10.2478/v10144-009-0001-7

Evaluation of Distribution Network Customer Outage Costs

Laila Zemīte[1], Jānis Gerhards[2]
[1] Riga Technical University (Riga, Latvia), [2] Riga Technical University (Riga, Latvia)
laila.zemite@rtu.lv, gerhards@eef.rtu.lv

***Abstract* – Customer outage cost criteria are considered, collected and analyzed outage costs in Latvia distribution network, as well as distribution network outage elimination structure, the most common outage causes, are proposed outage costs estimation model. Finally the discussion of results of expected customer outage costs and interrupted energy assessment rate calculation results in Latvia distribution network in 2007 are presented, based on customers' mean value of incomes, outcomes and profitability.**

Index terms – distribution network, customer outage cost model, estimation criteria.

I. INTRODUCTION

The cost of electrical power supply is depended not only on network structure, reliable power supply level and customers groups and load demand structure, but also on regional electrical power demand and gross domestic product (GDP). The power demand level, the customer turnover, GDP, climatic conditions, customer group's structure, distribution network operator technical resources, network configuration, network automatization level, distribution system operator (DSO) customer service and DSO capital investments have taken into account [1].

Due to the increased application of various electrical drives, electronic control devices, and high efficiency lighting installations, the line voltage quality is anticipated to degrade further. Simultaneously, the requirement for reliable and uninterrupted power supply is emphasized in the future. For instance, banking systems allow only a 30-second annual interruption time, while the maximum annual interruption time for hospitals and airports is about 5 minutes [2].

II. DIFFERENTATION OF CONSEQUENCES

In general terms power supply outage could be differentiated by the following versions:

The first version – when the outage is felt only in distribution system, while customers do not suffer damage, however, in this situation the comfort of customer's daily life deteriorates, e.g., lack of hot water, low indoor temperature, worse working conditions, changes in business plans, schedules, when customers have indirect costs (Fig. 1). In this case, DSO has direct and indirect costs, but customers have only indirect costs. The time of power supply outage elimination is that, what need for network automatic or manual switching (Fig. 2. version 1). The time of power supply outage could be from some seconds till some minutes.

The second version – when in addition to the first version, both DSO, and customers have direct costs. In this case customers have not only indirect costs, but also direct costs, e. g., lost production, product spoilage, paid staff unable to work (Fig. 1.). The time of power supply outage elimination is that, what need for network sectionalisationing and step by step power supply restoring first for not implicated customers, founding the outage point and after that restoring power supply for all implicate customers (Fig. 2. version 2). The time of power supply outage could be from some seconds till some hours.

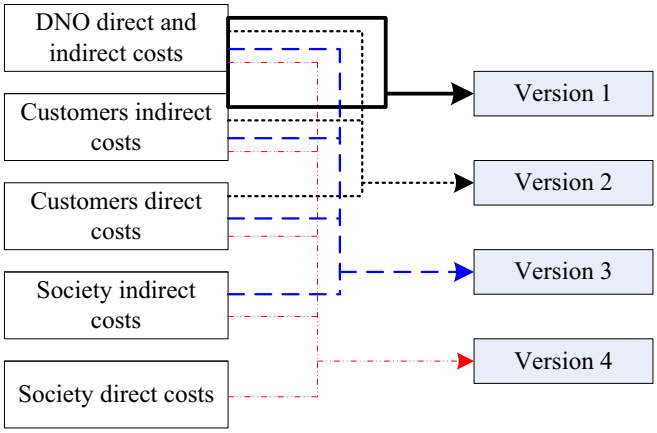

Fig. 1. Differentiation of power supply outage costs versions

The third version – when in additional to those of second version, both DSO, and customers have direct and indirect costs, but also society have indirect costs, e. g., looting, rioting, legal and insurance costs, changes in business patterns (Fig. 1.). In this case, apart from the damage due to the not delivered energy by all implicated customers, damage arises also in other areas of activity (customer services, tourist business, civil engineering etc.). The time of power supply outage elimination is that, what need for restoring power supply first for all not implicated customers, failure registration, founding the place of failure and elimination of failure (Fig. 2. version 3). The time of power supply outage could be from some seconds till 24h as it is mentioned in Regulations regarding the Trade and Use of Electricity of Latvia [10].

