed multi-dimensional customer segmentation model. The case studies and analysis results of CIC estimates are presented in Sections 'Case study' and 'Results', respectively. Section 'Discussion of results' discusses the results from the two case studies. Section 'Conclusions' contains the concluding remarks about the proposed multi-dimensional customer segmentation model and the future prospects for the value of the proposed concept in reliability-worth analysis of power systems.

Customer segmentation

This section briefly summarizes one- and two-dimensional customer segmentation models that have been used for CIC analysis.

One-dimensional customer segmentation

One-dimensional customer segmentation refers to the segmentation of customers using one parameter. The most common one-dimensional customer segmentation is based on economic activity-type parameters e.g. using the Standard Industrial Classification (SIC) system. When using economic activity-type parameter, electricity customers with similar economic activities are clustered together. For example, customer surveys that provides CIC estimates over a number of customer segments within the same customer sector e.g. segmenting commercial customers involved in retailing of non-food and food commodities, and financial services [15]. The main advantage of this customer segmentation method is that it can estimate CIC for each customer segment of electricity customers up to the last digit level of the SIC system. This may produce high resolution CIC estimates but the accuracy is limited by the customer survey resources available to survey all the customer segments formed and the variation of electricity intensity of customers within the customer segment.

Two-dimensional customer segmentation

Two-dimensional customer segmentation refers to the segmentation of customers using two parameters. Commonly, the economic activity-type parameter is combined together with size parameters. The most common examples of size parameters that are combined with economic activity-type parameters are energy consumption [27], voltage level [28] or turnover [27]. For example, commercial and industrial customers are grouped by their economic activity and economic size (turnover) as commercial-large, -medium and -small [27]. The main disadvantage with this technique is that electricity-intensive customers are combined with customers using relatively little electricity. For example, a large retailer company that uses electricity for lighting only (low electricity-intensity customer) can be combined with a hotel company which uses electricity for cooking and lighting (electricity-intensive customer). When the CIC estimates are combined, there is large dispersion of the final CIC estimate as a result of the difference in electricity-intensity of the customers.

Sometimes electricity customers are also segmented by their technical connection (e.g. single or three phase supply customers) to the power system network and/or according to the voltage level of the electric equipment (e.g. low, medium and high voltage transformer level) that is transmitted from the network to the electricity customer [28]. The type of technical connection to the grid or voltage level is used as a parameter that characterizes the CIC estimates of the electricity customers. However, some electricity customers are connected to particular voltage level because of the nature of the production process involved or its location. For example, a small mining company is connected to a high voltage level because of the production equipment used in the processing of its product. The turnover for the small mining company may be very low compared with a large mining or glass manufacturing company connected to the same voltage level. This mismatch of electricity customers to different customer segments may result in high dispersion of the final CIC estimates.

Proposed multi-dimensional customer segmentation model

The proposed multi-dimensional customer segmentation model consists of three steps. The first step corresponds to a one-dimensional model where the customers are segmented according to economic activity (SIC code). In the second step, the customers are further segmented into customer segments based on two size parameters. In Fig. 1 the method is illustrated for three macro-economic customer categories (residential, commercial and industrial) and for two size parameters: electrical size and economic size measured in electricity consumption and turnover, respectively. For the size parameters there are cut-off points that divide the customers into segments. The cut-off points must be well defined and readily