The fourth version – when in addition to those of third version, not only DSO and customers have direct and indirect costs, but also society have indirect costs as well as direct costs. In this case, as a result of long-lasting lack of electrical

power supply, damage of the basic funds/assets of industrial and social spheres is inflicted, e. g., the lack of water supply, the necessity to evacuate people from dwelling houses, transportation ability, risk of injury, death, fear of crime and so on (Fig. 1.). The time of power supply outage elimination is that, which need for restoring power supply first for all not implicated customers, failure registration, founding the place of failure and elimination of failure (Fig. 2. version 4). In this situation there are force major case, when are large amount of failures. The time of power supply outage could be more then 24h [1].

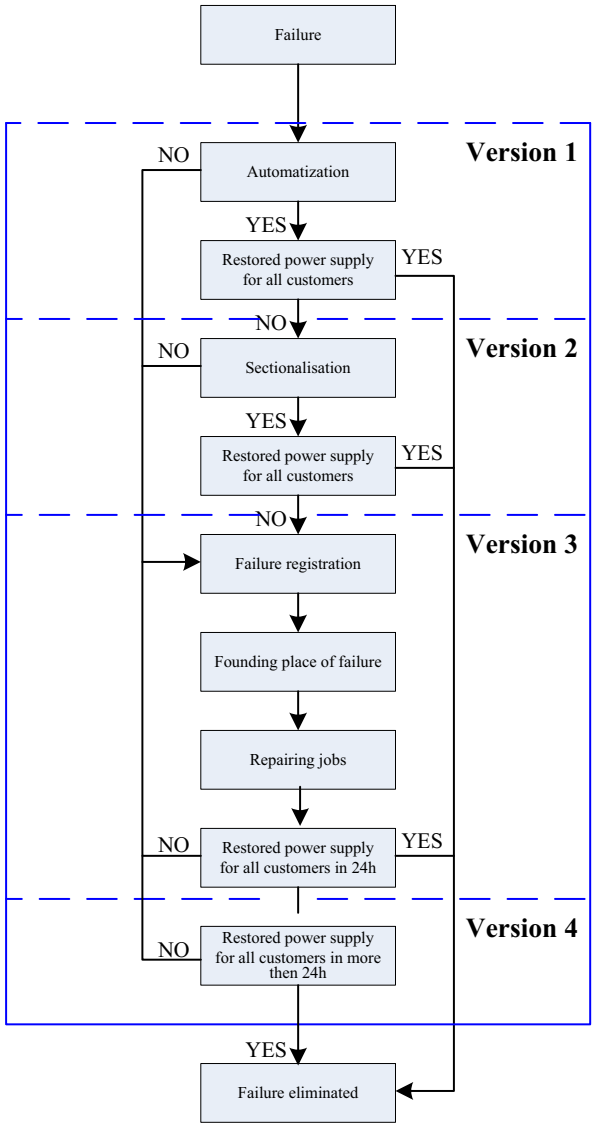

Fig. 2. Power supply failure elimination versions

III. CHOICE OF CUSTOMER OUTAGE COSTS CRITERIA

Mostly in practice, the value of actual outage costs is expressed in terms of money, however calculation of the undersupply of products, energy not supplied and others customers or society direct and indirect costs are used as appropriate criteria, because input data are used based on statistical data or experts judgments.

Different outage costs assessment methods exist. The general customer outage costs assessment methods can be divided into three categories (Fig. 3.) [5]. These methods are various analytical methods, simulation methods and customer survey methods.

DSO appears to favor customer surveys for outage cost information in their planning activities.

Usually, customer outage costs are divided into different customer groups – residential, agricultural, commercial, public and governmental, industrial (sometimes, subdivided into small and large users) and into others groups. Agricultural enterprises and farms belong to the agricultural customer group, households, gardens, garages and others cooperatives belong to the residential customer group. Business sector belongs to the commercial customer group; all kinds of public transport, engineering sector, and all public agencies belong to the public and governmental customer group and all factories and others industrial companies belong to industrial customer sectors.

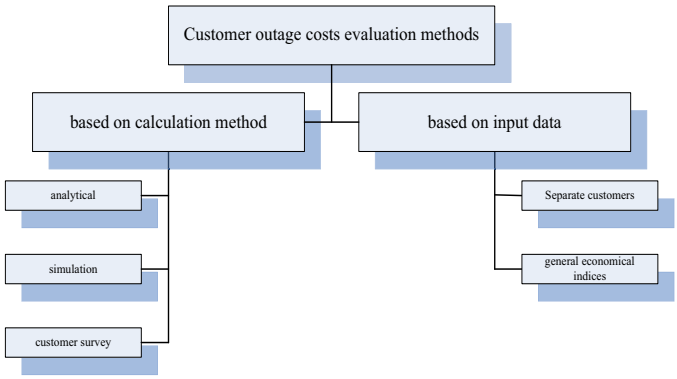

Fig. 3. Customer outage costs evaluation methods

The various analytical methods analyze the customer outage costs from the mainly theoretical perspective. To determine not produced products, there is taken into account GDP, total electrical power consumption. The advantage of the analytical methods is that they are based on available data. However, since these methods are based on economical calculations and there are not taken customers opinions, it is complicated to access the customers' actual needs and costs [4].

The simulation methods imply conducting a case study of a particular outage cases algorithm. These methods aim to include both direct and indirect costs calculation, where outage costs are determined from customer experience, but not from hypothetical assumptions. The disadvantage of these methods is that information obtained for particular simulation is hard to generalize, because no situations are identical. Another disadvantage is that simulation methods rarely are used for smaller outages, which are the most common [5].

The customer surveys methods focus on customers' subjective opinion of the outage costs. The advantage of these methods is that customers are in the best position to know their own outage costs. The customer surveys methods are divided into four subgroups – direct costing methods, indirect costing methods, contingent valuation methods and contingent ranking methods. The methodology of customer surveys methods is to ask occasional, but reasoned questions. Rarely these questions are divided into customer groups and focused on questionnaire by mail, phone or individual. Customer outage costs are assessed by direct outage evaluation of customer groups, by willingness to pay and willingness to accept and by indirect costs evaluation of hypothetical insurance premium for assured supply or compensation for costs and preparatory actions [4].

Customer outage costs evaluation methods based on the input data are divided into two subgroups – separate customers and general economical indices methods. For separate customers outage costs evaluation there is needed to know lot of detailed information. In the result of this, this method is used in cases for customer outage costs evaluation in small area. For customer outage costs evaluation in the region or in the country it is taken into account outage duration and frequency, customer groups' classification, tariffs of electrical power, electrical power consumption, and GDP and electrical power not supplied.

Different studies have been made for evaluation of the customer outage costs. The most common used methods are customer surveys and simulation. In the calculations presented here the lower limits of these values have been used. In Table 1 typical values of the cost of not delivered energy in some other countries are presented, as well [6].

TABLE I
TYPICAL VALUES OF THE COST OF NOT DELIVERED ENERGY OF DIFFERENT CUSTOMER GROUPS, €/kWh

Customer group	**Finland** [6]	**Norway** [6]	**The Netherlands** [6]	**The USA** [6]	**Sweden** [5]
Residential	2 -7	0,98	16,4	7 - 10	2-5
Agricultural	3 - 13	1,83	3,9	15	3-10
Commercial	2 - 47	12,07	7,9	60	5-124
Public	5 - 41	1,59	33,5	80	3-30
Industrial	4 - 20	1,59 - 8,05	0,3 - 33,1	17 - 56	10-47

IV. EVALUATION OF CUSTOMER OUTAGE COSTS

Distribution system operator outage costs evaluation is based on DSO expenditures, outage duration and frequency, tariffs of electrical power and electrical power not supplied.

Customers' outage costs evaluation is based on customer groups' classification, electrical power not supplied, outage duration and frequency, tariffs of electrical power, foregone income and turnover of customers and customers activity factor. As well as customer outage costs evaluation in based on density of population, incomes and outcomes of customers, discontentment of customer, customer groups proportion in definite area and others factors [1].

Since the all factors observance in calculation is the time-consuming and complicated process then there is a possibility to simplify this process taken into the account only economical indices, electrical power consumption, customer groups' classification, customers' activity factor and outage duration and frequency.

Customer activity factor is depended on the time, when outage occurred. The equitation for calculating the expected costs of customer outage (ECOST) are developed from expected energy not supplied (EENS) index. The ECOST is defined as [9]:

$$ECOST = \sum_{i=n}^{m} ECOST_i \,, \qquad (1)$$

where $ECOST_i$ - expected cost of customer outage in each customer group;

$_n$ - customer group.

$_m$ - sum of customer groups.

In order to estimate DSO outage costs must to be predict system behavior. The components in a distribution system, such as lines, cables, transformers and breakers, are usually modeled as either operating or not operating due to outage. The Time to Outage (TTO) for a component is the time until an outage occurs, and the component is no longer operable. The time until a broken component is available again, is the time it takes for it to automatic and manual switching (TTA) (version 1 and 2) or to be replaced or repaired (TTR) (version 3 and 4) (Fig. 4.) [5].

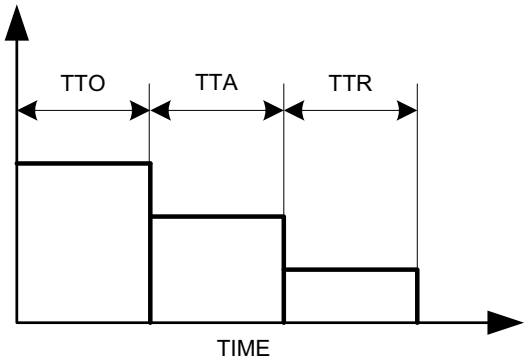

Fig. 4. The outage process of the component

Two different kinds of outages are generally considered in reliability analysis: active and passive outages. An example of a passive outage is a breaker that spontaneously opens. In order to detect whether an outage is temporary or permanent the breakers reclose. If the outage is cleared after the reclosing sequence the outage is only temporary and the affected load points will only be unsupplied during the short reclosing time. If the outage remains after the reclosing sequence the outage is permanent and the load point will be unsupplied for a longer duration [5].

Expected energy not supplied for one customer group $EENS_i$ can be calculated [5] by multiplication of outage duration with annual electrical power consumption:

$$EENS_i = t_a \cdot P_v , \quad (2)$$

where $EENS_i$ - expected energy not supplied;

P_v - average annual electrical power consumption, kWh/year;

t_a - outage duration, h.

Customer outage costs are evaluating using a calculation of separate customer groups. The sum of customer outage costs can be calculated as shown bellow [5]:

$$ECOST = \sum_{i=n}^{m} p_i \cdot ECOST_i , \quad (3)$$

where p_i - customer activity factor.

The customer activity factor is [5]:

$$p_i = p_n + \sum_{i=1}^{n} p_a , \quad (4)$$

where p_n - activities probability depended on electrical power consumption;

p_a - activities probability not depended on electrical power consumption;

$_n$ - activity.

Some of the household activities such as cooking and watching TV are dependent on electricity. Activities follows a daily pattern and do also vary with day of week. From time-use diary data, activity patterns for each hour can be drawn (Fig. 5.). On electrical power consumption not dependent activities for residential customers are sleeping, working and traveling, besides activity factor for other customer groups is depended on day of week, daily time and seasonality, when outage occurred. In calculations on electrical power consumption not dependent activities are assumed 0, but on electrical power consumption dependent activities for residential customers – as a sum of above mentioned activities, but for others customer groups – 1. On electrical power consumption dependent activities for other customer groups, excepted residential customers, are working time, security and others activities.

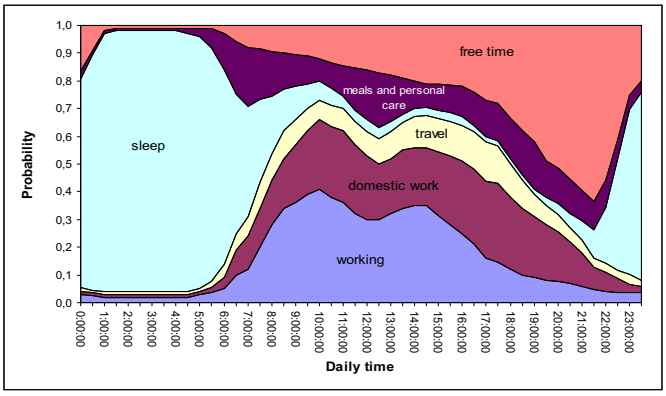

Fig. 5. Probability of different activities for residential customers, weekday [3]

Expected customer outage costs by Eq. (3) can be evaluated by foregone income, turnover of customers, additional outcomes, e.g., stuff, materials, purchased electrical power, completing items, and customers activity factor.

$$ECOST_i = \frac{\sum_{i=1}^{n} \left[S_i \cdot (1 + r_i) - E_{ai} \right]}{8760} \cdot t_a , \quad (5)$$

where S_i - the annual prime outages (materials, logistic costs, public utilities payment, rent cost, taxes and so on);

r_i - annual profitability;

E_{ai} - others from electrical power consumption dependent outcomes (staff, demurrage, re-planning and others) [1].

Therefore ECOST can be written as:

$$ECOST_i = \frac{P_i - I_i}{8760} \cdot t_a , \quad (6)$$

where

P_i - average customer annual turnover;

I_i - average customer annual profitability.

ECOST can be written as:

$$ECOST_i = \frac{E_i}{8760} \cdot t_a , \quad (7)$$

where

E_i - average customer annual outcomes,

because

$$I_i = P_i - E_i . \quad (8)$$

An often used index in reliability cost analysis is the interrupted energy assessment rate (IEAR), which is calculated as the ratio of the ECOST and the EENS at either the load buses or for the overall system, as shown below [9]:

$$IEAR = \frac{ECOST}{EENS} . \quad (9)$$

V. LATVIAN DISTRIBUTION SYSTEM

Latvian Distribution System Operator faces new challenges and have to become an efficient and dynamic provider of electric power distribution services to its customers, improve efficiency of distribution and reduce operating costs and maintenance costs whilst providing customers with a reliable power supply. Key challenges involving the initiatives are to electrical power deliver rate and low-cost electrical power, ensure excellence in customer care, and create a work environment that encourages teamwork and innovation. With the implementation of the initiatives, dramatic improvements in the performances in all the areas were observed which enabled the company to orient the core business operations with information systems and world-class practices for sustainable reforms [7].

In accordance with operator technical policy the main dispatcher service tasks are to organize distribution network operative work, saving the structure of the operative guidance of two levels – region and local, to implement IT applications in distribution network; such a distribution automation,

Geographic Information System (GIS), Distribution Management System (DMS), Supervisory Control and Data Acquisition (SCADA) platforms. SCADA refers to a system that enables an electric utility to remotely monitor, coordinate, control and operate distribution components, equipment and devices in a real-time mode from remote locations with acquisition of data for analysis, and planning from one central location.

After restructuring of the Latvian distribution network – consolidations of 7 distribution network districts, separation of distribution and realization business processes, dispatch control modernization and optimization, are an actual questions. After introduction new model structure in correlation on the operative work, as one from main challenges is the optimization of local dispatchers certain tasks such as their disengagement from the inoperative functions, such as customers' calls. Call Center (CC) were developed to support call distribution, capturing the caller line identification, priority customer handling, reduce average electric supply restoration time, facilitate dispatchers daily tasks.

For information exchange quality improvement between CC and dispatch centers (DC) there is developed distribution network electric supply outage system (STEPS).

CC operator registers customer's information in the STEPS Faults module for the automatic information exchange between CC and DC dispatchers and will be replaced by GIS Call Register module, but STEPS Outage module provides a registration of all 0,4kV – 20kV networks outages in a certain order [7].

VI. EXEPECTED CUSTOMER OUTAGE COSTS IN LATVIAN DISTRIBUTION NETWORK

In the Latvian distribution system electrical power consumption are growing each year in all customer groups (Fig. 6.).

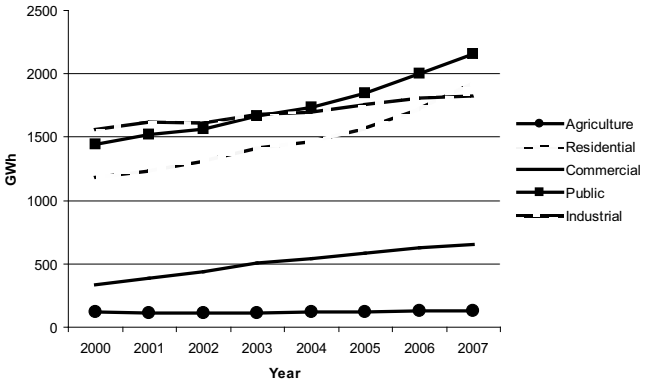

Fig. 6. Electrical power consumption in Latvia by customer groups

As well as Latvian distribution system operator incomes are grooving for all customer groups (Fig. 7.).

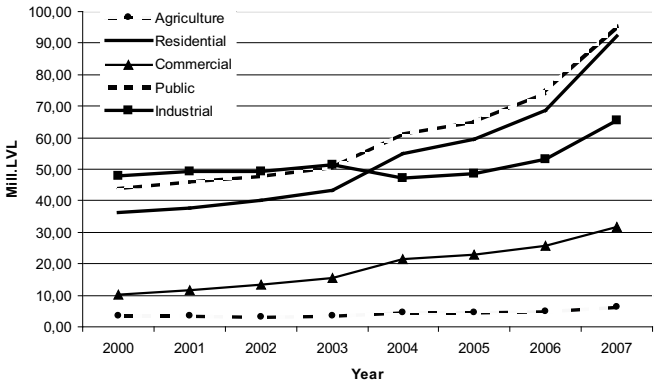

Fig. 7. Latvian Distribution System operator incomes by customer groups

Distribution system operator incomes percentages in 2007 are divided into customer groups (Fig. 8.).

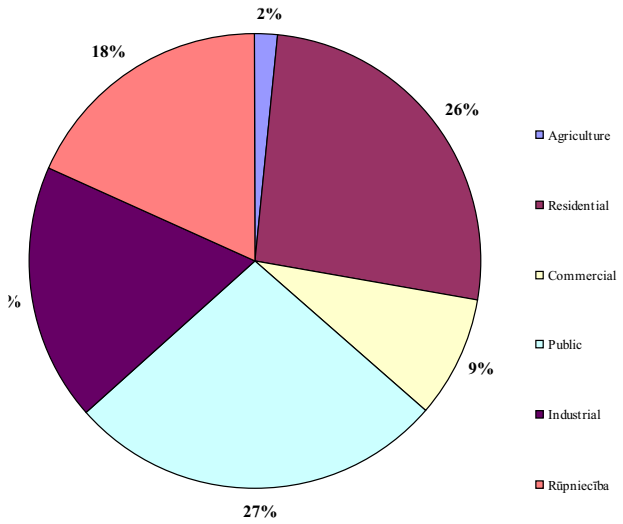

Fig. 8. DSO incomes divided into customer groups in 2007

Expected costs of customer outage can be calculated by Eq. (3), (4) and (6) from data of central statistical bureau of Latvia. For example, residential customers ECOST can be evaluated as householders' net incomes and cost of living. The average data of residential customers in 2007 is: the cost of living – 132.89LVL/person per month, sum of households – 899'400, persons in one household – 2.5, working population – 1191100 persons, retired persons – 467200, mean pension – 111LVL, net income – 289LVL/person per month [8].

ECOST for others customer groups can be calculated considering into account turnover and profitability. For example, commercial customers ECOST can be evaluated from the following average data in 2007: turnover – 18575.9 millions LVL, profitability – 733.2 millions LVL, sum of commercial customers – 59202.

The result of calculation of expected customers' outage costs (ECOST) in Latvian distribution system in 2007 is shown in table II.

TABLE II
CUSTOMER INTERRUPTED ENERGY ASSESSMENT RATE FOR ALL CUSTOMER GROUPS IN LATVIA

2007, €* for one customer	
Agricultural	**2,43**
Residential	**0,67**
Commercial	**41,97**
Public	**34,36**
Industrial	**71,55**

Customer interrupted energy assessment rate for all customer groups can be calculated by Eq. (9) and data of central statistical bureau of Latvia, where mentioned as 2,5 persons are in one household, residential customers net salary and companies turnover by groups.

And finally average interrupted energy assessment rates (IEAR) in Latvia distribution system for all customers' groups in 2007 are shown in table III:

TABLE III
AVERAGE IEAR FOR ALL CUSTOMERS' GROUPS IN 2007

2007, €/kWh * for one customer	
Agricultural	**2,61**
Residential	**1,29**
Commercial	**13,46**
Public	**13,61**
Industrial	**1,33**

VII. CONCLUSIONS

This paper describes the basic concept required for evaluation of distribution network outage costs. The investment cost is deterministic in nature and can be obtained using well-established methods. The customer damage cost is probabilistic and is conceptually the aggregated value the customers are willingness to pay in order to avoid load outage or voltage standard violations. The customer outage cost is a function of outage frequency, duration, load lost, location, and societal effects.

The paper illustrates the calculation of the ECOST (expected costs of customer outage) and the related IEAR (interrupted energy assessment rate) indices in Latvian distribution network. The basic data used to calculate the ECOST and IEAR come from central statistical bureau of Latvia. As the worth of outage costs tend to rise with time more than other costs, they will play a more and more important role in electricity network design in the future.

REFERENCES

[1] F. I. Molochko, A. F. Molochko, J. Ekmanis, N. Zeltins, V. Zebergs, *"Estimation of the energy security level and definition of the criteria for damage forecasts,"* Latvian Journal of Physics and Technical Sciences, vol. 1, pp. 15-24, 2009

[2] RESEARCH REPORT, *"Distribution Network 2030 Vision of the Future Power System",* 2007.

[3] "European Communities "*How Europeans spend their time Everyday life of women and men*", Office for Official Publications of the European Communities, 2004.

[4] Billington, R. *"Customer outage costs",* The 9th International Conference on Probabilistic Methods Applied to Power Systems June 11-15, 2006.

[5] K. Alvehag, *"Impact of Dependiecies in Risk Assessments of Power Distribution Systems",* Licentiate Thesis, KTH, 2008.

[6] Henry Lagland, K. Kauhaniemi, "*Outage cost comparison of different medium voltage networks*," 19th International Conference on Electricity Distribution, CIRED 2007

[7] JSC Latvenergo annual report 2007

[8] Central Statistical Bureau of Latvia

[9] Billinton R., Zhang W. *"Cost related reliability evaluation of bulk power systems",* electrical Power and Energy Systems, pp. 99 – 112, 2001

[10] Regulations regarding the Trade and Use of Electricity.